Technical Applications in Agriculture

CASE

Acknowledgments

The partners developing and managing *Technical Applications in Agriculture* include AgCentric at Central Lakes College, Northland Community and Technical College, Ridgewater College, and industry collaborators. This project is funded by the Advanced Technological Education program that focuses on the education of technicians for the advanced technology fields that drive the nation's economy.

AgCentric, The National Council for Agricultural Education, and the staff of the Curriculum for Agricultural Science Education™ (CASE™) wish to acknowledge the significant contribution of the following team members in the development of this curriculum.

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Agriscience Notebook Table of Contents

Technical Applications Detailed Course Outline

Unit 1: Agricultural Equipment

Lesson 1.1 Equipment Systems

1. Agricultural equipment used by industry varies based on local crops and geographic location.
    - Identify and describe the equipment used in the local area to produce and harvest crops. (Activity 1.1.1)
2. Technicians document plans and processes when servicing equipment.
    - Organize notebooks to record coursework and projects. (Activity 1.1.2)
    - Practice recording assembly and disassembly procedures in a logbook. (Activity 1.1.2)
3. Technicians use tools to make precise measurements.
    - Measure components using a dial caliper, dial indicator, torque wrench, and combination square. (Activity 1.1.2)
    - Use a micrometer to make precise measurements. (Activity 1.1.4)
4. A fastener’s strength and size vary based on its purpose.
    - Identify bolt size, type, and grade. (Activity 1.1.5)
5. Power take-off (PTO) systems transfer power to agricultural implements.
    - Disassemble and identify the components of a universal joint. (Activity 1.1.5)
6. Powertrain systems contain belts, chains, and gears to deliver power for work.
    - Identify types of belts, chains, and gears on a piece of equipment. (Activity 1.1.6)
7. Guarding and shielding agricultural equipment prevent injury to an operator.
    - Identify the safety hazards found in the internal motions of equipment. (Project 1.1.7)

Lesson 1.2 Technician Expectations

1. Technicians follow a standard diagnostic procedure to inspect a problem, make repairs, and verify operation.
    - Identify the parts of the six-step diagnostic process during a guest technician presentation. (Activity 1.2.1)
2. Agricultural equipment dealers prefer technicians with strong interpersonal skills.
    - Identify interpersonal skills desired by ag equipment dealers. (Activity 1.2.1)
3. Technicians use digital service procedure manuals to diagnose and repair equipment.
    - Create a picklist for equipment repair using a digital service manual. (Activity 1.2.2)
4. Technicians use a digital multimeter to diagnose and repair electrical systems.
    - Test for voltage, resistance, and continuity in an electrical component using a digital multimeter. (Activity 1.2.3)
5. Technicians utilize written reports, such as work/repair orders, to communicate services provided to a customer.
    - Write a work/repair order using technical writing. (Project 1.2.4)
    - Write a work/repair order for a universal joint repair. (Project 1.2.5)
6. Component failure analysis allows technicians to analyze root cause failures.

- Diagnose a failed universal joint and identify the root cause using the Five Whys method. (Project 1.2.5)

7. Technicians use service manuals to perform diagnostics and repairs on agricultural equipment, leading to a longer life in powertrain systems and reducing operation costs.
    - Repair a universal joint and identify steps to verify operation using a manufacturer's service manual. (Project 1.2.5)

Unit 2 Drive Systems

Lesson 2.1 Drive Train Components

1. Gears change a drive train's speed and torque.
    - Construct a drive train and measure speed. (Activity 2.1.1)
    - Measure a drive train's torque. (Activity 2.1.3)
2. Clutches engage and disengage torque from the power input to the power output.
    - Identify clutch systems & components present on agricultural equipment. (Activity 2.1.2)
    - Adjust and test the settings for an electromagnetic clutch. (Activity 2.1.2)
3. Bearings reduce friction to increase efficiency in power train systems.
    - Identify and select bearing types used in drive train systems. (Activity 2.1.4)
4. Technicians set and adjust gears to work effectively.
    - Disassemble a gearbox, identify components and inspect for wear and backlash. (Activity 2.1.5)
5. A drive train uses a combination of components to change the direction and speed of moving parts in a system.
    - Construct a drive train modeling agricultural equipment. (Project 2.1.6)

Lesson 2.2 Final Drives

1. Differentials allow implements to maintain equal torque at different speeds.
    - Assemble a model of a differential system. (Activity 2.2.1)
2. Planetary gears affect the torque, speed, and direction of a machine.
    - Simulate planetary gear settings and observe the input and output speeds. (Activity 2.2.2)
3. Technicians use precision measurement tools to set preload and endplay in a powertrain system.
    - Disassemble and adjust tapered bearings on a wheel hub. (Activity 2.1.3)
4. Tire and tracks provide traction in agricultural equipment when proper ground contact is applied.
    - Identify and select tires for a tractor. (Activity 2.2.3)
    - Determine ballast requirements for specific equipment applications. (Activity 2.2.4)
5. Technicians use precision tools to complete a failure analysis and determine the root cause of an equipment failure.
    - Troubleshoot and complete a work/repair order for a broken drive train. (Project 2.2.6)

Unit 3 Precision Agriculture

Lesson 3.1 Precision Systems

1. Equipment calibration increases the efficiency of outputs and limits overlaps and skips in a field.
    - Calibrate a hand sprayer and fertilizer spreader. (Activity 3.1.1)
2. Precision systems require a wireless connection with satellites to find a geographic location.

- Locate satellites and determine signal quality for a global positioning system. (Activity 3.1.2)

3. Controller systems in precision agriculture include guidance systems, yield monitors, sensors, and automated outputs.
    - Draw a flow chart explaining the relationship between precision agricultural components found on a combine. (Project 3.1.3)
    - Operate a simulated tractor and guidance system. (Activity 3.1.4)
4. Precision agriculture increases production efficiencies that reduce application costs while improving yields.
    - Calculate the potential savings for using an autosteer tractor and a piece of tillage equipment. (Activity.3.1.5)
5. Agricultural producers use sensors and automated controls to increase production efficiencies.
    - Set up a control system for activating an irrigator. (Activity 3.1.6)
    - Construct a control system modeling a tractor's autosteer system. (Project 3.1.7)

Lesson 3.2 Precision Applications

1. Geographic information systems display vectors, features, and attributes.
    - Use GIS to make field boundaries and display a soil sampling grid. (Activity 3.2.1)
2. A producer can predict a field's productivity by collecting data from specific locations.
    - Use interpolation to display GIS data. (Activity 3.2.2)
3. Variable-rate application systems reduce producer costs while protecting the environment.
    - Analyze data using GIS and recommend a seeding application based on soil type. (Activity 3.2.3)
    - Compare flat-rate and variable-rate applications by creating basic fertilizer recommendations for each scenario. (Project 3.2.4)

Lesson 3.3 The Data Advantage

1. Agricultural producers use remote sensing devices to collect data for making production decisions.
    - Use machine learning software to simulate remote sensing and data analysis. (Activity 3.3.1)
2. Technicians use data to predict future repairs and maintenance.
    - Interpret GIS data and identify machine failure. (Activity 3.3.2)

Unit 4 Electrical and Digital

Lesson 4.1 Electrical Systems

1. Agricultural equipment uses series, parallel, and series-parallel circuits.
    - Construct series, parallel, and series-parallel circuits. (Activity 4.1.1)
    - Calculate total resistance in series, parallel, and series-parallel circuits. (Activity 4.1.1)
2. Diodes protect electrical equipment by allowing power to flow in one direction.
    - Test a diode using a digital multimeter. (Activity 4.1.2)
    - Construct circuits using silicon diodes. (Activity 4.1.2)
    - Construct circuits using Zener diodes. (Activity 4.1.3)
3. Electrical systems use alternating and direct current.
    - Rectify AC voltage to power an LED. (Activity 4.1.3)
    - Troubleshoot a tractor's charging system using a digital multimeter. (Activity 4.1.3)

4. Rheostats and potentiometers vary the resistance in an electrical circuit.
    - Model a rheostat using a graphite pencil. (Activity 4.1.4)
    - Use a potentiometer to change the voltage in a circuit. (Activity 4.1.4)

Lesson 4.2 Electrical Controls

1. Technicians read schematics when designing, constructing, and troubleshooting electrical circuits.
    - Describe a cranking system using an electrical schematic. (Activity 4.2.1)
2. Electrical systems control how engine systems operate and function.
    - Test the continuity of an ignition key switch. (Activity 4.2.2)
    - Assemble a shutdown circuit using a wiring schematic. (Project 4.2.3)
3. Agricultural equipment uses relays to control high amperage circuits that power specific components.
    - Identify common terminals used on relays. (Activity 4.2.4)
    - Assemble a circuit using a relay. (Activity 4.2.4)
4. Electrical systems use resistors, diodes, potentiometers, and relays to control equipment components.
    - Design and construct a circuit to control motor speed and direction. (Project 4.2.5)
5. Technicians manage and troubleshoot controller systems used in precision agriculture.
    - Construct and troubleshoot a transducer. (Project 4.2.6)

Lesson 4.3 Electrical Analysis

1. Technicians use diagnostic tools and Ohm's law as part of a systematic troubleshooting process.
    - Calculate voltage drop in a circuit. (Activity 4.3.1)
    - Troubleshoot voltage drops with a digital multimeter. (Project 4.3.2)
    - Diagnose parasitic battery drain with a digital multimeter. (Activity 4.3.3)
2. Technicians maintain and troubleshoot systems directing electrical current between components.
    - Construct an ignition/shutdown circuit using cables and connectors. (Project 4.3.4)
    - Troubleshoot an ignition/shutdown circuit using a digital multimeter and a schematic. (Project 4.3.4)
3. Technicians use tools to troubleshoot and maintain GPS/GIS equipment.
    - Modify a sprayer to include electrical and GPS controls. (Problem 4.3.5)
    - Develop a troubleshooting and maintenance plan for a GPS sprayer. (Problem 4.3.5)

Unit 5 Diesel Systems

Lesson 5.1 Diesel Components

1. There are functional differences between diesel and gasoline engines.
    - Identify similarities and differences between small gasoline and diesel engines. (Activity 5.1.1)
2. Mechanical diesel injection systems have several components with specific functions.
    - Identify the high and low-pressure components of a fuel system. (Activity 5.1.2)
    - Flare and assemble a fuel line. (Activity 5.1.2)
    - Inspect a fuel injector for faults. (Activity 5.1.2)
3. Diesel engines have systems that clean and pressurize the air and clean the exhaust.
    - Inspect and identify the components of a turbocharger and air filter. (Activity 5.1.3)
    - Measure the urea content in diesel exhaust fluid samples. (Activity 5.1.3)

4. Diesel engine systems have a variety of lubrication and liquid cooling systems.
    - Change oil and oil filter using OEM specifications. (Activity 5.1.4)
    - Inspect a cooling system using industry equipment. (Activity 5.1.4 and Project 5.1.5)
    - Model a cooling system to cool the engine coolant. (Project 5.1.5)
5. Technicians use customer complaints combined with an inspection to determine the cause of engine failure.
    - Determine the cause of broken engine components and complete a work repair order. (Project 5.1.6)

Lesson 5.2 Diesel and Electrical

6. Diesel engines control connected systems using Controller Area Network (CAN) bus systems with Electronic Control Units (ECU) to monitor and control the engine.
    - Diagnose faults in a CAN bus model using a DMM. (Activity 5.2.1)
    - Identify how a circuit fault in CAN bus impacts an 8-bit signal. (Activity 5.2.1)
7. A CAN bus allows a system of microcontrollers to control agricultural equipment.
    - Simulate CAN bus data in response to sensor data. (Activity 5.2.2)
    - Inspect an oil pressure transducer for faults. (Activity 5.2.2)
8. High-pressure common rail diesel fuel systems have essential components with specific functions.
    - Develop a flowchart of CAN bus operations within fuel and intake systems. (Project 5.2.3)

Unit 6 Fluid Power

Lesson 6.1 Fluid Power Principles

1. A hydraulic system has a pump, control valves, actuators, fluid, and hoses.
    - Virtually assemble a fluid power system. (Activity 6.1.1)
2. Technicians use schematics to identify fluid power components and systems.
    - Draw and identify the components found in a hydraulic system schematic. (Activity 6.1.2)
3. The hydraulic systems can be closed or open-loop systems using positive or non-positive pumps.
    - Construct example models of hydraulic systems (Activity 6.1.3)
4. A technician can control the fluid flow and pressure in a hydraulic system.
    - Add flow and pressure gauges and adjust the fluid pressure and flow in a hydraulic system. (Activity 6.1.4)
    - Calculate pressure drop in a hydraulic system. (Activity 6.1.4)
5. Pascal’s Law determines the system pressure and components needed for a machine to operate.
    - Find the force exerted by hydraulic cylinders. (Activity 6.1.5)
    - Use Pascal’s Law to find the needed pressure and cylinder size for equipment. (Activity 6.1.5)

Lesson 6.2 Hydraulic Systems and Safety

1. Hydraulic fluids have specifications and properties that meet industry standards.
    - Read an SDS and identify the ISO Standards for hydraulic fluids. (Activity 6.2.1)
    - Compare the physical properties of hydraulic fluids. (Activity 6.2.1)
2. Technicians need to be aware of the potential safety hazards when working with hydraulic equipment.
    - Inspect a hydraulic system for safety hazards. (Activity 6.2.2)
    - Record and practice the steps to place a hydraulic system in a zero energy state. (Activity 6.2.2)

3. Hydrostatic transmissions use variable displacement pumps to transfer energy in a power train.
    - Model and calculate the advantage of variable displacement pumps. (Activity 6.2.3)
4. Electro-hydraulic systems control cylinders in agricultural implements.
    - Evaluate a solenoid and relay for functionality on electro-hydraulic components. (Activity 6.2.4)
    - Construct an electro-hydraulic system. (Project 6.2.5)
5. Hydraulics provide power in agricultural equipment for steering, braking, drivetrains, and axillary equipment.
    - Inspect and document the physical characteristics of fluid power systems found on a tractor. (Activity 6.2.6)

Lesson 6.3 Hydraulic Maintenance

1. Hydraulic components need to seal correctly and be free of air and contaminants to prevent wear and damage.
    - Disassemble a hydraulic cylinder and valve to inspect for wear and damage. (Activity 6.3.1)
    - Disassemble a hydraulic pump and complete a work/repair order. (Project 6.3.2)
2. Technicians select fittings based on design and purpose.
    - Identify the fittings needed for a hydraulic system. (Activity 6.3.3)
3. Routine repair of a hydraulic system includes flushing a system and inspecting for particulate matter.
    - Inspect used hydraulic oil for potential causes of contamination. (Project 6.3.4)
    - Fill out a work/repair order for hydraulic parts damaged by contaminated oil. (Project 6.3.4)

Unit 7 Partnering in the Field

Lesson 7.1 Practical Evaluation

1. Technicians work with producers to periodically maintain equipment for optimum agricultural production.
    - Assess the mechanical systems of a tractor and implement and write a work/repair order for recommended maintenance. (Project 7.1.1)
2. Troubleshooting and service procedures are essential for long-term equipment performance.
    - Complete service procedures for hydraulic, electrical, and power train systems. (Activity 7.1.2)
3. Practical experiences are essential when preparing for a technical career.
    - Compile a work portfolio of technical skill competencies. (Foundational SAE Checklist)

TAA Course Description

Technical Applications in Agriculture is a specialization-level course designed to provide students with the skill needed to enter the agricultural technician career field. Throughout the course, students develop technological competencies through rigorous hands-on experiences in the classroom. Students will learn how electrical, fluid, diesel, precision, and mechanical systems function. Then they will use their mechanical skills to identify and communicate the cause and correction of equipment failures. The course will expose students to the newest agricultural technologies that support equipment industries while connecting them with future employers.

The Technical Applications in Agriculture Course includes the following topics.

- Mechanical System Design
- Safety
- Drivetrains
- Electrical Systems
- Precision Agriculture
- Fluid Power
- Diesel Technology
- Machine and Equipment Maintenance
- Repair and Work Order Completion
- Customer Service

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Technical Applications in Agriculture
National AFNR Common Career Technical Core Standards Alignment

	Unit 1 Agricultural Equipment	Unit 2 Drive Systems	Unit 3 Precision Agriculture	Unit 4Electrical and Digital	Unit 5 Diesel Systems	Unit 6 Fluid Power	Unit 7 Partnering in the Field
Career Ready Practices Content Standards							
1. Act as a responsible and contributing citizen and employee.							
2. Apply appropriate academic and technical skills.	X	X	X	X	X	X	X
3. Attend to personal health and financial well-being.	X						
4. Communicate clearly, effectively and with reason.	X	X	X	X	X	X	X
5. Consider the environmental, social, and economic impacts of decisions.							
6. Demonstrate creativity and innovation.							
7. Employ valid and reliable research strategies.							
8. Utilize critical thinking to make sense of problems and persevere in solving them.		X	X	X	X	X	X
9. Model integrity, ethical leadership, and effective management.							X
10. Plan education and career path aligned to personal goals.							
11. Use technology to enhance productivity.			X	X			X
12. Work productively in teams while using cultural/global competence.		X	X	X	X	X	X

	Unit 1 Agricultural Equipment	Unit 2 Drive Systems	Unit 3 Precision Agriculture	Unit 4Electrical and Digital	Unit 5 Diesel Systems	Unit 6 Fluid Power	Unit 7 Partnering in the Field
Agriculture, Food, and Natural Resources Career Cluster							
1. Analyze how issues, trends, technologies and public policies impact systems in the Agriculture, Food & Natural Resources Career Cluster.			X				
2. Evaluate the nature and scope of the Agriculture, Food & Natural Resources Career Cluster and the role agriculture, food and natural resources (AFNR) play in society and the economy.							
3. Examine and summarize importance of health, safety, and environmental management systems in AFNR organizations.	X						
4. Demonstrate stewardship of natural resources in AFNR activities.							
5. Describe career opportunities and means to achieve those opportunities in each of the AFNR career pathways.							
6. Analyze the interaction among AFNR systems in the production, processing and management of food, fiber and fuel and the sustainable use of natural resources.							X

Power, Structural, and Technical Pathway Content Standards							
1. Apply physical science principles and engineering applications related to mechanical equipment, structures, and biological systems to solve problems and improve performance in AFNR power, structural, and technical systems.							
AG-PST 1.1: Select energy sources for power generation.							
AG-PST 1.2: Use hand and power tools commonly required in power, structural, and technical systems	X	X	X	X	X	X	X
AG-PST 1.3: Investigate solutions to AFNR power, structural, and technical systems.		X	X	X	X	X	X
AG-PST 1.4: Design or modify equipment, structures, or biological systems to improve the performance of an AFNR enterprise or business unit.		X	X	X			X
2. Operate and maintain mechanical equipment related to AFNR power, structural, and technical systems.							
AG-PST 2.1: Maintain machinery and equipment by performing scheduled service routines.					X		X
AG-PST 2.2: Perform service routines to maintain power units and equipment.			X		X		X

	Unit 1 Agricultural Equipment	Unit 2 Drive Systems	Unit 3 Precision Agriculture	Unit 4Electrical and Digital	Unit 5 Diesel Systems	Unit 6 Fluid Power	Unit 7 Partnering in the Field
AG-PST 2.3: Operate machinery and equipment while observing all safety precautions.		X				X	X
3. Service and repair mechanical equipment and power systems used in AFNR power, structural and technical systems.	X	X	X	X	X	X	X
AG-PST 3.1: Service and repair the components of internal combustion engines using procedures for troubleshooting and evaluating performance.							
AG-PST 3.2: Service and repair power transmission systems following manufacturer's guidelines.	X	X					X
AG-PST 3.3: Service and repair hydraulic systems by evaluating performance using maintenance manuals.						X	
AG-PST 3.4: Service and repair steering, suspension, traction, and vehicle performance systems by checking performance parameters.					X		X
AG-PST 3.5: Execute the safe and proper use of construction/fabrication hand tools in the workplace.	X	X	X	X	X	X	X
AG-PST 3.6: Service electrical systems by troubleshooting from schematics.			X	X			
4. Plan, build and maintain AFNR structures.							
AG-PST 4.1: Create sketches and plans of agricultural structures.							
AG-PST 4.2: Apply structural plans, specifications, and building codes.							
AG-PST 4.3: Determine requirements and estimate costs for construction materials and procedures.							
AG-PST 4.4: Follow architectural and mechanical plans to construct AFNR structures.							
5. Use control, monitoring, geospatial and other technologies in AFNR power, structural and technical systems.	X	X	X	X	X	X	X
AG-PST 5.1: Execute procedures and techniques for monitoring and controlling electrical systems using basic principles of electricity.			X	X			
AG-PST 5.2 Design control systems by referencing electrical drawings.				X			
AG-PST 5.3 Use geospatial technologies in AFNR applications.			X				X

TAA Glossary

A B C D E F G H I J K L M N O P Q R S T U V W X Y Z

#

8-bit – A digital, binary signal comprising of an eight-digit long sequence of 0 and 1.

A

Abrasive wear – Wear to components caused by foreign particles.

AC voltage test – A diagnostic test that checks for alternating current being produced by an alternator in order to determine the condition of the alternator's diodes.

Actuator – 1. A device for converting the energy of compressed fluid into work. The term is generally applied to cylinders. 2. A device on a valve that changes the directional passageways.

Additive – Added to fluids to improve physical and chemical properties.

Adhesive wear – Wear that occurs when friction between two components results in the two surfaces welding to each other.

Aeration – The process by which air is circulated through, mixed with, or dissolved in a liquid.

Aftermarket – The market for replacement parts, accessories, and equipment.

Air cleaner – A device for filtering, cleaning, and removing dust, dirt, and foreign debris from the air drawn into an engine.

Alternating current (AC) – An electrical current that moves in one direction and then the other.

Alternator – A generator in which alternating current (AC) is first generated, then changed into direct current (DC).

Altitude – The height of an object or point in relation to sea level or ground level.

Ampere – The unit of measurement for the flow of electric current. It is defined as the amount of current that one volt can send through one ohm of resistance.

Ampere (amp) – A unit of measure that represents the number of electrons passing a given point in one second.

Analog – A continuous, millivolt signal used to communicate outputs from a transducer. Analog signals are used when information can be within a range, such as flow rate or pressure.

Angular load – Combination of angular and axial loads.

Anode – The positive pole of an electrical circuit.

Antenna – Hardware component needed to receive a signal from satellites and differential sources.

Antifriction bearing – A bearing containing moving elements to provide a low friction support surface for rotating or sliding surfaces.

Asperities– Microscopic jagged spikes found on metal surfaces.

Atomization – Separating a liquid into fine particles.

Attribute – A characteristic of a feature in a geographic information system (GIS).

Axial load – A load applied parallel to the shaft.

B

Ballast – Weight added to a tractor to increase its stability.

Ballasting – Adjusting the amount and position of weight added to a tractor.

Ball-bearing – Bearing consisting of several spherical rolling elements between inner and outer races.

Barrel – Piston pump component housing the pistons.

Barrel – The tube hydraulic cylinders tube or outer shell.

Base layer – A map containing geographic features used for reference.

Baud rate – Rate of processing data measured in bits per second.

Bead – A group of high-strength steel wires encased in rubber at the edges of a tire that form a firm circular base for attaching the tire to the rim of the wheel.

Bearing – A machine component used to reduce friction and maintain clearance between stationary and moving parts.

Bearing – A machine component used to reduce friction and maintain clearance between stationary and moving parts.

Bearing cup – Serves as the outer race of the bearing to keep the bearing needles clean.

Bending – To force an object from a straight form to a curved or angular one.

Beta ratio – Ratio of the number of particles injected upstream compared to the number of particles that are able to pass through the filter and make it downstream while testing a filter.

Bevel gear – A gear with straight, tapered teeth used in applications where shaft axes intersect.

Bias-ply – A thick sidewall tire constructed with layers of nylon, polyester, or rayon cords that are angled at 45° to the tire's centerline and extend in opposite directions across the tire from bead to bead.

Bleed – Removing air or fluid from a closed system, such as fuel lines.

Bleed screws – Screws used to create a temporary opening in an otherwise closed system to bleed air from the line.

Body control module (BCM) – A designated ECU for controlling electronic accessories in a vehicle.

Bore – The hollow part inside a tube.

Breadboard – Solderless construction base used for prototyping electronics.

Bridge rectifier – An electrical device that converts an alternating current (AC) into direct current (DC) by allowing a current to flow through in one direction only.

British Standard Pipe (BSP) – A set of technical standards for screw threads that have been adopted internationally for interconnecting and sealing pipes.

Bushing – A replaceable thin tube or sleeve mounted in a case or housing as a bearing.

C

Cage – Separator or retainer that holds the spherical objects in a bearing.

Calibration – In field agriculture, the setting of a distributor or spreader to meter the predetermined amount of pesticide, lime, or fertilizer.

Cam gear – The portion of the camshaft that meshes with the crank gear.

Cam ring – Controls the fluid displaced by a vane pump.

Camshaft – A shaft with cams that operates valves and components found in an engine.

CAN bus – CAN bus (controller area network) includes multiple microprocessors that communicate using an 8-bit signal.

CAN_H – The high voltage signal of a CAN bus network.

CAN_L – The low voltage signal of a CAN bus network.

Cathode – The negative pole of an electrical circuit.

Cause – The portion of the work/repair order explaining the specific reason for the failure.

Cavitation – A localized gaseous condition within a liquid stream that occurs where the pressure is reduced to vapor pressure.

Channel – A channel of a GPS receiver consisting of the circuitry necessary to track the signal from a single GPS satellite.

Check valve – A device that allows compressed fluid to pass through in one direction but prevents it from returning in the same path.

Chemical stability – The resistance of a chemical to change in a chemical reaction.

Circ clip – A retaining ring that fits in a groove to allow rotation without horizontal movement. Also known as a snap ring.

Closed circuit – An electrical circuit in which current can flow.

Closed-loop – Hydraulic system where the oil returns to the pump.

Clutch – A device to engage or disengage the power from various working parts of machinery.

Clutch disc – Steel disc linked with friction material.

Clutch shaft – Splined to the clutch disc and turns when the clutch is engaged.

Combine – A self-propelled machine that cuts, threshes, and cleans a crop while traveling across a field.

Combustion – A rapid, oxidizing chemical reaction in which a fuel chemically combines with atmospheric oxygen and releases energy in the form of heat.

Complaint – The customer's problem or concern with the equipment is known as the complaint. The complaint is the first section of a work/repair order.

Component failure – The inability of a component to function correctly.

Components – A part of a mechanical or electrical system.

Compound gears – a combination of fixed or moveable gears.

Compound logic – PLC program used to control output devices under various conditions.

Compression event – An engine operation event in which a trapped air-fuel mixture is compressed inside a combustion chamber.

Compressor – A mechanical device that increases the pressure of a gas by reducing its volume.

Conductor – Hoses or tubing that carry fluid to various components.

Confirm – The portion of the work/repair order that documents the technician's verification of proper operation.

Contaminant – A polluting or poisonous substance that makes something impure.

Continuity – The presence of a complete path for current flow.

Continuous data – Elevation or temperature that varies without discrete steps. Since computers store data discretely, continuous data is usually represented by TINs, rasters, or contour lines so that any location has either a specified value or one that can be derived.

Contour – The edge or line that defines or bounds a shape or object.

Control panel – Consists of power circuits or control circuits that direct the performance of machinery or equipment.

Cooling fins – A series of thin metal strips placed between cooling passages to help dissipate heat.

Cooling system – A system that allows air or liquid to the circuit to maintain a constant pressure.

Coordinate – A set of numeric quantities that describe the location of a point in a geographic reference system. Coordinates represent locations on the Earth's surface relative to other locations.

Corrosion – Wear that occurs when materials chemically react with a foreign substance causing components to corrode.

Crankshaft – That main shaft supporting the connectors rods and turns piston reciprocation into rotary motion.

Crankshaft position transducer – Monitors the position and rotational speed of the crankshaft.

Crimp – To pinch or press together; A process used to fasten a connector to a wire mechanically.

Cross shaft – A perpendicular shaft that connects the yokes in a universal joint.

Crude oil – Liquid petroleum oil that has not been refined.

Current – The flow of free electrons through a conductor.

Current draw – The amperage, or volume of current, pulled by an electrical component.

Cylinder – A linear actuator.

D

Data link connector (DLC) – A 16-pin diagnostic port found on equipment to interface with a scan tool.

Database – One or more structured data sets, managed and stored as a unit and generally associated with software to update and query data.

Degree – Unit of angular measurement used to measure latitude and longitude. One degree of latitude anywhere on the Earth's surface and one degree of longitude at the equator equals a distance of 69.17 miles. (At 85 degrees N latitude, 1 degree of longitude equals approx. 6 miles)

Demulsifier – Additive that separates water from oil.

Department of Transportation (DOT) tire code – Manufacturers code used to identify where and when a tire was manufactured.

Diagnostic process – A systematic process used by technicians to diagnose, correct, and confirm the repair's operation.

Dial caliper – An instrument for measuring thickness and internal or external diameters.

Diesel – A hydrocarbon-based fuel with a low flash point used to power diesel engines.

Diesel exhaust fluid (DEF) – Short for diesel exhaust fluid, a liquid used to reduce air pollution created by the diesel engine.

Differential – A drive mechanism designed to allow two different wheels (or axles) to spin at different speeds as a machine turns a corner.

Differential carrier – The structure that holds the differential case in proper alignment with the pinion gear.

Differential correction (DGPS) – The technique of comparing GPS data collected in the field to GPS data collected at a known point. A correction factor can be determined and applied to the field GPS data by collecting GPS data at a known point.

Differential receiver – Device receiving ground-based DGPS signals.

Digital – A signal used to communicate data within a series of discrete values, such as 0 and 1.

Digital multimeter – A diagnostic tool used to measure two or more electrical values.

Dilution of precision (DOP) – An indicator of satellite geometry for a unique constellation of satellites used to determine a position. Positions tagged with a higher DOP value generally constitute poorer measurement results than those tagged with lower DOP.

Diode – A semiconductor device that allows current flow in one direction but resists it in the other.

Direct current (DC) – Electric current that flows steadily in one direction only.

Direct drive – When two input members are moving at the same speed in a planetary gear system.

Directional control valve – A valve whose primary function is to direct or prevent flow through selected passages.

Double-acting cylinder – A cylinder which actuated by compressed fluid in both extending and retracting strokes.

Doubles – Measure of seed singulation where a planter places more than one seed in a single location.

Down force – Weight of a planter's gauge wheel during planting that keeps the seed depth consistent.

Drive gear – Gear rotated by the shaft attached to the power source.

Drive pulley – Pulley rotated by the shaft attached to the power source.

Drive train – The collective set of components used to transfer power from a power source to a load.

Driven gear – Gear rotating the device or implement to do work.

Driven pulley – Pulley rotating the driveshaft to do work.

Driveshaft – A rotating shaft that transmits torque.

Drivetrain – The collective set of components used to transfer power from a power source to a load.

Drone – A remote-controlled pilotless aircraft of small flying device.

E

Electro-hydraulic system – System in which an electronic control module is used to energize a proportional solenoid valve, which, in turn, directs hydraulic oil pressure.

Electromagnet – A magnet developed by a current of electricity.

Electronic control unit (ECU) – A small device responsible for controlling a specific function in a CAN bus network.

Elevator mount unit (EMU) – Precision agricultural component used for measuring moisture levels of grain harvested by a combine.

Emulsify – Dispersion of fine droplets of one liquid in another, such as water in oil.

End play – A distance a shaft or gear can move after bearing installation.

Engine block – The main structure of an engine that supports and helps maintain the alignment of internal and external parts.

Ephemeris – The predicted changes in the orbit of a satellite transmitted to the GPS receiver from the individual satellites.

Ephemeris errors – Errors that originate in the ephemeris data transmitted by a GPS satellite. Ephemeris errors are removed by differential correction.

Equator – The parallel of reference zero north or south.

Exhaust – The steam and gases escaping from the cylinder of an engine.

Exhaust event – An engine operation event in which spent gases are removed from a combustion chamber and released into the atmosphere.

Exhaust system – Components that carry exhaust emissions from the engine, including the muffler, exhaust pipes, exhaust manifold, and turbocharger turbine.

F

Failure analysis – Identifying the root cause of a failure.

Feature – A representation of a real-world object on a map.

Feeler gauge – Measurement tool used to verify distances between parts.

Female connector – A connector that holds the pin of the male connector.

Filter – Filtration device designed to remove particles that are finer than those removed by a strainer.

Five Whys – A Socratic questioning style used to identify the underlying condition of a cause and effect relationship.

Flashpoint – The temperature at which an organic compound produces sufficient vapor to ignite in the air.

Flat-head screwdriver – Screwdriver that fits into a single slot on a screw.

Flow control valve – A valve whose primary function is to control flow rate.

Flowmeter – Instrument designed for measuring the volume of oil flow in a hydraulic circuit.

Flow-rate – The volume, mass, or weight of a fluid passing through any conductor per unit of time.

Fluid – A liquid, gas, or combination thereof.

Fluid power – Energy transmitted and controlled through pressurized fluid.

Fluid power system – A system that transmits and controls power through the use of a pressurized fluid within an enclosed circuit.

Flywheel – A cast iron, aluminum, or zinc disc mounted on one end of the crankshaft to provide inertia for an engine to prevent the loss of engine speed between combustion intervals.

Forage harvester – A machine designed to cut and chop complete plants into silage.

Force – An influence that changes the motion of an object, or produces motion of a stationary object.

Force sensor – Converts an input mechanical load, weight, tension, compression, or pressure into an electrical output signal.

Forward bias – An arrangement of a diode in a circuit where the diode works as a conductor.

Fracture – Failure that occurs when a component breaks into two or more pieces.

Friction – Resistance of the flow of fluid in a passage resulting in increased fluid temperature and loss of work potential.

Friction bearing – A bearing that consists of a fixed nonmoving bearing surface, such as machined metal or pressed in the bushing, that provides a low-friction support surface for rotating or sliding surfaces.

Friction clutch – A clutch that uses a friction-lined plate to transfer torque.

Friction disc – Discs lined with friction material and are stacked in alternative fashing between the separator plates.

Fuel injector – Valve controlled by electronic solenoid or spring pressure to inject fuel into the combustion chamber.

Fuel solenoid – A solenoid that opens fuel access to the engine when the key switch is in the start and on positions but closes the access when the engine is off.

Fuel system – Components that carries, cleans, and pressurizes fuel en route to the fuel injectors.

Fuel temperature transducer – Signals fuel temperature to the ECU.

Fuse – Protective device that interrupts current flow if an overload condition is present in a circuit.

G

Gasoline – A hydrocarbon-based fuel with a high flash point used to power gasoline engines.

Gauge wheel – Planter component that regulates the seed depth.

Gear – A toothed wheel that meshes with another wheel to transfer rotational power.

Gear pump – Fixed-displacement pumps in which gears provide the pumping action.

Gear ratio – Ratio of speed of input shaft to that of the output shaft. The number of teeth on a drive gear compared to the number of teeth on the driven gear.

Gear reduction – Inverse of a gear ratio. The number is found by dividing the number of teeth on a driven gear by the number of teeth on a drive gear.

Gearbox – A sealed container with the input shaft and output shaft and houses at least one set of mating gears.

Geographic information system (GIS) – A system that collects, stores, and manages geographic reference information.

Georeferencing – Aligning geographic data to a known coordinate system to be viewed, queried, and analyzed with other geographic data.

GIS database – Data about spatial locations and shapes of geographic features recorded as points, lines, areas, pixels, grid cells, or TINs, as well as their attributes.

Gland – A mechanical device that is used to contain a seal, O-ring, or gasket in a specified space to result in a leak-proof connection between two or more mechanical components.

Global positioning receiver – A device receiving and processing signals from GPS satellites to determine a geographic location. Hardware components are needed to process signals received by the antenna.

Global positioning system (GPS) – A positioning system that uses the location of navigational satellites orbiting the Earth to determine the location and elevation of a GPS receiver.

Glow plug – A heating element used to help diesel engines start initially or in cold weather by warming the air in the cylinders.

GPS console – Monitor displaying GPS information and data.

Grease seal – A seal used to retain grease in a case or housing.

Grease zerk – A metal fitting used to feed grease to a bearing from a grease gun.

Guard – A device, appliance, or attachment that prevents injury or loss.

Guidance system – A virtual or physical device used to control an object's movement.

H

Hay baler – An implement used to pick up a swath of hay and pack it into a bale.

Heat shrink – A protective electrical insulation that shrinks to fit onto a cable or connection when heat is applied.

Helical gear – Gear with external teeth closest to the outer edge of the gear.

Herringbone gear – A gear with a chevron-shaped tooth pattern.

I

Idler gear – Gear inserted between driven and drive gears to change the direction or speed of the driven gear.

Ignition – The process of causing fuel in an engine to burn so the engine begins operation.

Ignition systems – Components used to vaporize, compress, and ignites the fuel; includes piston, intake and exhaust valves, and glow plugs.

Illustrated parts list – An exploded diagram of a machine component that shows each part as a separate entity.

Impeller – A wheel-like device that has fins cast into it and uses centrifugal force to transfer liquids or air.

Implement - Any tool which aids a person to make work and effort more effective and productive.

Indicator light – A light used to indicate the component function or malfunction to the operator.

Injection pump – A device used by which fuel is metered and delivered under pressure to the injectors.

Input – The power or energy supplied to a machine.

Inputs – Items purchased to carry out a farm's operation. Such items include fertilizers, pesticides, seeds, fuel, and animal feed.

In-running nip points – Pinch points where machine parts move towards each other or when one part moves past a stationary object.

Intake event – An engine operation event in which an air-fuel mixture is introduced to a combustion chamber.

Intake manifold – Series of connecting tubes or housing between the air filter and openings to the intake valves.

International Standards Organization (ISO) viscosity grade – Scale developed by ISO for indicating a fluid's viscosity.

Interpersonal skills – Traits technicians rely on when communicating or working with others.

Interpolation – The estimation of surface values at unsampled points based on known surface values of surrounding points. Interpolation is commonly a raster operation but can also be in a vector environment.

ISO 446:1999 – Common standard for evaluating system cleanliness in the mobile equipment industry. Standard used for determining the number of particles of a particular size in hydraulic fluid.

J

Journal – A part of a shaft or axle that rests on bearings.

K

Key part – Parts to replace or rebuild, as reported in a work/repair order.

Key switch – A key-operated switch mounted on the steering column for connecting and disconnecting power to the electrical system. Also known as an ignition switch.

L

Latitude – The north/south component of a location on the surface of the Earth. Latitudes north of the equator are considered positive, and those south of the equator are negative.

Layer – A thematic set of spatial data described and stored in a digital database or map library.

Lift pump – A device used to lift fuel from the fuel tank and deliver fuel to the injection pump.

Light sensor – Converts an input of visible or infrared light into an electrical output signal.

Lightbar – Guidance system using GPS to assist operators to drive in a specific direction.

Light-emitting diode (LED) – A semiconductor diode that glows when a voltage is applied.

Load – An electrical component that consumes electric power.

Load index – Numerical values given to tires to indicate the weight load a tire can handle.

Load sensor – Measures electrical load on mechanical devices powered by electricity.

Logbook – A record of important events in management and operation of the workplace.

Longitude – The east/west component of a location on the surface of the Earth. Longitude lines east of the prime meridian are considered positive, and those west of the prime meridian are negative.

Low-side – The side of the circuit with a lower amperage to control the high-side of the circuit without damaging circuit components.

M

Machine learning – The process by which a computer can improve its performance (as in analyzing image files) by continuously incorporating new data into an existing statistical model.

Magneto – A coil of copper wire that conducts electricity as the magnet in the flywheel crosses its path. The charge provides a spark for gasoline engines to undergo ignition.

Male connector – A connector that includes a solid pin that fits into the jack of the female connector.

Manifold absolute pressure (MAP) – Sends the ECU vacuum and positive air pressure readings from the intake manifold to control fuel injection for optimum combustion.

Mass airflow (MAF) – Measures the air flowing through the intake system.

Micrometer – A precision instrument that measures to one-ten thousandths of an inch (0.0001″). Different types are used to measure dimensions, thicknesses, and depth of parts and openings.

Micron – On millionth of a meter.

Minute – Unit of angular measurement subdivision of Degrees. Each degree is divided into 60′ (minutes). One minute of latitude anywhere on the Earth's surface and one minute of longitude at the equator equals 1.15 miles or one nautical mile.

Moisture sensor – Converts an input moisture level into an electrical output signal.

Monitor – An instrument or device used for observing, checking, or keeping a continuous record of a process or quantity.

Mower – An implement designed to cut and lay down hay crops in a field.

Multipath – The interference to a signal that has reached the receiver antenna by multiple paths is usually caused by the signal being bounced or reflected. Signals from satellites low on the horizon will have high multipath errors. Receivers that can be configured to "mask out" signals from such satellites can help minimize multipath.

N

National Pipe Thread (NPT) – Course thread type used on pipe fittings.

Needle roller bearing – A type of antifriction bearing with thin cylindrical rollers, known as needles, between an inner and an outer race.

Needle valve – A valve having fine thread on the valve stem, which allows small, precise adjustments to the valve's orifice size and the resulting pressure and flow.

Nominal diameter – Size at which a pipe or tube is identified.

Non-positive displacement pump – Pump without a tight seal that uses centrifugal force to displace a fluid.

Nonsynchronous drive – A drive system that does not provide a positive engagement between the drive and driven sides of a system.

Normally closed (N.C.) – A connection in the relay that is closed when the relay is not energized.

Normally open (N.O.) – A connection in the relay that is open when the relay is not energized.

O

Offset – The amount or distance by which something is out of line relative to the GPS receiver.

Ohm – A unit of measure that represents electrical resistance.

Ohm's Law – The relationship between voltage, current, and resistance.

Oil filter – A device used to strain abrasive impurities from engine oil.

Open circuit – An electrical circuit in which there is at least one place where current cannot flow.

Opened – A condition where the supply voltage cannot reach its destination. Occurs when an electrical wire or connection is broken and opening a circuit.

Open-loop – Hydraulic system where the pump draws all of its inlet oil directly from the reservoir.

Operating controls – A device for regulating and guiding a machine.

Original Equipment Manufacturer (OEM) – An industry abbreviation for Original Equipment Manufacturer.

O-ring – A seal made from rubber or other synthetic material in the shape of a circle and of circular or other polygonal cross-section.

Output – The quantity or amount produced, as in a given time.

Outputs – A result, good or bad, of the operation of any system.

Overdrive mode – Anytime the planetary carrier is the input member.

Overlap – Area where equipment has treated a field more than once during a single application.

Oxidation – The absorption of oxygen into fluid and the subsequent plating of the oxygen/fluid mixture onto metal surfaces.

P

Parallel circuit – An electrical circuit that has two or more resistance units wired so that current can flow through them at the same time.

Parasitic battery drain – A battery drain that continues after the engine has been turned off, decreasing battery life.

Parts number – A series of numbers and/or letters that signify a specific part of a machine component.

Pascal's Law – Pressure exerted at any point on a confined static liquid is transmitted with equal force on areas at right angles to all surfaces.

Pick List – A list of parts used to pull materials from warehouse shelves.

Pinion gear – A small gear that drives a larger gear. Often used as the input gear in a differential.

Pinion gear – The smaller of two interlocking gears.

Piston – 1. A cylindrical engine component that slides back and forth in a cylinder bore by forces produced during combustion. 2. A sliding cylinder fitting within a cylindrical vessel that receives force from hydraulic pressure.

Piston pump – Variable displacement pump using pistons controlled by a swashplate to displace fluid in a hydraulic system.

Piston rod – The element transmitting mechanical force and motion from the piston.

Piston shoes – Connect the pistons to the swashplate of a piston pump.

Pitch – The distance between threads on a fitting.

Pitch gauge – Tool used to determine the pitch and type of threads on a fitting.

Pitting – Make a hollow or indentation in a surface.

Planetary carrier – A frame that planetary gears are attached to that keeps the gears in position relative to each other.

Planetary gear set – A gear set consisting of a central gear, sun gear, planetary gears, planetary carrier, and a ring gear.

Planter – A mechanical device used for the rapid, efficient, and uniform planting of seeds.

Plies – Layers of fabric-type cords that are bonded into the rubber of a tire carcass to give strength to the tire.

Ply rating – A numerical value given to a bias-ply tire to designate the tire’s strength and load-carrying capacity.

Point – A specific location represented by latitude and longitude coordinates.

Point of operation – Where work is performed on material.

Polygon – A closed plane figure having three or more straight sides.

Polymer – A chemical compound or mixture of compounds formed by polymerization and consisting essentially of repeating structural units.

Port – A physical connection in an actuator to which a peripheral device or a transmission line from a remote terminal can be attached.

Port – An internal or external terminus of a passage in a component.

Portfolio – A set of pieces of creative work collected by someone to display their skills, especially to a potential employer.

Position dilution of precision (PDOP) – A value describing how many satellites are spread evenly throughout the sky. The more the satellites directly above you and the less on the horizon, the lower the PDOP value is.

Positive displacement pump – Pump with a tight seal that displaces all fluid it takes in.

Potentiometer – A variable resistor that can be used to adjust the voltage in a circuit.

Pounds per square inch (psi) – Unit of measurement for pressure in a fluid power system.

Pour point – Minimum temperature at which a fluid can still be poured.

Power take-off (PTO) - An extension of the crankshaft that allows the engine to transmit power to an application.

Powertrain control module (PCM) – A designated ECU for controlling the powertrain.

Precision agriculture – Systematic approach to site-specific agriculture management.

Preload – The amount of static force applied to the bearing rollers after being adjusted for zero endplay.

Prescription agriculture – Applying detailed, site-specific recommendations for a farm field based upon analysis of GIS data.

Pressure – Force per unit area, usually expressed in pounds per square inch.

Pressure gauge – A gauge indicating the pressure in the system to which it is connected.

Pressure plate – Applies pressure to the clutch disc to engage a drivetrain.

Pressure relief valve – Safety device designed to protect a pressurized vessel or system during an overpressure event.

Prime meridian – A line running vertically from the North Pole to the South Pole along which all locations have the same longitude of zero.

Programmable logic controller (PLC) – Computer used to collect information from sensors and use the information to control machines.

Proximity sensor – Sensor able to detect the presence of nearby objects without any physical contact.

Punching – To strike or hit in operation.

Q

Qualified person – A term used by OSHA to recognize a person who is properly educated and trained for the assigned job.

Qualitative data – Observable information based on physical characteristics.

Quantitative data – Measurable information.

Query – A request to select features or record from a database. A query is written as a statement or logical expression.

Quick disconnects – Electrical connectors used to provide a fast and easy connection to disconnect cables. Includes both male and female connectors.

Quick-connect coupler – A mechanical device that may be engaged or disengaged to attach two fluid passages. Typically, disengagement is possible by manual means.

R

Race – A metal ring that provides a smooth rolling surface for the rolling elements in a friction bearing.

Rack gear – A spur gear with teeth along a straight line.

Radial load – A load applied perpendicular to the shaft.

Radial-ply – A thin sidewall tire constructed with steel cords that are angled at 45° to the tire's centerline and extend in opposite directions across the tire from bead to bead.

Radiator – A heat exchanger used to remove heat from the engine coolant.

Raster – A spatial data model defining space as an array of equally sized cells arranged in rows or columns and composed of single or multiple bands.

Reciprocating – To move alternatively back and forth.

Rectified – A term used to describe alternating current (AC) that is changed to direct current (DC).

Reference number – A number used in illustrated parts lists to reference a part to more information displayed in a table.

Refractometer – A device used to measure the index of refraction. Technicians use it to test engine coolant and DEF concentrations.

Relay – A magnetically operated switch used to make or break current flow in a circuit.

Remote sensing – The scanning of the earth by satellite or high-flying aircraft to obtain information about it.

Reservoir – The hydraulic reservoir is a container for holding the fluid required to supply the system, including a reserve to cover any losses from minor leakage and evaporation.

Resistance – The opposition of current flow.

Resistor – A device having a designed resistance to the passage of an electric current.

Retaining ring – A ring that fits in a groove to allow rotation without horizontal movement. Also known as a snap ring.

Return line – A fuel line that returns unused fuel to the fuel tank.

Reverse bias – An arrangement of a diode in a circuit where the diode works as an insulator.

Rheostat – A variable resistor used to control current flow.

Ring gear – 1. A gear attached to a differential housing is driven by a spiral bevel pinion gear or an external toothed spur or helical gear. 2. A large internal tooth gear in a planetary gear system surrounding the planetary gears.

Ring terminal – Electrical connectors with a ring on the end of the connection.

Rod – Portion of a hydraulic cylinder providing linear movement that is connected to the piston.

Roller bearing – Bearing consisting of multiple rollers between the inner and outer races.

Root cause – A base cause of a failure in a cause-and-effect relationship.

Rotating – To turn around on an axis.

Rotor – Hydraulic device that transforms fluid energy into rotational mechanical energy.

RPM – Revolutions per minute.

S

Safety Data Sheet (SDS) – Information sheets that provide end-users important safety, hazard, property, and transport information to the user.

Satellite constellation – The group of GPS satellites from which data is used to determine a position.

Scan tool – A diagnostic tool that connects to the DLC to communicate fault codes to the technician.

Schematic – A diagram that shows hydraulic or electrical system circuitry using symbols that depict devices and lines representing conductors.

Schematic – A schematic diagram, in particular, of an electric or electronic circuit.

Sealed bearing – A type of antifriction bearing with seals outside the races to keep contamination out of the bearing and keep in lubrication.

Second – Unit of angular measurement subdivision of minutes. Each minute is divided into 60″ (seconds). One second of latitude anywhere on the Earth's surface and one second of longitude at the equator equals 33.82 yards.

Sensor – A device that detects or measures a physical property and indicates a response.

Series circuit – A circuit with only one path for current to flow.

Series-parallel circuit – A circuit in which a series and parallel circuits are combined.

Serpentine belt – A single, continuous belt used to drive multiple peripheral devices in an engine.

Service desk – A sector of agricultural equipment dealerships that provides service to the customer to collect information on repairs, sells replacement parts, and bills the customer for repairs.

Service manuals – A manual produced by the manufacturer to communicate maintenance, diagnostics, and repair specifications to technicians.

Shear force – A type of force when two objects slide parallel to one another.

Shearing – To cut or clip with a sharp instrument.

Short – Occurs when an electrical circuit is connected to an undesirable point.

Shutdown circuit – An interruption circuit used to shut down the engine by grounding the magneto.

Side gear – Gears that drive the wheels and are attached to the axle shafts.

Sidewall – The flexible rubber exterior that covers the sides of a tire from the bead to the tire's shoulder.

Silica – A hard, unreactive, colorless compound that occurs as the mineral quartz and as a principal constituent of sandstone and other rocks.

Single-pole switch – A switch controlling one electrical circuit.

Singulation – Lateral and vertical seed placement in a planting row.

Singulation quality – The rate seeds are planted correctly in a field without a skip or double.

Site-specific management –Observing and measuring differences within specific locations in a field and using the information to make improvements.

Skip – Area of a field not treated by equipment during a single application.

Snap ring – A spring ring that is sprung open and snapped into place in its groove and is used especially for a piston or other retaining ring function.

Snap rings – A retaining ring that fits in a groove to allow rotation without horizontal movement. Also known as a circlip.

Solder – An alloy with a low melting point used to fuse electrical connections.

Soldering – The process of joining two items together with filler metal, solder, of a lower melting point than the metals to be joined. Soldering is commonly used in electrical devices.

Solenoid – 1. A coil of metallic wire, usually copper, wrapped around a steel plunger that can move when it becomes magnetized. 2. An electrically operated magnetic device used to operate a unit.

Source – The source of voltage in a circuit, such as a battery or an outlet.

Spalling – Surface contact stress fatigue in which the mating surface chips, breaks or flakes off in pieces.

Spatial data – Information about the locations and shapes of geographic features and relationships between them, usually stored as coordinates and topology.

Specific gravity – The ratio of a density of a substance to a density of a standard, usually water for a liquid.

Speed rating – A tire sidewall marking that designates the top speed that the manufacturer has designed the tire to travel.
Spider gear – Small bevel gears that transfer power from the case to the side gears in a differential.

Spool – Core with lands separated by spaces used in a valve to divert hydraulic fluid to specific ports.

Sprocket – A toothed wheel that meshes with a chain.

Spur gear – A gear with straight teeth cut parallel to the shaft axes.

Starter – A motor that uses a geared drive to crank the engine.

Starter solenoid – A solenoid that moves the starter pinion into engagement with the ring gear and provides the starter motor with a full cranking current.

Starting circuit – A circuit that provides electrical power to the starter to start the engine.

Stator – The stationary part of a rotary system, found in electric generators.

Sun gear – The central gear in a planetary gear set that is surrounded by the planetary pinion gears.

Supervised Agricultural Experience (SAE) – A student-led, instructor-supervised, work-based learning experience that results in measurable outcomes within a predefined, agreed-upon set of Agriculture, Food and

Natural Resources (AFNR) Technical Standards and Career Ready Practices aligned to your Career Plan of study.

Swashplate – Controls the fluid displaced by a piston pump.

Symptom – A sign or indication of a component failure.

Synchronous drive – A drive system that provides a positive engagement between the drive and driven sides of a system.

T

Tapered roller bearing – Antifriction bearing consisting of multiple tapered rollers housed in a cage and positioned between two tapered races.

Technician – Worker in a field of technology who is proficient in the relevant skill and technique, with a relatively practical understanding of the theoretical principles.

Telescoping gauge – Measuring tool with spring-loaded plunges used together with a micrometer to measure the inside of holes or bores.

Terminating resistor – A single resistor located at the end of an electrical transmission line.

Thermistor – A device that changes its resistance in relation to heat.

Thermostat – A temperature-sensitive device used in cooling systems to control coolant flow in relation to temperature.

Threshold logic – Conditions set for a PLC to activate an output at, above, or below a specific input value.

Tillage – Act of cutting, agitating, stirring, and overturning the soil.

Timing belt – A flat belt with cogs or teeth.

Torque – A force acting on a perpendicular radial distance from the point of rotation.

Torque multiplying – Anytime in a planetary system when the planetary carrier is the output member.

Torque wrench – A calibrated tool used to apply a specified amount of torque to a fastener.

Tractor – A vehicle with an automotive or diesel-like engine used to supply power to other machines in one of five ways: Pulling at the drawbar; belt power from the belt pulley; rotary power from the power take-off shaft; hydraulic power of the operation of hydraulic cylinders; electric power when a generator is on the tractor.

Transducer – A device that converts variations into a physical quantity, such as pressure or temperature, into an electronic signal.

Transmission – A device in the powertrain of motorized vehicles that provides different gear ratios between the engine and drive wheels as well as neutral and reverse positions.

Transversing – Movement in a straight, continuous line.

Tread – The outer surface of a tire that contacts the soil or pavement.

Trilateration - The measurement of the lengths of the three sides of a series of touching or overlapping triangles on the Earth's surface to determine the relative position of points by geometrical means.

Turbine – An impeller on the turbocharger's exhaust side that drives the compressor.

Turbocharger – A device that utilizes exhaust pressure to increase the air pressure in cylinders.

U

Universal joint (U-joint) – A component that connects two shafts and makes it possible for one shaft to transfer rotation to the other through various angles.

Unmanned aerial vehicle (UAV) – Commonly referred to as a drone.

V

Value – Descriptive information about a feature. Values can be thought of as the answers to the questions posed by attributes.

Valve – 1. A device that controls the fluid flow, direction, pressure, or flow rate. 2. An engine component that opens and closes at precise times to allow the flow of an air-fuel mixture into and exhaust gases from a cylinder.

Vane pump – Variable displacement pump using vanes controlled by a cam ring to displace fluid in a hydraulic system.

Variable displacement pump – Pump in which the chamber's effective volumes can be changed to increase or decrease flow for a given rpm.

Variable-rate technology (VRT) – Instrumentation used for varying the rates of fertilizer, pesticides, and seed application as one travels across a field.

V-belt – A belt with a V wedge-shaped cross-section.

Vector – A coordinate-based data structure commonly used to represent geographic features.

Vertical dilution of precision (VDOP) – The effect of the DOP on the vertical position value. The more visible satellites low in the sky, the better the VDOP and the vertical position (Altitude) are.

Viscosity – Liquid's resistance to flow based on its thickness.

Viscosity Index – Rating assigned to oil to indicate how much or how little the oil's viscosity changes across a wide temperature spectrum.

Volt – A unit of measurement of electrical pressure or force that will move a current of one ampere through a resistance of one ohm.

Voltage drop – A decrease of electrical potential across a point of resistance.

W

Wastegate – A valve that vents excess exhaust gas to limit the amount of boost pressure delivered by the turbocharger.

Water jacket – The area around the engine cylinders that is left hollow so that coolant may be admitted.

Water pump – A pump used to circulate coolant through an engine.

Wheel ballast – Weights bolted to a tractor's wheels to correctly ballast a tractor's weight.

Wheel slip – The relative motion between a tire and the road surface it is moving on.

Wire strippers – A tool used to strip the insulation from a cable without damaging the wire within.

Work/Repair Order – A order written by the technician that communicates services rendered by the technician.

Worm gear – A spur gear with specially cut teeth that are driven by a worm.

Y

Yield map – Maps used to visualize data collected during yield monitoring.

Yoke – A Y-shaped component located in a driveline used to connect a U-joint. A portion of a universal joint that allows the shaft to flex or slip. The yoke joins to the cross shaft.

Z

Zener diode – A silicon diode that serves as a rectifier. It will allow current to flow in one direction only until the applied voltage reaches a certain level. Once it reaches this point, the diode allows the current to flow in the opposite direction.

Zero-energy state – Safe state of a hydraulic system where the system is not energized and has no internal fluid pressure.

TAA Course Materials

APP	Qty/ 20	Qty/ 30	Unit	Item Specifications	Vendor
1.1.1	20	30	Each	*Heavy Equipment Power Trains and Systems* text	Goodheart-Wilcox
1.1.2	40	60	Each	Bolt, $^{5}/_{16}$″-1″ low-grade UNC	Local – Hardware
1.1.2	10	15	Each	Combination square	Local – Tool
1.1.2	10	15	Each	Combination wrench, $^{1}/_{2}$″	Local – Tool
1.1.2	10	15	Each	Dial caliper 6″/150mm	Local – Amazon
1.1.2	10	15	Each	Dial indicator	Local – Amazon
1.1.2	10	15	Each	Flat stock 1/8″x1″-5″	Local – Hardware
1.1.2	30	45	Each	Flat stock 1/8″x1″-9″	Local – Hardware
1.1.2	240	360	Each	Flat washer 5/16″	Local – Hardware
1.1.2	20	30	Each	Glue stick	Local
1.1.2	20	30	Each	Logbook	Local
1.1.2	40	60	Each	Nut, $^{5}/_{16}$″, UNC	Local – Hardware
1.1.2	20	30	Pair	Safety glasses	Ward's
1.1.2	10	15	Each	Socket $^{3}/_{8}$″ drive, $^{1}/_{2}$″	Local – Tool
1.1.2	10	15	Each	Socket wrench, $^{3}/_{8}$″ drive	Local – Tool
1.1.2	200	300	Each	Tab divider	Local
1.1.2	200	300	Each	Tab label insert	Local
1.1.2	10	15	Each	Torque wrench, in-lb, $^{3}/_{8}$″ drive	Local – Tool
1.1.2	20	30	Each	Two-inch, three-ring binder	Local
1.1.3	20	30	Each	Bolts, assorted types, sizes, threads, and grades	Local – Hardware
1.1.3	20	30	Each	Clipboard	Local
1.1.3	10	15	Each	Dial caliper 6″/150mm	Local – Amazon
1.1.3	10	15	Each	*Heavy Equipment Power Trains and Systems* text	Goodheart-Wilcox
1.1.4	1	1	Each	Depth micrometer	Local – Tool
1.1.4	1	1	Each	Inside micrometer	Local – Tool
1.1.4	15	25	Each	Machine components	Local – Industry
1.1.4	1	1	Each	Outside micrometer, 0–1″	Local – Tool
1.1.4	1	1	Each	Outside micrometer, 1–2″	Local – Tool
1.1.4	1	1	Each	Outside micrometer, 2–3″	Local – Tool
1.1.5	10	15	Each	Ball joint service kit (**Harbor Freight**)	Local – Tool
1.1.5	10	15	Each	Ball-peen hammer	Local – Tool
1.1.5	10	15	Each	Dial caliper 6″/150mm	Local – Amazon
1.1.5	10	15	Each	Flat-head screwdriver	Local – Tool
1.1.5	2	3	Each	Grease	Local – Hardware
1.1.5	2	3	Each	Grease gun	Local – Tool
1.1.5	10	15	Each	*Heavy Equipment Power Trains and Systems* text	Goodheart-Wilcox
1.1.5	10	15	Each	Marker/pen	Local
1.1.5	10	15	Pair	Needle nose pliers	Local – Tool
1.1.5	10	15	Each	Paper plate, 12″	Local
1.1.5	20	30	Pair	Safety glasses	Ward's
1.1.5	10	15	Pair	Snap-ring pliers	Local – Tool
1.1.5	10	15	Each	Universal joint and service manual, new	Local – Equipment

APP	Qty/ 20	Qty/ 30	Unit	Item Specifications	Vendor
1.1.5	10	15	Each	Workbench with vise	Local – Tool
1.1.6	3	3	Each	Chains (drive chains)	Local – Industry
1.1.6	10	15	Each	Combination square	Local – Tool
1.1.6	10	15	Each	Dial caliper 6″/150mm	Local – Amazon
1.1.6	10	15	Each	Equipment service manual	Local – Industry
1.1.6	1	1	Each	Equipment with V-belts and chains	Local – Industry
1.1.6	2	3	Each	Grease	Local – Hardware
1.1.6	2	3	Each	Grease gun	Local – Tool
1.1.6	20	30	Each	*Heavy Equipment Power Trains and Systems* text	Goodheart-Wilcox
1.1.6	3	3	Each	Pulley for V belt	Local – Industry
1.1.6	20	30	Pair	Safety glasses	Ward's
1.1.6	3	3	Each	Sprocket	Local – Industry
1.1.6	10	15	Each	String, 3′	Local
1.1.6	10	15	Each	Tape measure, 25′	Local – Tool
1.1.6	3	3	Each	V-belts	Local – Industry
1.1.7	20	30	Each	Clipboard	Local
1.1.7	20	30	Pair	Safety glasses	Ward's
1.2.1	20	30	Each	Clipboard	Local
1.2.1	20	30	Pair	Safety glasses	Ward's
1.2.2	20	30	Each	Device with PowerPortal access	Local
1.2.3	5	8	Each	Battery case, D size	Local – Amazon
1.2.3	5	8	Each	Battery, D size	Local
1.2.3	5	8	Each	Beaker, 600ml	Ward's
1.2.3	15	20	Each	Components, electrical	Local – Teacher Notes
1.2.3	10	15	Each	Digital multimeter (DMM)	EETC
1.2.3	20	30	Each	Headphones	Local
1.2.3	20	30	Pair	Safety glasses	Ward's
1.2.3				Water	
1.2.3	5	8	Each	Water pump	Vernier
1.2.3	5	8	Each	Wire with alligator clips, black	EETC
1.2.3	5	8	Each	Wire with alligator clips, red	EETC
1.2.4	5	8	Each	Battery case, D size	Local – Amazon
1.2.4	5	8	Each	Battery, D size	Local
1.2.4	5	8	Each	Beaker, 600ml	Ward's
1.2.4	5	8	Each	Digital multimeter (DMM)	EETC
1.2.4	5	8	Each	Graduated cylinder, 250ml	Vernier
1.2.4	5	8	Each	Hot glue gun	Local
1.2.4	5	8	Each	Hot glue stick	Local
1.2.4	5	8	Each	Plastic hose, ¼″ I.D., 12″ - clear	Vernier
1.2.4	5	8	Pair	Pliers	Local – Tool
1.2.4	20	30	Pair	Safety glasses	Ward's
1.2.4				Water	
1.2.4	5	8	Each	Water pump	Vernier
1.2.4	10	16	Each	Wire with alligator clips	Local – Amazon
1.2.5	10	15	Each	Ball joint service kit (**Harbor Freight**)	Local – Tool
1.2.5	10	15	Each	Dial caliper 6″/150mm	Local – Amazon
1.2.5	10	15	Each	Flathead screwdriver	Local – Tool
1.2.5	2	3	Each	Grease gun	Local – Tool
1.2.5	10	15	Each	Marker/pen	Local
1.2.5	10	15	Pair	Needle nose pliers	Local – Tool

APP	Qty/ 20	Qty/ 30	Unit	Item Specifications	Vendor
1.2.5	20	30	Each	Paper plate, 12″	Local
1.2.5	20	30	Each	Pen, red	Local
1.2.5	20	30	Pair	Safety glasses	Ward's
1.2.5	10	15	Each	Universal joint with service manual, used	Local – Industry
2.1.1	7	10	Each	Battery, 12V	EETC
2.1.1	7	10	Each	Breadboard pin wire, male to female, black	Local – Amazon
2.1.1	7	10	Each	Breadboard pin wire, male to female, red	Local – Amazon
2.1.1	7	10	Each	Flat bearing	VEX 276-2232
2.1.1	14	20	Each	Gear, 12-tooth	VEX 276-2232
2.1.1	14	20	Each	Gear, 36-tooth	VEX 276-2232
2.1.1	14	20	Each	Gear, 60-tooth	VEX 276-2232
2.1.1	21	30	Each	Gear, 60-tooth extra strength	VEX 276-7748
2.1.1	7	10	Each	Hex wrench, $^{3}/_{32}$″	Local – Amazon
2.1.1	7	10	Each	Hex wrench, $^{5}/_{64}$″	Local – Amazon
2.1.1	7	10	Rolls	Masking tape	Local
2.1.1	7	10	Each	Motor clutch	VEX 276-2232
2.1.1	7	10	Each	Motor, 2-wire motor, VEX 393	VEX 276-2177
2.1.1	28	40	Each	Nut, #8-32 keps	VEX 276-2232
2.1.1	7	10	Each	Plastic storage containers (toolbox size)	Local
2.1.1	20	30	Pair	Safety glasses	Ward's
2.1.1	14	20	Each	Screw, #6-32 x ½″	VEX 276-2232
2.1.1	56	80	Each	Screw, #8-32 x ¼″	VEX 276-2232
2.1.1	77	110	Each	Shaft collar	VEX 276-2232
2.1.1	7	10	Each	Shaft, 11mm	VEX 276-2232
2.1.1	14	20	Each	Shaft, 12″ square	VEX 276-2232
2.1.1	7	10	Each	Shaft, 4″ square	VEX 276-2232
2.1.1	35	50	Each	Spacers, 8mm	VEX 276-2232
2.1.1	28	40	Each	Standoff 3″	VEX 276-2232
2.1.1	14	20	Each	Steel angle 2x2x25	VEX 276-2232
2.1.1	21	30	Each	Steel rail, 2x1x25	VEX 276-2232
2.1.1	7	10	Each	Wheel, 4″	VEX 276-1497
2.1.1	7	10	Each	Wrench or nut driver, ¼″	Local – Tool
2.1.2	5	8	Each	Battery, 12V	EETC
2.1.2	15	24	Each	Clutch disc	Local – Industry
2.1.2	15	24	Each	Dowel, 6″ x 1″ diameter	Local – Hardware
2.1.2	5	8	Each	Electromagnetic clutch and **Manual**	EETC
2.1.2	5	8	Each	Feeler gauge	Local – Tool
2.1.2	5	8	Each	Fuse, 10A	EETC
2.1.2	20	30	Each	*Heavy Equipment Power Trains* and Systems text	Goodheart-Wilcox
2.1.2	5	8	Each	Hot glue gun	Local
2.1.2	5	8	Each	Hot glue stick	Local
2.1.2	15	24	Each	Paper plate, 10″	Local
2.1.2	5	8	Each	Permanent marker	Local
2.1.2	5	8	Each	Plate, heavy, 12″	Local
2.1.2	20	30	Pair	Safety glasses	Ward's
2.1.2	5	8	Each	Sandpaper disc, 120 grit – 6″	Local – Hardware

APP	Qty/ 20	Qty/ 30	Unit	Item Specifications	Vendor
2.1.2	5	8	Each	Sandpaper disc, 200 grit–6″	Local – Hardware
2.1.2	10	16	Each	Sandpaper disc, 40-grit 6″	Local – Hardware
2.1.2	5	8	Each	Socket extension $^3/_8$″drive	Local – Tool
2.1.2	5	8	Each	Socket wrench, $^3/_8$″ drive	Local – Tool
2.1.2	5	8	Each	Socket, $^9/_{16}$″, $^3/_8$″ drive	Local – Tool
2.1.2	5	8	Each	Switch, single-pole, single-throw	Local – Hardware
2.1.2	100	160	Each	Washers, 1″	Local – Hardware
2.1.2	20	32	Each	Wire with alligator clips	EETC
2.1.3	7	10	Each	Battery, 12V	EETC
2.1.3	7	10	Each	Calculator	Local
2.1.3	7	10	Each	Cup, 9 oz	Local
2.1.3	2	3	Each	Electronic balance	Ward’s
2.1.3	7	10	Each	Ruler	Local
2.1.3	20	30	Pair	Safety glasses	Ward’s
2.1.3	7	10	Each	String, 3′	Local
2.1.3	7	10	Each	Switch, single-pole, single-throw	Local – Hardware
2.1.3	7	10	Each	Transmission model	*Activity 2.1.1*
2.1.3	280	400	Each	Washers, 1″	Local – Hardware
2.1.3	7	10	Each	Wire with alligator clips, black	EETC
2.1.3	14	20	Each	Wire with alligator clips, red	EETC
2.1.4	10	15	Each	Bearing, ball	Local – Industry
2.1.4	10	15	Each	Bearing, friction	Local – Industry
2.1.4	10	15	Each	Bearing, roller	Local – Industry
2.1.4	1	2	Bottles	Cleaning fluid	Local – Hardware
2.1.4	10	15	Each	Dial caliper 6″/150mm	Local – Amazon
2.1.4	10	15	Each	Flathead screwdriver	Local – Tool
2.1.4	20	30	Pair	Nitrile gloves	Ward’s
2.1.4	20	30	Pair	Safety glasses	Ward’s
2.1.4	1	1	Roll	Shop towels	Local
2.1.4	10	15	Each	Telescoping gauge	Local – Tool
2.1.5	7	10	Each	Battery, 12V	EETC
2.1.5	7	10	Each	Combination square	Local – Tool
2.1.5	7	10	Each	Hacksaw	Local – Tool
2.1.5	1	1	Each	Metal chop saw	Local – Tool
2.1.5	7	10	Each	Metal file	Local – Tool
2.1.5	20	30	Pair	Nitrile gloves	Ward’s
2.1.5	20	30	Pair	Safety glasses	Ward’s
2.1.5	7	10	Each	Switch, single pole, single throw	Local – Hardware
2.1.5				VEX supplies	VEX 276-2232, 276-2184, 275-1189, 275-1187
2.1.6	5	8	Each	Ball-peen hammer	Local – Tool
2.1.6	5	8	Each	Brass drift punch	Local – Tool
2.1.6	5	8	Each	Chisel	Local – Tool
2.1.6	5	8	Each	Dial caliper 6″/150mm	Local – Amazon
2.1.6	5	8	Each	Dial indicator	Local – Amazon
2.1.6	5	8	Each	Gearbox	Local – Industry
2.1.6	20	30	Pair	Nitrile gloves	Ward’s
2.1.6	5	8	Each	Paint pen	Local

APP	Qty/ 20	Qty/ 30	Unit	Item Specifications	Vendor
2.1.6	20	30	Pair	Safety glasses	Ward's
2.1.6	5	8	Each	Seal installer	Local – Tool
2.1.6	1	1	Roll	Shop towels	Local
2.1.6	5	8	Pair	Slip joint pliers	Local – Tool
2.1.6	5	8	Each	Socket set, $^3/_8$″ drive	Local – Tool
2.1.6	5	8	Each	Socket wrench, $^3/_8$″ drive	Local – Tool
2.1.6	5	8	Each	Torque wrench, in-lb, $^3/_8$″ drive	Local – Tool
2.1.6	5	8	Each	Transmission model	*Activity 2.1.1*
2.2.1	7	10	Each	Assembled transmission	*Activity 2.1.1*
2.2.1	7	10	Each	Battery, 12V	EETC
2.2.1	21	30	Each	Bevel gear	VEX 276-2184
2.2.1	7	10	Each	Differential case	VEX 276-2184
2.2.1	7	10	Each	Gear, 84-tooth	VEX 276-2232
2.2.1	7	10	Each	Hex wrench, $^5/_{64}$″	Local – Amazon
2.2.1	20	30	Pair	Safety glasses	Ward's
2.2.1	21	30	Each	Shaft collar	VEX 276-2232
2.2.1	7	10	Each	Shaft, 12″ square	VEX 276-2232
2.2.1	14	20	Each	Shaft, 4″ square	VEX 276-2232
2.2.1	7	10	Each	Switch, single-pole, single-throw	Local – Hardware
2.2.1	14	20	Each	Wheel, 4″	VEX 276-1497
2.2.1	14	20	Each	Wire with alligator clips, black	EETC
2.2.1	7	10	Each	Wire with alligator clips, red	EETC
2.2.3	5	8	Each	Ball-peen hammer	Local – Tool
2.2.3	1	2	Bottles	Brake cleaner	Local – Hardware
2.2.3	5	8	Each	Brass drift punch	Local – Tool
2.2.3	5	8	Each	Chisel	Local – Tool
2.2.3	5	8	Each	Cotter pin, replacement	Local – Hardware
2.2.3	5	8	Each	Dial caliper 6″/150mm	Local – Amazon
2.2.3	5	8	Each	Dial indicator	Local – Amazon
2.2.3	20	30	Pair	Ear plugs	Local
2.2.3	2	3	Each	Grease gun	Local – Tool
2.2.3	5	8	Each	Hub user manual	Local – Equipment
2.2.3	2	3	Tubes	Lithium grease	Local – Hardware
2.2.3	20	30	Pair	Nitrile gloves	Ward's
2.2.3	5	8	Each	Pry bar	Local – Tool
2.2.3	20	30	Pair	Safety glasses	Ward's
2.2.3	5	9	Each	Seal, replacement (**NAPA Part #27SS2768**)	Local – Hardware
2.2.3	5	8	Each	Seal/bearing driver	Local – Tool
2.2.3	1	2	Roll	Shop towels	Local
2.2.3	5	8	Pair	Slip joint pliers	Local – Tool
2.2.3	5	8	Each	Socket 38mm, ½″ drive	Local – Tool
2.2.3	5	8	Each	Socket wrench, ½″ drive	Local – Tool
2.2.3	5	8	Each	Tapered punch	Local – Tool
2.2.3	5	8	Each	Torque wrench, 5–80 ft-lb, ½″ drive	Local – Tool
2.2.3	5	8	Each	**Wheel hub/spindle (128008)**	Local – Northern Tool
2.2.3	10	16	Each	Woodblock, 6″-2x4	Local – Hardware
2.2.3	5	8	Each	Workbench with vise	Local – Tool
2.2.4	2	3	Each	Equipment with tires	Local – Equipment
2.2.5	1	1	Each	Electronic balance	Ward's
2.2.5	5	8	Each	Eye hook	Local

APP	Qty/ 20	Qty/ 30	Unit	Item Specifications	Vendor
2.2.5	5	5	Rolls	Masking tape	Local
2.2.5	5	8	Kg	Pea gravel	Local
2.2.5	5	8	Each	Permanent marker	Local
2.2.5	5	8	Each	Plastic container, 64 oz	Local
2.2.5	5	8	Each	RC tractor	Reality Works
2.2.5	5	8	Each	Tape measure, 25′	Local – Tool
2.2.5	5	8	Each	Transmitter	Reality Works
2.2.5	100	160	Each	Washers, 1″	Local – Hardware
2.2.6	2	2	Each	Ball-peen hammer	Local – Tool
2.2.6	2	2	Each	Battery, 12V	EETC
2.2.6	2	2	Each	Brass drift punch	Local – Tool
2.2.6	2	2	Each	Chisel	Local – Tool
2.2.6	5	5	Each	Dial caliper 6″/150mm	Local – Amazon
2.2.6	5	5	Each	Dial indicator	Local – Amazon
2.2.6	1	1	Each	Electromagnetic clutch with a large air gap.	EETC
2.2.6	1	1	Each	Electromagnetic clutch with no air gap.	EETC
2.2.6	2	2	Each	Feeler gauge	Local – Tool
2.2.6	2	2	Each	Fuse, 10A	EETC
2.2.6	2	2	Each	Hub user manual	Local – Equipment
2.2.6	1	1	Each	Misaligned shaft on worn bearings	Local – Industry
2.2.6	20	30	Pair	Nitrile gloves	Ward’s
2.2.6	2	2	Each	Pry bar	Local – Tool
2.2.6	20	30	Pair	Safety glasses	Ward’s
2.2.6	2	2	Each	Seal/bearing driver	Local – Tool
2.2.6	2	2	Pair	Slip joint pliers	Local – Tool
2.2.6	2	2	Each	Socket 1″, ½″ drive	Local – Tool
2.2.6	2	2	Each	Socket extension $^3/_8$″drive	Local – Tool
2.2.6	2	2	Each	Socket wrench, ½″ drive	Local – Tool
2.2.6	2	2	Each	Socket wrench, $^3/_8$″ drive	Local – Tool
2.2.6	2	2	Each	Socket, $^9/_{16}$″, $^3/_8$″ drive	Local – Tool
2.2.6	2	2	Each	Switch, single-pole, single-throw	Local – Hardware
2.2.6	2	2	Each	Tapered punch	Local – Tool
2.2.6	4	4	Each	Torque wrench, 5–80 ft-lb, ½″ drive	Local – Tool
2.2.6	1	1	Each	Two misaligned sprockets with a tight chain	Local – Industry
2.2.6	1	1	Each	Two pulleys with a loose belt	Local – Industry
2.2.6	1	1	Each	Two pulleys with a tight belt	Local – Industry
2.2.6	1	1	Each	Two sprockets with loose chain	Local – Industry
2.2.6	1	1	Each	Wheel hub with seized bearing	Local – Industry
2.2.6	1	1	Each	Wheel hub with worn bearing	Local – Industry
2.2.6	2	2	Each	Wheel hub/spindle	Local – Northern Tool
2.2.6	8	8	Each	Wire with alligator clips	EETC
2.2.6	4	4	Each	Woodblock, 6″-2x4	Local – Hardware
2.2.6	2	2	Each	Workbench with vise	Local – Tool
2.2.6	1	1	Each	Worn partially deflated tire on a wheel	Local – Industry
3.1.1	1	1	Bag	Cat litter, 10 lbs	Local
3.1.1	10	15	Each	Device with timer	Local
3.1.1	5	8	Each	Electronic balance	Ward’s
3.1.1	5	8	Each	Handheld fertilizer spreader	Local – Tool
3.1.1	5	8	Each	Handheld sprayer	Local – Tool

APP	Qty/ 20	Qty/ 30	Unit	Item Specifications	Vendor
3.1.1	10	15	Roll	Masking tape	Local
3.1.1	5	8	Each	Measuring cup (volume oz lines)	Local
3.1.1	20	30	Pair	Nitrile gloves	Ward's
3.1.1	20	30	Each	Plastic spoons	Local
3.1.1	20	30	Pair	Safety glasses	Ward's
3.1.1	10	15	Each	Tape measure, 25′	Local – Tool
3.1.1	1	1	Each	Water source with a hose	Local - Equipment
3.1.1	10	15	Each	Weighing dish	Ward's
3.1.2	10	15	Each	Mobile device with GPS application	Local
3.1.2	4	4	Each	Survey flag	Local
3.1.3	1	1	Each	Combine with precision components	Local – Industry
3.1.3	20	30	Each	Device with a digital camera	Local
3.1.3	20	30	Each	Mind-mapping software	Local
3.1.5	20	30	Each	Calculator	Local
3.1.6	10	15	Each	Battery adapter, 9V	Local – Amazon
3.1.6	10	15	Each	Battery, 9V	Local
3.1.6	10	15	Each	Box, small – shoe box size	Local
3.1.6	10	15	Each	Breadboard	Local – Amazon
3.1.6	70	105	Each	Breadboard pin wire, male to male	Local – Amazon
3.1.6	10	15	Each	Container and lid, 24 oz	Local
3.1.6	10	15	Each	DCU power output kit • 6 wires with alligator clip and pin ends • 2 Light-emitting diodes • 2 Resistors, 220 ohm	Vernier
3.1.6	10	15	Each	Digital control unit	Vernier
3.1.6	10	15	Each	Digital multimeter (DMM)	EETC
3.1.6	10	15	Each	LabQuest	Vernier
3.1.6	10	15	Each	Screwdriver, small flathead	Local – Tool
3.1.6	1	1	Each	Survey flag	Local
3.1.6	10	15	Each	Vernier soil moisture sensor	Vernier
3.1.6	10	15	Each	Water pump and hose	Vernier
3.1.7	10	15	Each	Battery adapter, 9V	Local – Amazon
3.1.7	10	15	Each	Box, small	Local
3.1.7	10	15	Each	Breadboard	Local – Amazon
3.1.7	70	115	Each	Breadboard pin wire, male to male	Local – Amazon
3.1.7	10	15	Each	DCU power output kit • Wires with alligator clip and pin ends • Light-emitting diodes • Resistors, 220 ohm	Vernier
3.1.7	10	15	Each	Digital control unit	Vernier
3.1.7	10	15	Each	Digital multimeter (DMM)	EETC
3.1.7	10	15	Each	LabQuest	Vernier
3.1.7	10	15	Each	Screwdriver, small flathead	Local – Tool
3.1.7	20	30	Each	Survey flag	Local
3.2.1	20	30	Seats	SMS Software with example data	Ag Leader
3.2.2	20	30	Seats	SMS Software with example data	Ag Leader
3.2.3	20	30	Seats	SMS Software with example data	Ag Leader
3.2.4	20	30	Seats	SMS Software with example data	Ag Leader
3.3.1	10	15	Each	Computer with Lobe software	Lobe
3.3.1	1	2	Bags	Planting media	Local
3.3.1	30	45	Each	Planting tray, small (12 cells)	Local
3.3.1	10	15	Each	Spray bottle	Local

APP	Qty/ 20	Qty/ 30	Unit	Item Specifications	Vendor
3.3.1	10	15	Each	Webcam with a USB cord	Local
3.3.2	10	15	Each	Green highlighter	Local
3.3.2	10	15	Each	Pink highlighter	Local
3.3.2	10	15	Seats	SMS Software with example data	Ag Leader
3.3.2	10	15	Each	Yellow highlighter	Local
4.1.1	5	8	Each	Basic Electrical Training Board	EETC
4.1.1	5	8	Each	Battery charger, 12V	EETC
4.1.1	5	8	Each	Battery, 12V	EETC
4.1.1	20	30	Each	Calculator	Local
4.1.1	5	8	Each	Digital multimeter (DMM)	EETC
4.1.1	5	8	Each	Fuse, 10A	EETC
4.1.1	5	8	Each	Resistor, 100Ω	EETC
4.1.1	20	30	Pair	Safety glasses	Ward’s
4.1.1	75	120	Each	Wire with alligator clips	EETC and Amazon
4.1.2	5	8	Each	Basic Electrical Training Board	EETC
4.1.2	5	8	Each	Battery charger, 12V	EETC
4.1.2	5	8	Each	Battery, 12V	EETC
4.1.2	5	8	Each	Digital multimeter (DMM)	EETC
4.1.2	5	8	Each	Fuse, 10A	EETC
4.1.2	5	8	Each	*Ignition Systems Service Manual*	Print
4.1.2	5	8	Each	LED bulb, 10mm	Local – Amazon
4.1.2	5	8	Each	Resistor, 100Ω	EETC
4.1.2	20	30	Pair	Safety glasses	Ward’s
4.1.2	5	8	Each	Silicon diode, failed	Local – Industry
4.1.2	5	8	Each	Silicon diode, new	EETC
4.1.2	30	48	Each	Wire with alligator clips	EETC and Amazon
4.1.3	5	8	Each	AC mini-hand motor	Local – Amazon
4.1.3	10	16	Each	Breadboard pin wire, male to male	Local – Amazon
4.1.3	5	8	Each	Digital multimeter (DMM)	EETC
4.1.3	5	8	Each	KidWind Output Power Board	Vernier
4.1.3	5	8	Each	LED bulb, 10mm	Local – Amazon
4.1.3	20	30	Pair	Safety glasses	Ward’s
4.1.3	20	32	Each	Wire with alligator clips	EETC
4.1.3	5	8	Each	Zener diode, 2V rating	Local – Amazon
4.1.4	20	30	Each	Clipboard	Local
4.1.4	5	8	Each	Digital multimeter (DMM)	EETC
4.1.4	20	30	Pair	Ear plugs	Local
4.1.4	20	30	Pair	Safety glasses	Ward’s
4.1.4	2	3	Each	Tractor	Local – Equipment
4.1.5	10	15	Each	Battery case, D size	Local - Amazon
4.1.5	10	15	Each	Battery, D size	Local
4.1.5	5	8	Each	Digital multimeter (DMM)	EETC
4.1.5	2	3	Roll	Electrical tape	Local – Hardware
4.1.5	10	15	Each	Graphite pencil, 6B	Local – Amazon
4.1.5	10	15	Each	Potentiometer, 10KΩ	Local – Amazon
4.1.5	20	30	Pair	Safety glasses	Ward’s
4.1.5	25	40	Each	Wire with alligator clips	EETC
4.2.1	5	8	Each	Basic Electrical Training Board	EETC
4.2.1	5	8	Copies	*Cranking Circuit Schematic*	Print
4.2.1	5	8	Copies	*John Deere Gator Service Manual*	Print
4.2.1	5	8	Sets	Marker, assorted colors	Local

APP	Qty/ 20	Qty/ 30	Unit	Item Specifications	Vendor
4.2.2	5	8	Each	Basic Electrical Training Board	EETC
4.2.2	5	8	Each	Battery charger, 12V	EETC
4.2.2	5	8	Each	Battery, 12V	EETC
4.2.2	5	8	Each	Digital multimeter (DMM)	EETC
4.2.2	10	16	Each	Fuse, 10A	EETC and Local
4.2.2	5	8	Each	Fuse, 7.5A	Local – Hardware
4.2.2	5	8	Each	Key	EETC
4.2.2	1	1	Roll	Masking tape	Local
4.2.2	5	8	Each	Permanent marker	Local
4.2.2	20	30	Pair	Safety glasses	Ward's
4.2.2	75	120	Each	Wire with alligator clips	EETC and Amazon
4.2.3	5	8	Each	Basic Electrical Training Board	EETC
4.2.3	5	8	Each	Battery, 12V	EETC
4.2.3	10	16	Each	C-clamp	Local – Tool
4.2.3	5	8	Each	Digital multimeter (DMM)	EETC
4.2.3	5	8	Each	Funnel	Local – Tool
4.2.3	5	8	Each	Highlighter	Local
4.2.3	5	8	Each	Magneto	Power Distributors
4.2.3	5	8	Quarts	Oil, 30W	Local – Hardware
4.2.3	20	30	Pair	Safety glasses	Ward's
4.2.3	1	2	Roll	Shop towels	Local
4.2.3	5	8	Each	Small engine, OHV	Power Distributors
4.2.3	5	8	Each	Socket wrench, ¼″ drive	Local – Tool
4.2.3	5	8	Each	Socket, 8mm, ¼″ drive	Local – Tool
4.2.3	5	8	Each	Spark plug	Power Distributors
4.2.3	60	96	Each	Wire with alligator clips	EETC and Amazon
4.2.4	5	8	Each	Basic Electrical Training Board	EETC
4.2.4	5	8	Each	Battery, 12V	EETC
4.2.4	10	15	Each	Battery, 9V	Local
4.2.4	5	8	Each	Digital multimeter (DMM)	EETC
4.2.4	1	1	Roll	Masking tape	Local
4.2.4	5	8	Each	Permanent marker	Local
4.2.4	10	16	Each	Relay, single-pole, single-throw, N.C.	Local – Amazon
4.2.4	10	16	Each	Relay, single-pole, single-throw, N.O.	Local – Amazon
4.2.4	50	80	Each	Wire with alligator clips	EETC and Amazon
4.2.5	5	8	Each	Battery charger, 12V	EETC
4.2.5	5	8	Each	Battery, 12V	EETC
4.2.5	5	8	Each	Battery, 9V	Local
4.2.5	5	8	Each	Button switch, N.C., SPST	Local – Amazon
4.2.5	5	8	Each	DC Motor, brushed, 12V	Local – Amazon
4.2.5	10	16	Each	LED bulb, 10mm	Local – Amazon
4.2.5	5	8	Each	Posterboard	Local
4.2.5	5	8	Each	Potentiometer, 10KΩ	Local – Amazon
4.2.5	10	16	Each	Relay, single-pole, single-throw, N.C.	Local – Amazon
4.2.5	20	30	Pair	Safety glasses	Ward's
4.2.5	5	8	Pair	Scissors	Local
4.2.5	5	8	Each	Switch, single-pole, single-throw	Local – Hardware
4.2.5	100	160	Each	Wire with alligator clips	EETC and Amazon
4.2.6	5	8	Each	Battery, 9V	Local
4.2.6	1	2	Pkg.	Breadboard pin wire, male to male	Local – Amazon
4.2.6	1	1	Set	Colored pencils, assorted	Local

APP	Qty/ 20	Qty/ 30	Unit	Item Specifications	Vendor
4.2.6	5	8	Each	Cup, 3 oz	Local
4.2.6	8	8	Each	Device with timer	Local
4.2.6	5	8	Each	Digital multimeter (DMM)	EETC
4.2.6	1	1	Roll	Duct tape	Local – Hardware
4.2.6	5	8	Roll	Electrical tape	Local – Hardware
4.2.6	5	8	Each	Flow meter	SEEED (Product ID: 314150001)
4.2.6	20	30	Pair	Safety glasses	Ward's
4.2.6	5	8	Each	Syringe, 60ml	Local – Amazon
4.2.6	1	1	Each	Wire stripper	Local – Tool
4.2.6	20	40	Each	Wire with alligator clips	EETC
4.3.1	5	8	Each	Basic Electrical Training Board	EETC
4.3.1	5	8	Each	Battery, 12V	EETC
4.3.1	5	8	Each	Calculator	Local
4.3.1	5	8	Each	Digital multimeter (DMM)	EETC
4.3.1	5	8	Each	Fuse, 10A	EETC
4.3.1	20	30	Pair	Safety glasses	Ward's
4.3.1	30	48	Each	Wire with alligator clips	EETC
4.3.2	1	1	Box	Baking soda	Local
4.3.2	5	8	Each	Basic Electrical Training Board	EETC
4.3.2	5	8	Each	Battery post terminal cleaner	Local – Tool
4.3.2	1	1	Each	Beaker, 600ml	Ward's
4.3.2	1	1	Each	Dielectric grease	Local – Hardware
4.3.2	5	8	Each	Digital multimeter (DMM)	EETC
4.3.2	1	1	Roll	Electrical tape	Local – Hardware
4.3.2	1	1	Each	Electrical Testing – Voltage Drop DVD (EETC CE3101)	EETC
4.3.2	5	8	Each	Equipment for students to test (tractor, lawnmower, etc)	Local – Equipment
4.3.2	5	8	Each	Fuse puller	Local – Tool
4.3.2	20	30	Pair	Nitrile gloves	Ward's
4.3.2	1	1	Each	Phillips screwdriver, #2	Local – Tool
4.3.2	2	3	Sets	*Project 4.3.2 Complaint Cards*	Print
4.3.2	20	30	Pair	Safety glasses	Ward's
4.3.2	5	8	Each	Service manual, New Regent	Print
4.3.2	5	8	Each	Socket wrench, ¼″ drive	Local – Tool
4.3.2	1	1	Each	Socket, $^{1}/_{2}$″, ¼″ drive	Local – Tool
4.3.2	5	8	Each	Socket, 10mm, ¼″ drive	Local – Tool
4.3.2	1	1	Each	Socket, $^{7}/_{16}$″,¼″ drive	Local – Tool
4.3.2	1	2	Each	Solenoid, faulty	Local – Industry
4.3.2	1	1	Bag	Steel wool	Local
4.3.2	50	80	Each	Wire with alligator clips	EETC
4.3.3	5	8	Each	Basic Electrical Training Board	EETC
4.3.3	5	8	Each	Battery post terminal cleaner	Local – Tool
4.3.3	5	8	Each	Battery, 12V	EETC
4.3.3	5	8	Each	Digital multimeter (DMM)	EETC
4.3.3	5	8	Each	Equipment for students to test (Tractor, lawnmower, etc)	Local – Equipment
4.3.3	5	8	Each	Fuse, 10A	EETC
4.3.3	20	30	Pair	Safety glasses	Ward's
4.3.3	5	8	Each	Socket wrench, ¼″ drive	Local – Tool

APP	Qty/ 20	Qty/ 30	Unit	Item Specifications	Vendor
4.3.3	5	8	Each	Socket, 10mm, ¼″ drive	Local – Tool
4.3.3	20	32	Each	Wire with alligator clips	EETC
4.3.4	5	8	Each	Basic Electrical Training Board	EETC
4.3.4	5	8	Each	Battery, 12V	EETC
4.3.4	5	8	Each	Digital multimeter (DMM)	EETC
4.3.4	1	2	Each	Electric Hook Up Wire Kit, 16 gauge, 100 feet, assorted colors	Local – Amazon
4.3.4	2	4	Box	Electrical connectors assorted, 16 ga	Local – Amazon
4.3.4	5	8	Each	Electrical flux	Local – Hardware
4.3.4	5	8	Roll	Electrical solder	Local - Amazon
4.3.4	5	8	Each	Fuse, 10A	EETC
4.3.4	2	3	Each	Heat gun	Local – Amazon
4.3.4	5	8	Each	Heat shrink, ¼ x 4″	Local – Amazon
4.3.4	3	4	Box	Heat shrink, assorted sizes	Local – Amazon
4.3.4	20	30	Pair	Safety glasses	Ward's
4.3.4	5	8	Each	Soldering iron helping hands	Local – Amazon
4.3.4	5	8	Each	Soldering iron with stand	Local – Amazon
4.3.4	5	8	Each	Wire crimper, 12–16 ga	Local – Tool
4.3.4	5	8	Each	Wire stripper	Local – Tool
4.3.5	1	2	Each	16 gauge Electric Hook Up Wire Kit, 100 feet, assorted colors	Local – Amazon
4.3.5	5	8	Each	Battery adapter, 9V	Local – Amazon
4.3.5	5	8	Each	Battery, 12V	EETC
4.3.5	5	8	Each	Battery, 9V	Local
4.3.5	1	2	Pkg.	Breadboard pin wire, male to male	Local – Amazon
4.3.5	5	8	Each	Digital control unit	Vernier
4.3.5	2	4	Box	Electrical connectors assorted, 16 ga	Local – Amazon
4.3.5	5	8	Each	Female union, $^{5}/_{16}$″ x $^{1}/_{8}$″ female union	Local – Amazon
4.3.5	5	8	Each	FIMCO 30 Gallon Trailer Sprayer	Tractor Supply Company
4.3.5	2	3	Each	Heat gun	Local – Amazon
4.3.5	3	4	Box	Heat shrink, assorted sizes	Local – Amazon
4.3.5	5	8	Each	LabQuest	Vernier
4.3.5	20	32	Each	LED bulb, 10mm	Local – Amazon
4.3.5	5	8	Each	Motion sensor	Vernier
4.3.5	1	1	Sheet	Plywood, 4′ x 8′	Local – Hardware
4.3.5	5	8	Each	Pressure 400 sensor	Vernier
4.3.5	15	24	Each	Relay, single-pole, single-throw, N.C.	Local – Amazon
4.3.5	20	30	Pair	Safety glasses	Ward's
4.3.5	5	8	Each	Soldering iron helping hands	Local – Amazon
4.3.5	5	8	Each	Soldering iron with stand	Local – Amazon
4.3.5	Misc.	Misc.	Misc.	Sprayer supplies	Local
4.3.5	1	2	Roll	Teflon tape	Local
4.3.5	5	8	Each	Wire crimper, 12–16 ga	Local – Tool
4.3.5	5	8	Each	Wire stripper	Local – Tool
5.1.1	10	15	Sets	Highlighters, assorted colors	Local
5.1.1	10	15	Each	*PowerPortal* account	Briggs and Stratton
5.1.2	1	2	Quart	Automatic transmission fluid, quart	Local -Hardware
5.1.2	3	5	Each	Bosch diesel fuel injector	Local – Industry
5.1.2	3	5	Each	Diesel fuel injector pressure tester	Local – **MercedesSource**
5.1.2	1	3	Gallon	Diesel fuel, gallon	Local
5.1.2	3	5	Each	Double flaring tool kit	Local – Amazon

APP	Qty/ 20	Qty/ 30	Unit	Item Specifications	Vendor
5.1.2	6	9	Each	Face shield	Local – Tool
5.1.2	10	25	Feet	Fuel line, steel, 12″ x ¼″	Local – Hardware
5.1.2	20	30	Each	Green highlighter	Local
5.1.2	3	5	Sets	Metric wrench set	Local – Tool
5.1.2	20	30	Pair	Nitrile gloves	Ward's
5.1.2	20	30	Each	Pen	Local
5.1.2	20	30	Each	Pink highlighter	Local
5.1.2	20	30	Pair	Safety glasses	Ward's
5.1.2	20	30	Pair	Safety goggles	Ward's
5.1.2	1	2	Roll	Shop towels	Local
5.1.2	10	15	Each	Steel fuel line compression union	Local – Hardware
5.1.2	3	3	Each	Steel fuel line cutter	Local – Tool
5.1.2	3	5	Each	Tractor user manuals	Local – Equipment
5.1.2	1	1	Each	Tractor with diesel engine	Local – Equipment
5.1.3	3	3	Each	Beaker, 250ml	Ward's
5.1.3	5	8	Each	Beaker, 600ml	Ward's
5.1.3	20	32	Each	Cup, 3 oz	Local
5.1.3	1	1	Gallon	Distilled water	Local
5.1.3	1	1	Gallon	Engine coolant	Local – Hardware
5.1.3			Each	Engine oil	Local – Hardware
5.1.3	5	8	Each	Funnel	Local – Tool
5.1.3	5	8	Each	Hot plate	Ward's
5.1.3	5	8	Pair	Needle nose pliers	Local – Tool
5.1.3	20	30	Pair	Nitrile gloves	Ward's
5.1.3	10	16	Feet	Nylon string	Local – Hardware
5.1.3	5	8	Each	OEM specifications for tractor	Local – Equipment
5.1.3	5	8	Each	Oil drip pan	Local – Tool
5.1.3	5	8	Each	Oil filter	Local – Hardware
5.1.3	5	8	Each	Oil filter wrench	Local – Tool
5.1.3	5	8	Each	Permanent marker	Local
5.1.3	5	8	Each	Plastic pipet, 1 ml	Ward's
5.1.3	5	8	Each	Refractometer kit	Local – Amazon
5.1.3	5	8	Each	Ring stand	Ward's
5.1.3	5	8	Each	Ring, 10cm	Ward's
5.1.3	20	30	Pair	Safety glasses	Ward's
5.1.3	5	8	Each	Socket set, 6 pt, $^3/_8$″ drive	Local – Tool
5.1.3	5	8	Each	Socket wrench, $^3/_8$″ drive	Local – Tool
5.1.3	5	8	Each	Thermometer	Ward's
5.1.3	5	8	Each	Thermostat, used	Local – Industry
5.1.3	5	8	Each	Torque wrench, in-lb, $^3/_8$″ drive	Local – Tool
5.1.3	5	8	Each	Tractor	Local – Equipment
5.1.4	5	8	Each	Battery, 12V	EETC
5.1.4	1	2	Each	Bicycle pump	Local
5.1.4	5	8	Each	Erlenmeyer flask, 1L	Ward's
5.1.4	2	3	Each	Flashlights	Local
5.1.4	5	8	Each	Hot plate	Ward's
5.1.4	5	8	Each	IR thermometer	Local – Tool
5.1.4	5	8	Roll	Lab tape	Local
5.1.4	5	8	Each	Permanent marker	Local
5.1.4	5	8	Each	Plastic coupler, $^1/_8$″ O.D.	Local – Amazon
5.1.4	5	8	Each	Plastic cup, 16 oz	Local

APP	Qty/ 20	Qty/ 30	Unit	Item Specifications	Vendor
5.1.4	30	48	Feet	Plastic tubing, 1′ x $^{1}/_{8}$″ I.D.	Local – Amazon
5.1.4	5	8	Each	Positive displacement pump, 12V	Local – Amazon
5.1.4	1	2	Each	Radiator, assembled for inspection	Local – Teacher Notes
5.1.4	5	8	Each	Rubber stopper, two holes, size 6	Ward's
5.1.4	20	30	Pair	Safety glasses	Ward's
5.1.4	5	8	Pair	Scissors	Local
5.1.4				Supplies and tools to construct radiator	Local – Teacher Notes
5.1.4	1	2	Each	Water pump, belt-driven	Local – Industry
5.1.4	1	2	Each	Water pump, gear-driven	Local – Industry
5.1.4	1	2	Each	Water tank	Local
5.1.4	10	16	Each	Wire with alligator clips	EETC
5.1.5	3	5	Each	Air filter	Local – Industry
5.1.5	3	3	Each	Box wrench set	Local – Tool
5.1.5	5	8	Set	Colored pencils, assorted	Local
5.1.5	4	4	Each	Cup, 16 oz	Local
5.1.5	20	32	Each	Cup, 3 oz	Local
5.1.5	3	5	Each	DEF samples	Local – Teacher Notes
5.1.5	1	1	Gallon	Distilled water	Local
5.1.5	5	8	Each	Plastic pipet, 1 ml	Ward's
5.1.5	3	5	Each	Refractometer kit	Local – Amazon
5.1.5	20	30	Pair	Safety glasses	Ward's
5.1.5	3	5	Each	Turbocharger	Local – Industry
5.1.6	1	1	Each	Air filter, dirty	Local – Industry
5.1.6	1	1	Each	Beaker, 600ml	Ward's
5.1.6	1	1	Each	Bearing, seized	Local – Industry
5.1.6	1	1	Liter	Coolant	Local – Hardware
5.1.6	1	1	Liter	DEF	Local – Hardware
5.1.6	1	1	Each	Diesel fuel injector pressure tester	Local – **MercedesSource**
5.1.6	1	1	Gallon	Distilled water	Local
5.1.6	1	1	Each	Fuel filter, dirty	Local – Industry
5.1.6	1	1	Each	Fuel injector, leaking	Local – Industry
5.1.6	1	1	Each	Hot plate	Ward's
5.1.6	1	1	Each	LabQuest	Vernier
5.1.6	1	1	Foot	Nylon string	Local – Hardware
5.1.6	1	1	Each	Oil filter with dirty oil	Local – Industry
5.1.6	1	1	Each	Piston with a broken ring	Local – Industry
5.1.6	20	30	Pair	Safety glasses	Ward's
5.1.6	1	1	Each	Starter solenoid, broken	Local – Industry
5.1.6	1	1	Each	Thermostat, broken	Local – Industry
5.1.6	1	1	Each	Turbocharger, broken	Local – Industry
5.1.6	1	1	Each	Vernier temperature sensor	Vernier
5.2.1	10	16	Each	Breadboard pin wire, female to female	Local – Amazon
5.2.1	10	16	Each	Breadboard, small	Local – Amazon
5.2.1	1	1	Each	*CAN Bus Template*	Print
5.2.1	5	8	Each	Digital multimeter (DMM)	EETC
5.2.1	1	2	Each	Electrical wires, various colors, 100 feet, solid strand 22 ga	Local - Amazon
5.2.1	1	2	Each	Manual staple gun with staples	Local – Tool
5.2.1	5	8	Each	Phillips screwdriver, #2	Local – Tool
5.2.1	1	1	Sheet	Plywood, minimum ½″ thick	Local – Hardware
5.2.1	20	32	Each	Resistor, 120Ω	Local – Amazon

APP	Qty/ 20	Qty/ 30	Unit	Item Specifications	Vendor
5.2.1	70	115	Each	Ring terminal, red	Local – Amazon
5.2.1	20	30	Pair	Safety glasses	Ward's
5.2.1	5	8	Each	SparkFun® RedBoard with cable	Vernier
5.2.1	1	1	Each	Table saw or circular saw	Local – Tool
5.2.1	20	32	Each	Terminal block, 2-pole	Local – Amazon
5.2.1	5	8	Each	USB power source	Local
5.2.1	5	8	Each	Wire crimper, 12–16 ga	Local – Tool
5.2.1	5	8	Each	Wire stripper	Local – Tool
5.2.1	20	32	Each	Wire with alligator clips	EETC
5.2.1	40	65	Each	Wood screw, #6 x ¾″	Local – Hardware
5.2.2	2	3	Each	Air compressor with blowguns	Local – Tool
5.2.2	5	8	Each	Beaker, 100ml	Ward's
5.2.2	5	8	Each	CAN bus board	*Activity 5.2.1*
5.2.2	5	8	Each	Digital multimeter (DMM)	EETC
5.2.2	2	3	Each	Hot glue gun	Local
5.2.2	2	3	Each	Hot glue stick	Local
5.2.2	5	8	Each	Oil pressure transducer, used	Local – Industry
5.2.2	20	32	Inches	Plastic tubing, $^1/_8$″ ID	Local
5.2.2	5	8	Each	Pressure 400 sensor	Vernier
5.2.2	5	8	Each	Syringe, 60ml	Local – Amazon
5.2.2	5	8	Each	Vernier Arduino® Interface Shield	Vernier
5.2.3	10	15	Each	Glue stick	Local
5.2.3	10	15	Sets	Marker, assorted colors	Local
5.2.3	10	15	Each	Posterboard	Local
6.1.1	20	30	Each	Amatrol® hydraulic simulator subscriptions	Amatrol
6.1.2	20	30	Each	Amatrol® hydraulic simulator subscriptions	Amatrol
6.1.3	10	15	Each	Battery, 9V	Local
6.1.3	5	5	Each	Cooking spray	Local
6.1.3	10	15	Each	Cup, 30ml	Local
6.1.3	10	15	Each	Plastic container, 10 oz	Local
6.1.3	30	45	Each	Plastic coupler, $^1/_8$″ O.D.	Local – Amazon
6.1.3	10	15	Each	Plastic tee, $^1/_8$″ O.D.	Local – Amazon
6.1.3	40	60	Each	Plastic tubing, 1′ x $^1/_8$″ I.D.	Local – Amazon
6.1.3	10	15	Each	Positive displacement pump, 12V	Local – Amazon
6.1.3	20	30	Pair	Safety glasses	Ward's
6.1.3	20	30	Each	Syringe, 10ml	Local – Amazon
6.1.3	10	15	Each	Wire with alligator clips, black	EETC
6.1.3	10	15	Each	Wire with alligator clips, red	EETC
6.1.4	20	30	Each	Amatrol® hydraulic simulator subscriptions	Amatrol
6.1.4	20	30	Each	Calculator	Local
6.1.5	10	15	Each	Battery, 9V	Local
6.1.5	10	15	Each	Calculator	Local
6.1.5	5	5	Each	Cooking spray	Local
6.1.5	10	15	Each	Dial caliper 6″/150mm	Local – Amazon
6.1.5	10	15	Each	LabQuest	Vernier
6.1.5	10	15	Each	Plastic container, 10 oz	Local
6.1.5	10	15	Each	Plastic tee, $^1/_8$″ O.D.	Local – Amazon
6.1.5	40	60	Each	Plastic tubing, 1′ x $^1/_8$″ I.D.	Local – Amazon
6.1.5	10	15	Each	Positive displacement pump, 12V	Local – Amazon
6.1.5	10	15	Each	Pressure 400 sensor	Vernier
6.1.5	20	30	Pair	Safety glasses	Ward's

APP	Qty/ 20	Qty/ 30	Unit	Item Specifications	Vendor
6.1.5	10	30	Each	Syringe, 10ml	Local – Amazon
6.1.5	10	15	Each	Syringe, 20ml	Local – Amazon
6.1.5	10	15	Each	Syringe, 60ml	Local – Amazon
6.1.5	10	15	Each	Wire with alligator clips, black	EETC
6.1.5	10	15	Each	Wire with alligator clips, red	EETC
6.2.1	20	30	Each	Beaker, 600ml	Ward's
6.2.1	20	30	Each	Cup,12 oz	Local
6.2.1	1	1	Quart	Hydraulic fluid	Local – Hardware
6.2.1	5	7	Lbs	Ice	Local
6.2.1	10	15	Roll	Lab tape	Local
6.2.1	1	2	Each	Microwave	Local
6.2.1	20	30	Pair	Nitrile gloves	Ward's
6.2.1	10	15	Each	Permanent marker	Local
6.2.1	1	1	Quart	Power steering fluid	Local – Hardware
6.2.1	20	30	Pair	Safety glasses	Ward's
6.2.1	20	30	Each	Syringe, 60ml	Local – Amazon
6.2.1	40	60	Each	Test tubes	Ward's
6.2.1	1	1	Each	Water source	Local
6.2.2	1	1	Each	Agricultural implement	Local – Equipment
6.2.2	20	30	Each	Amatrol® hydraulic simulator subscriptions	Amatrol
6.2.2	20	30	Pair	Safety glasses	Ward's
6.2.3	10	15	Each	Battery, 9V	Local
6.2.3	20	30	Each	Cup,12 oz	Local
6.2.3	10	15	Each	Cups of various sizes	Local
6.2.3	5	8	Each	Graduated cylinder, 100ml	Ward's
6.2.3	5	8	Each	Hot glue gun	Local
6.2.3	10	15	Each	Hot glue stick	Local
6.2.3	10	15	Each	Paper plate, 12″	Local
6.2.3	10	15	Each	Permanent marker	Local
6.2.3	10	15	Each	Plastic container, 10 oz	Local
6.2.3	20	30	Feet	Plastic tubing, 1′ x $^{1}/_{8}$″ I.D.	Local – Amazon
6.2.3	10	15	Each	Positive displacement pump, 12V	Local – Amazon
6.2.3	10	15	Each	Poster board	Local
6.2.3	10	15	Each	Potentiometer, 10KΩ	Local – Amazon
6.2.3	20	30	Pair	Safety glasses	Ward's
6.2.3	10	15	Pair	Scissors	Local
6.2.3	10	15	Each	Switch, single-pole, single-throw	Local – Hardware
6.2.3	30	45	Each	Syringe, 20ml	Local – Amazon
6.2.3	30	45	Each	Wire with alligator clips, black	EETC
6.2.3	10	15	Each	Wire with alligator clips, red	EETC
6.2.3	10	15	Each	Wooden dowels, 12″ x 3/4″ diameter	Local – Hardware
6.2.4	10	15	Each	Battery, 12V	EETC
6.2.4	10	15	Each	Battery, 9V	Local
6.2.4	10	15	Each	Digital multimeter (DMM)	EETC
6.2.4	20	40	Each	Relay, single-pole, single-throw, N.O.	Local – Amazon
6.2.4	20	30	Pair	Safety glasses	Ward's
6.2.4	10	15	Each	Solenoid valve	Local – Amazon
6.2.4	10	15	Each	Switch, single-pole, single-throw	Local – Hardware
6.2.4	60	80	Each	Wire with alligator clips	EETC and Amazon
6.2.5	10	15	Each	Battery, 12V	EETC
6.2.5	10	15	Each	Battery, 9V	Local

APP	Qty/ 20	Qty/ 30	Unit	Item Specifications	Vendor
6.2.5	10	15	Each	Digital multimeter (DMM)	EETC
6.2.5	10	15	Each	Flow meter	SEEED (Product ID: 314150001)
6.2.5	20	32	Each	LED bulb, 10mm	Local – Amazon
6.2.5	10	15	Each	Plastic container, 10 oz	Local
6.2.5	20	30	Feet	Plastic tubing, 1′ x $^{1}/_{8}$″ I.D.	Local
6.2.5	10	15	Each	Positive displacement pump, 12V	Local – Amazon
6.2.5	10	15	Each	Potentiometer, 10KΩ	Local – Amazon
6.2.5	20	40	Each	Relay, single-pole, single-throw, N.C.	Local – Amazon
6.2.5	20	30	Pair	Safety glasses	Ward’s
6.2.5	10	15	Each	Switch, single-pole, single-throw	Local – Hardware
6.2.5	60	80	Each	Wire with alligator clips	EETC and Amazon
6.2.6	20	30	Pair	Safety glasses	Ward’s
6.2.6	1	1	Each	Tractor	Local – Equipment
6.2.6	10	15	Each	Tractor maintenance manual	Local – Equipment
6.3.1	5	8	Each	Hydraulic cylinder	Local – Industry
6.3.1	5	8	Each	Hydraulic valve	Local – Industry
6.3.1	20	30	Pair	Nitrile gloves	Ward’s
6.3.1	20	30	Pair	Safety glasses	Ward’s
6.3.1	2	3	Roll	Shop towels	Local
6.3.1	10	15	Set	Tools: • Adjustable wrench • Gland nut wrench • Hex wrench set • Rubber mallet • Snap ring tool • Socket wrench set • Spanner wrench	Local – Teacher Notes
6.3.1	5	8	Each	Woodblock, 6″-2x4	Local – Hardware
6.3.2	10	15	Each	Hydraulic pump with user manual	Local – Industry
6.3.2	20	30	Pair	Nitrile gloves	Ward’s
6.3.2	1	2	Sets	*Project 6.3.2 Pump Complaint Cards*	Print
6.3.2	20	30	Pair	Safety glasses	Ward’s
6.3.2	2	3	Roll	Shop towels	Local
6.3.2	10	15	Set	Tools: • Adjustable wrench • Hex wrench set • Rubber mallet • Socket wrench set	Local – Teacher Notes
6.3.3	10	15	Each	Dial caliper 6″/150mm	Local – Amazon
6.3.3	5	8	Each	Hydraulic cylinder (female fitting)	Local – Industry
6.3.3	10	15	Each	Hydraulic female fitting • 316 Stainless Steel Nut for 8 mm Tube OD High-Pressure Compression Fitting • Nut for 3/8" Tube OD 37 Degree Flared Fitting for Stainless Steel Tubing • Precision Compression Fitting for Stainless Steel Tubing, Straight Adapter for 3/8" Tube OD x 1/8 NPT Female	Local – Industry or **McMaster Carr**
6.3.3	5	8	Each	Hydraulic hose with fittings	Local – Industry
6.3.3	10	15	Each	Hydraulic male fitting	Local – Industry or

APP	Qty/ 20	Qty/ 30	Unit	Item Specifications	Vendor
				• Compression Fitting for Stainless Steel Tubing, Straight Adapter, 8 mm Tube OD x 1/4 NPT Male • 37 Degree Flared Fitting for Stainless Steel Tubing, Adapter for 3/8" Tube OD x 3/8 BSPT Male • Precision Compression Fitting for Stainless Steel Tubing, Straight Adapter for 3/8" Tube OD x 1/8 NPT Male	**McMaster Carr**
6.3.3	5	8	Each	Hydraulic valve (female fitting)	Local – Industry
6.3.3	20	30	Pair	Nitrile gloves	Ward’s
6.3.3	10	15	Each	Pitch gauge	Local – Tool
6.3.3	20	30	Pair	Safety glasses	Ward’s
6.3.3	2	3	Roll	Shop towels	Local
6.3.4	10	15	Each	Microscope	Ward’s
6.3.4	20	30	Pair	Nitrile gloves	Ward’s
6.3.4	10	15	Each	Oil samples	Local – Teacher Notes
6.3.4	10	15	Each	Petri-dish	Ward’s
6.3.4	10	15	Each	Plastic pipet, 1 ml	Ward’s
6.3.4	1	2	Set	*Project 6.3.4 Oil Contamination Cards*	Print
6.3.4	20	30	Pair	Safety glasses	Ward’s
6.3.4	2	3	Roll	Shop towels	Local
6.3.4	10	15	Each	Vial,10ml, plastic	Local
7.1.1	20	30	Each	Clipboard	Local
7.1.1	1	2	Each	Coolant sample	Local – Teacher Notes
7.1.1	5	8	Each	Digital multimeter (DMM)	EETC
7.1.1	2	2	Each	Microscope	Ward’s
7.1.1	1	2	Box	Nitrile gloves	Ward’s
7.1.1	1	2	Each	Oil sample	Local – Teacher Notes
7.1.1	2	2	Each	Petri-dish	Ward’s
7.1.1	2	2	Each	Plastic pipet, 1ml	Ward’s
7.1.1	2	2	Each	Refractometer kit	Local – Amazon
7.1.1	20	30	Pair	Safety glasses	Ward’s
7.1.1	5	8	Each	SDS sheet	Print
7.1.1	1	2	Roll	Shop towels	Local
7.1.1	1	2	Each	Tractor and attached implement	Local – Equipment
7.1.1	5	8	Each	Tractor maintenance manual	Print
7.1.1	2	4	Each	Vial, 10ml, plastic	Local
7.1.2	5	8	Each	Basic Electrical Training Board	EETC
7.1.2	2	2	Each	Battery, 12V	EETC
7.1.2	2	2	Each	Dial caliper 6″/150mm	Local – Amazon
7.1.2	2	2	Each	Dial indicator	Local – Amazon
7.1.2	5	8	Each	Digital multimeter (DMM)	EETC
7.1.2	1	1	Each	Fuse, 10A	EETC
7.1.2	1	2	Each	Gear system	Local – Teacher Notes
7.1.2	1	2	Each	Hydraulic cylinder with piston	Local – Industry
7.1.2	1	1	Each	Potentiometer, 10KΩ	Local – Amazon
7.1.2	1	1	Each	Relay, single-pole, single-throw, N.O.	EETC
7.1.2	1	1	Each	Resistor, 100Ω	EETC
7.1.2	20	30	Pair	Safety glasses	Ward’s
7.1.2	2	2	Each	Torque wrench, 5–80 ft-lb, ½″ drive	Local – Tool
7.1.2	2	3	Each	Wheel hub/spindle	Local – Northern Tool

APP	Qty/ 20	Qty/ 30	Unit	Item Specifications	Vendor
7.1.2	25	40	Each	Wire with alligator clips	EETC
7.1.2	2	3	Each	Workbench with vise	Local – Tool

CASE

TAA Inventory by Vendor

Engine and Equipment Training Council

Need	Qty/ 20	Qty/ 30	Unit	Item Specifications	Vendor
	5	8	Each	Basic Electrical Training Board • Battery charger, 12V • Battery, 12V • Digital multimeter (DMM) • Electromagnetic clutch • Fuse, 10A • Key • Silicon diode • 16 Wires with alligator clips	EETC
	1	1	Each	Electrical Testing – Voltage Drop DVD (EETC CE3101)	EETC

Local

Need	Qty/ 20	Qty/ 30	Unit	Item Specifications	Vendor
	1	1	Box	Baking soda	Local
	10	15	Each	Battery, 9V	Local
	10	15	Each	Battery, D size	Local
	1	2	Each	Bicycle pump	Local
	10	15	Each	Box, small – shoe box size	Local
	20	30	Each	Calculator	Local
	1	1	Bag	Cat litter, 10 lbs	Local
	20	30	Each	Clipboard	Local
	5	8	Set	Colored pencils, assorted	Local
	10	15	Each	Container and lid, 24 oz	Local
	5	5	Each	Cooking spray	Local
	4	4	Each	Cup, 16 oz	Local
	20	32	Each	Cup, 3 oz	Local
	10	15	Each	Cup, 30ml	Local
	7	10	Each	Cup, 9 oz	Local
	20	30	Each	Cup,12 oz	Local
	10	15	Each	Cups of various sizes	Local
	20	30	Each	Device with a digital camera	Local
	20	30	Each	Device with PowerPortal access	Local
	10	15	Each	Device with timer	Local
	1	3	Gallon	Diesel fuel, gallon	Local
	2	3	Gallon	Distilled water	Local
	40	60	Pair	Ear plugs	Local
	5	8	Each	Eye hook	Local
	2	3	Each	Flashlights	Local
	20	30	Each	Glue stick	Local
	20	30	Each	Green highlighter	Local
	20	30	Each	Headphones	Local
	10	15	Sets	Highlighters, assorted colors	Local
	5	8	Each	Hot glue gun	Local

	15	24	Each	Hot glue stick	Local
	5	7	Lbs	Ice	Local
	10	15	Roll	Lab tape	Local
	20	30	Each	Logbook	Local
	10	15	Sets	Marker, assorted colors	Local
	10	15	Each	Marker/pen	Local
	10	15	Roll	Masking tape	Local
	5	8	Each	Measuring cup (volume oz lines)	Local
	1	2	Each	Microwave	Local
	20	30	Each	Mind-mapping software	Local
	10	15	Each	Mobile device with GPS application	Local
	5	8	Each	Paint pen	Local
	15	24	Each	Paper plate, 10″	Local
	40	60	Each	Paper plate, 12″	Local
	5	8	Kg	Pea gravel	Local
	20	30	Each	Pen	Local
	20	30	Each	Pen, red	Local
	10	15	Each	Permanent marker	Local
	20	30	Each	Pink highlighter	Local
	1	2	Bags	Planting media	Local
	30	45	Each	Planting tray, small (12 cells)	Local
	10	15	Each	Plastic container, 10 oz	Local
	5	8	Each	Plastic container, 64 oz	Local
	5	8	Each	Plastic cup, 16 oz	Local
	20	30	Each	Plastic spoons	Local
	7	10	Each	Plastic storage containers (toolbox size)	Local
	5	8	Each	Plate, heavy, 12″	Local
	25	38	Each	Poster board	Local
	7	10	Each	Ruler	Local
	10	15	Pair	Scissors	Local
	10	15	Roll	Shop towels	Local
	10	15	Each	Spray bottle	Local
	1	1	Bag	Steel wool	Local
	10	15	Each	String, 3′	Local
	20	30	Each	Survey flag	Local
	200	300	Each	Tab divider	Local
	200	300	Each	Tab label insert	Local
	1	2	Roll	Teflon tape	Local
	20	30	Each	Two-inch, three-ring binder	Local
	5	8	Each	USB power source	Local
	10	15	Each	Vial,10ml, plastic	Local
	1	2	Each	Water tank	Local
	10	15	Each	Webcam with a USB cord	Local
	10	15	Each	Yellow highlighter	Local

Local – Amazon

Need	Qty/ 20	Qty/ 30	Unit	Item Specifications	Vendor
	10	15	Each	Battery case, D size	Local - Amazon
	5	8	Roll	Electrical solder	Local - Amazon
	1	2	Each	Electrical wires, various colors, 100 feet, solid strand 22 ga	Local - Amazon

Need	Qty/ 20	Qty/ 30	Unit	Item Specifications	Vendor
	1	2	Each	16 gauge Electric Hook Up Wire Kit, 100 feet, assorted colors	Local – Amazon
	5	8	Each	AC mini-hand motor	Local – Amazon
	10	15	Each	Battery adapter, 9V	Local – Amazon
	5	8	Each	Battery case, D size	Local – Amazon
	10	15	Each	Breadboard	Local – Amazon
	1	2	Pkg.	Breadboard pin wire, female to female (200)	Local – Amazon
	1	2	Pkg.	Breadboard pin wire, male to male (200)	Local – Amazon
	10	16	Each	Breadboard, small	Local – Amazon
	5	8	Each	Button switch, N.C., SPST	Local – Amazon
	5	8	Each	DC Motor, brushed, 12V	Local – Amazon
	10	15	Each	Dial caliper 6″/150mm	Local – Amazon
	10	15	Each	Dial indicator	Local – Amazon
	3	5	Each	Double flaring tool kit	Local – Amazon
	1	2	Each	Electric Hook Up Wire Kit, 16 gauge, 100 feet, assorted colors	Local – Amazon
	2	4	Box	Electrical connectors assorted, 16 ga	Local – Amazon
	5	8	Each	Female union, 5/16″ x 1/8″ female union	Local – Amazon
	10	15	Each	Graphite pencil, 6B	Local – Amazon
	2	3	Each	Heat gun	Local – Amazon
	5	8	Each	Heat shrink, ¼ x 4″	Local – Amazon
	3	4	Box	Heat shrink, assorted sizes	Local – Amazon
	7	10	Each	Hex wrench, 3/32″	Local – Amazon
	7	10	Each	Hex wrench, 5/64″	Local – Amazon
	20	32	Each	LED bulb, 10mm	Local – Amazon
	30	45	Each	Plastic coupler, 1/8″ O.D.	Local – Amazon
	10	15	Each	Plastic tee, 1/8″ O.D.	Local – Amazon
	70	100	Feet	Plastic tubing, 1′ x 1/8″ I.D.	Local – Amazon
	10	15	Each	Positive displacement pump, 12V	Local – Amazon
	10	15	Each	Potentiometer, 10KΩ	Local – Amazon
	5	8	Each	Refractometer kit	Local – Amazon
	20	40	Each	Relay, single-pole, single-throw, N.C.	Local – Amazon
	20	40	Each	Relay, single-pole, single-throw, N.O.	Local – Amazon
	20	32	Each	Resistor, 120Ω	Local – Amazon
	70	115	Each	Ring terminal, red	Local – Amazon
	5	8	Each	Soldering iron helping hands	Local – Amazon
	5	8	Each	Soldering iron with stand	Local – Amazon
	10	15	Each	Solenoid valve	Local – Amazon
	20	30	Each	Syringe, 10ml	Local – Amazon
	30	45	Each	Syringe, 20ml	Local – Amazon
	20	30	Each	Syringe, 60ml	Local – Amazon
	20	32	Each	Terminal block, 2-pole	Local – Amazon
	1	1	Pkg	Wire with alligator clips (150)	Local – Amazon
	5	8	Each	Zener diode, 2V rating	Local – Amazon

Local – Equipment

Need	Qty/ 20	Qty/ 30	Unit	Item Specifications	Vendor
	1	1	Each	Water source with a hose	Local - Equipment
	1	1	Each	Agricultural implement	Local – Equipment

Need	Qty/ 20	Qty/ 30	Unit	Item Specifications	Vendor
	5	8	Each	Equipment for electrical starter test (Tractor, lawnmower, etc)	Local – Equipment
	2	3	Each	Equipment with tires	Local – Equipment
	5	8	Each	Hub user manual	Local – Equipment
	5	8	Each	OEM specifications for tractor	Local – Equipment
	5	8	Each	Tractor (1 should be diesel)	Local – Equipment
	1	2	Each	Tractor and attached implement	Local – Equipment
	10	15	Each	Tractor maintenance manual	Local – Equipment
	10	15	Each	Universal joint and service manual, new	Local – Equipment

Local – Hardware

Need	Qty/ 20	Qty/ 30	Unit	Item Specifications	Vendor
	20	30	Each	Bolts, assorted types, sizes, threads, and grades	Local – Hardware
	1	1	Liter	Coolant	Local - Hardware
	10	16	Each	Fuse, 10A	Local - Hardware
	40	65	Each	Wood screw, #6 x ¾″	Local - Hardware
	5	9	Each	Seal, replacement (**NAPA Part #27SS2768**)	Local – Hardware
	1	2	Quart	Automatic transmission fluid, quart	Local – Hardware
	40	60	Each	Bolt, $^5/_{16}$″-1″ low-grade UNC	Local – Hardware
	1	2	Bottles	Brake cleaner	Local – Hardware
	1	2	Bottles	Cleaning fluid	Local – Hardware
	5	8	Each	Cotter pin, replacement	Local – Hardware
	1	1	Liter	DEF	Local – Hardware
	1	1	Each	Dielectric grease	Local – Hardware
	15	24	Each	Dowel, 6″ x 1″ diameter	Local – Hardware
	1	1	Roll	Duct tape	Local – Hardware
	5	8	Each	Electrical flux	Local – Hardware
	5	8	Roll	Electrical tape	Local – Hardware
	1	1	Gallon	Engine coolant	Local – Hardware
			Each	Engine oil	Local – Hardware
	30	45	Feet	Flat stock 1/8″x1″	Local – Hardware
	240	360	Each	Flat washer 5/16″	Local – Hardware
	10	25	Feet	Fuel line, steel, 12″ x ¼″	Local – Hardware
	5	8	Each	Fuse, 7.5A	Local – Hardware
	2	3	Each	Grease	Local – Hardware
	1	1	Quart	Hydraulic fluid	Local – Hardware
	2	3	Tubes	Lithium grease	Local – Hardware
	40	60	Each	Nut, $^5/_{16}$″, UNC	Local – Hardware
	10	16	Feet	Nylon string	Local – Hardware
	5	8	Each	Oil filter	Local – Hardware
	5	8	Quarts	Oil, 30W	Local – Hardware
	1	1	Sheet	Plywood, 4′ x 8′	Local – Hardware
	1	1	Sheet	Plywood, minimum ½″ thick	Local – Hardware
	1	1	Quart	Power steering fluid	Local – Hardware
	5	8	Each	Sandpaper disc, 120 grit – 6″	Local – Hardware
	5	8	Each	Sandpaper disc, 200 grit–6″	Local – Hardware
	10	16	Each	Sandpaper disc, 40-grit 6″	Local – Hardware

Need	Qty/ 20	Qty/ 30	Unit	Item Specifications	Vendor
	10	15	Each	Steel fuel line compression union	Local – Hardware
	10	15	Each	Switch, single-pole, single-throw	Local – Hardware
	280	400	Each	Washers, 1″	Local – Hardware
	10	16	Each	Woodblock, 6″-2x4	Local – Hardware
	10	15	Each	Wooden dowels, 12″ x 3/4″ diameter	Local – Hardware

Local – Industry

Need	Qty/ 20	Qty/ 30	Unit	Item Specifications	Vendor
	3	5	Each	Air filter	Local – Industry
	1	1	Each	Air filter, dirty	Local – Industry
	10	15	Each	Bearing, ball	Local – Industry
	10	15	Each	Bearing, friction	Local – Industry
	10	15	Each	Bearing, roller	Local – Industry
	1	1	Each	Bearing, seized	Local – Industry
	3	5	Each	Bosch diesel fuel injector	Local – Industry
	3	3	Each	Chains (drive chains)	Local – Industry
	15	24	Each	Clutch disc	Local – Industry
	1	1	Each	Combine with precision components	Local – Industry
	10	15	Each	Equipment service manual	Local – Industry
	1	1	Each	Equipment with V-belts and chains	Local – Industry
	1	1	Each	Fuel filter, dirty	Local – Industry
	1	1	Each	Fuel injector, leaking	Local – Industry
	5	8	Each	Gearbox	Local – Industry
	5	8	Each	Hydraulic cylinder	Local – Industry
	5	8	Each	Hydraulic cylinder (female fitting)	Local – Industry
	1	2	Each	Hydraulic cylinder with piston	Local – Industry
	10	15	Each	Hydraulic female fitting • 316 Stainless Steel Nut for 8 mm Tube OD High-Pressure Compression Fitting • Nut for 3/8" Tube OD 37 Degree Flared Fitting for Stainless Steel Tubing • Precision Compression Fitting for Stainless Steel Tubing, Straight Adapter for 3/8" Tube OD x 1/8 NPT Female	Local – Industry or **McMaster Carr**
	5	8	Each	Hydraulic hose with fittings	Local – Industry
	10	15	Each	Hydraulic male fitting • Compression Fitting for Stainless Steel Tubing, Straight Adapter, 8 mm Tube OD x 1/4 NPT Male • 37 Degree Flared Fitting for Stainless Steel Tubing, Adapter for 3/8" Tube OD x 3/8 BSPT Male • Precision Compression Fitting for Stainless Steel Tubing, Straight Adapter for 3/8" Tube OD x 1/8 NPT Male	Local – Industry or **McMaster Carr**
	10	15	Each	Hydraulic pump with user manual	Local – Industry
	5	8	Each	Hydraulic valve	Local – Industry
	5	8	Each	Hydraulic valve (female fitting)	Local – Industry
	15	25	Each	Machine components	Local – Industry
	1	1	Each	Misaligned shaft on worn bearings	Local – Industry
	1	1	Each	Oil filter with dirty oil	Local – Industry

Need	Qty/ 20	Qty/ 30	Unit	Item Specifications	Vendor
	5	8	Each	Oil pressure transducer, used	Local – Industry
	1	1	Each	Piston with a broken ring	Local – Industry
	3	3	Each	Pulley for V belt	Local – Industry
	5	8	Each	Silicon diode, failed	Local – Industry
	1	2	Each	Solenoid, faulty	Local – Industry
	3	3	Each	Sprocket	Local – Industry
	1	1	Each	Starter solenoid, broken	Local – Industry
	1	1	Each	Thermostat, broken	Local – Industry
	5	8	Each	Thermostat, used	Local – Industry
	3	5	Each	Turbocharger	Local – Industry
	1	1	Each	Turbocharger, broken	Local – Industry
	1	1	Each	Two misaligned sprockets with a tight chain	Local – Industry
	1	1	Each	Two pulleys with a loose belt	Local – Industry
	1	1	Each	Two pulleys with a tight belt	Local – Industry
	1	1	Each	Two sprockets with loose chain	Local – Industry
	10	15	Each	Universal joint with service manual, used	Local – Industry
	3	3	Each	V-belts	Local – Industry
	1	2	Each	Water pump, belt-driven	Local – Industry
	1	2	Each	Water pump, gear-driven	Local – Industry
	1	1	Each	Wheel hub with seized bearing	Local – Industry
	1	1	Each	Wheel hub with worn bearing	Local – Industry
	1	1	Each	Worn partially deflated tire on a wheel	Local – Industry

Local – Tools

Need	Qty/ 20	Qty/ 30	Unit	Item Specifications	Vendor
	10	15	Set	Tools for hydraulic cylinder disassembly (vary) • Adjustable wrench • Gland nut wrench • Hex wrench set • Rubber mallet • Snap ring tool • Socket wrench set • Spanner wrench	Local – Tool
	10	15	Set	Tools for hydraulic valve and pump disassembly (vary) • Adjustable wrench • Hex wrench set • Rubber mallet • Socket wrench set	Local – Tool
	2	3	Each	Air compressor with blowguns	Local – Tool
	10	15	Each	Ball joint service kit (**Harbor Freight**)	Local – Tool
	10	15	Each	Ball-peen hammer	Local – Tool
	5	8	Each	Battery post terminal cleaner	Local – Tool
	3	3	Each	Box wrench set	Local – Tool
	5	8	Each	Brass drift punch	Local – Tool
	10	16	Each	C-clamp	Local – Tool
	5	8	Each	Chisel	Local – Tool
	10	15	Each	Combination square	Local – Tool

Need	Qty/ 20	Qty/ 30	Unit	Item Specifications	Vendor
	10	15	Each	Combination wrench, $^{1}/_{2}$″	Local – Tool
	1	1	Each	Depth micrometer	Local – Tool
	6	9	Each	Face shield	Local – Tool
	5	8	Each	Feeler gauge	Local – Tool
	10	15	Each	Flat-head screwdriver	Local – Tool
	5	8	Each	Funnel (6–8 inch)	Local – Tool
	5	8	Each	Fuse puller	Local – Tool
	2	3	Each	Grease gun	Local – Tool
	7	10	Each	Hacksaw	Local – Tool
	5	8	Each	Handheld fertilizer spreader	Local – Tool
	5	8	Each	Handheld sprayer	Local – Tool
	1	1	Each	Inside micrometer	Local – Tool
	5	8	Each	IR thermometer	Local – Tool
	1	2	Each	Manual staple gun with staples	Local – Tool
	1	1	Each	Metal chop saw	Local – Tool
	7	10	Each	Metal file	Local – Tool
	3	5	Sets	Metric wrench set	Local – Tool
	10	15	Pair	Needle nose pliers	Local – Tool
	5	8	Each	Oil drip pan	Local – Tool
	5	8	Each	Oil filter wrench	Local – Tool
	1	1	Each	Outside micrometer, 0–1″	Local – Tool
	1	1	Each	Outside micrometer, 1–2″	Local – Tool
	1	1	Each	Outside micrometer, 2–3″	Local – Tool
	5	8	Each	Phillips screwdriver, #2	Local – Tool
	10	15	Each	Pitch gauge	Local – Tool
	5	8	Pair	Pliers	Local – Tool
	5	8	Each	Pry bar	Local – Tool
	10	15	Each	Screwdriver, small flathead	Local – Tool
	5	8	Each	Seal installer	Local – Tool
	5	8	Each	Seal/bearing driver	Local – Tool
	5	8	Pair	Slip joint pliers	Local – Tool
	10	15	Pair	Snap-ring pliers	Local – Tool
	5	8	Each	Socket 38mm, ½″ drive	Local – Tool
	10	15	Each	Socket $^{3}/_{8}$″ drive, $^{1}/_{2}$″	Local – Tool
	5	8	Each	Socket extension $^{3}/_{8}$″drive	Local – Tool
	5	8	Each	Socket set, $^{3}/_{8}$″ drive	Local – Tool
	5	8	Each	Socket set, 6 pt, $^{3}/_{8}$″ drive	Local – Tool
	5	8	Each	Socket wrench, ¼″ drive	Local – Tool
	5	8	Each	Socket wrench, ½″ drive	Local – Tool
	10	15	Each	Socket wrench, $^{3}/_{8}$″ drive	Local – Tool
	1	1	Each	Socket, $^{1}/_{2}$″, ¼″ drive	Local – Tool
	5	8	Each	Socket, 10mm, ¼″ drive	Local – Tool
	1	1	Each	Socket, $^{7}/_{16}$″,¼″ drive	Local – Tool
	5	8	Each	Socket, 8mm, ¼″ drive	Local – Tool
	5	8	Each	Socket, $^{9}/_{16}$″, $^{3}/_{8}$″ drive	Local – Tool
	3	3	Each	Steel fuel line cutter	Local – Tool
	1	1	Each	Table saw or circular saw	Local – Tool
	10	15	Each	Tape measure, 25′	Local – Tool
	5	8	Each	Tapered punch	Local – Tool
	10	15	Each	Telescoping gauge	Local – Tool
	5	8	Each	Torque wrench, 5–80 ft-lb, ½″ drive	Local – Tool

Need	Qty/ 20	Qty/ 30	Unit	Item Specifications	Vendor
	10	15	Each	Torque wrench, in-lb, $^3/_8$″ drive	Local – Tool
	5	8	Each	Wire crimper, 12–16 ga	Local – Tool
	5	8	Each	Wire stripper	Local – Tool
	10	15	Each	Workstations with a vise	Local – Tool
	7	10	Each	Wrench or nut driver, ¼″	Local – Tool

Miscellaneous Vendors

Need	Qty/ 20	Qty/ 30	Unit	Item Specifications	Vendor
	5	8	Each	RC tractor	Reality Works
	5	8	Each	Transmitter	Reality Works
	5	8	Each	Flow meter	SEEED (Product ID: 314150001)
	10	15	Each	Flow meter	SEEED (Product ID: 314150001)
	5	8	Each	FIMCO 30 Gallon Trailer Sprayer	Tractor Supply Company
	5	8	Each	Magneto	Power Distributors
	5	8	Each	Small engine, OHV	Power Distributors
	5	8	Each	Spark plug	Power Distributors
	3	5	Each	Diesel fuel injector pressure tester	Local – **MercedesSource**
	5	8	Each	**Wheel hub/spindle (128008)**	Local – Northern Tool

Print (See Teacher Notes for Details)

Need	Qty/ 20	Qty/ 30	Unit	Item Specifications	Lesson
	5	8	Copies	*Cranking Circuit Schematic*	Lesson 4.2
	5	8	Each	*Ignition Systems Service Manual*	Lesson 4.2
	5	8	Copies	*John Deere Gator Service Manual*	Lesson 4.2
	2	3	Sets	*Project 4.3.2 Complaint Cards*	Lesson 4.3
	5	8	Each	Service manual, New Regent	Lesson 4.3
	1	1	Each	*CAN Bus Template*	Lesson 5.2
	1	2	Sets	*Project 6.3.2 Pump Complaint Cards*	Lesson 6.3
	1	2	Set	*Project 6.3.4 Oil Contamination Cards*	Lesson 6.3
	5	8	Each	SDS sheet	Lesson 7.1
	5	8	Each	Tractor maintenance manual	Lesson 7.1

Software

Need	Qty/ 20	Qty/ 30	Unit	Item Specifications	Vendor
	20	30	Each	Amatrol® hydraulic simulator subscriptions	Amatrol
	20	30	Seats	SMS software with example data	Ag Leader
	10	15	Each	Computer stations with Lobe software	**Lobe**
	10	15	Each	*PowerPortal* account	Briggs and Stratton
	1	1	Each	*LunchBox Session subscription*	**LunchBox Sessions**

Textbook

Need	Qty/	Qty/	Unit	Item Specifications	Vendor

	20	30			
	20	30	Each	*Heavy Equipment Power Trains and Systems*	Goodheart-Wilcox
	1	1	Each	*Hydraulic Systems for Mobile Equipment*	Goodheart-Wilcox
	1	1	Each	*Diesel Technology*	Goodheart-Wilcox

Vernier

Need	Qty/ 20	Qty/ 30	Unit	Item Specifications	Vendor
	10	15	Each	DCU power output kit • 6 wires with alligator clip and pin ends • 2 Light-emitting diodes • 2 Resistors, 220 ohm	Vernier
	10	15	Each	Digital control unit	Vernier
	5	8	Each	Graduated cylinder, 250ml	Vernier
	5	8	Each	KidWind Output Power Board	Vernier
	10	15	Each	LabQuest	Vernier
	5	8	Each	Motion detector	Vernier
	10	15	Each	Pressure 400 sensor	Vernier
	5	8	Each	SparkFun® RedBoard with cable	Vernier
	5	8	Each	Vernier Arduino® Interface Shield	Vernier
	10	15	Each	Vernier soil moisture sensor	Vernier
	1	1	Each	Vernier temperature sensor	Vernier
	10	15	Each	Water pump and hose	Vernier

VEX

Need	Qty/ 20	Qty/ 30	Unit	Item Specifications	Vendor
	4	5	Package	Wheel, 4″ (4 per package)	VEX 276-1497
	7	10	Each	Motor, 2-wire motor 393	VEX 276-2177
	7	10	Kits	Advanced Gear Kit • 7 Bevel gears • 1 Differential • 4 Worm gears • 4 Rack and pinion	VEX 276-2184
	7	10	Kits	Booster Kit • Flat bearing • Gear, 12-tooth • Gear, 36-tooth • Gear, 60-tooth • Gear, 84-tooth • Motor clutch • Nut, #8-32 keps • Screw, #6-32 x ½″ • Screw, #8-32 x ¼″ • Shaft collar • Shaft collar • Shaft, 11mm • Shaft, 12″ square • Shaft, 12″ square • Shaft, 4″ square • Shaft, 4″ square • Spacers, 8mm • Standoff 3″ • Steel angle 2x2x25 • Steel rail, 2x1x25	VEX 276-2232

Need	Qty/ 20	Qty/ 30	Unit	Item Specifications	Vendor
	3	4	Package	Gear, 60-tooth extra strength (8 pack)	VEX 276-7748
	3	4	Package	Worm gearbox bracket	VEX 275-1189
	3	4	Package	Bevel gearbox bracket	VEX 275-1187

Ward’s

Need	Qty/ 20	Qty/ 30	Unit	Item Specifications	Vendor
	5	8	Each	Beaker, 100ml	Ward’s
	3	3	Each	Beaker, 250ml	Ward’s
	20	30	Each	Beaker, 600ml	Ward’s
	5	8	Each	Electronic balance	Ward’s
	5	8	Each	Erlenmeyer flask, 1L	Ward’s
	5	8	Each	Graduated cylinder, 100ml	Ward’s
	5	8	Each	Hot plate	Ward’s
	10	15	Each	Microscope	Ward’s
	1	2	Boxes	Nitrile gloves, medium – 100 count	Ward’s
	1	2	Boxes	Nitrile gloves, large – 100 count	Ward’s
	1	2	Boxes	Nitrile gloves, x-large – 100 count	Ward’s
	12	17	Each	Petri-dish	Ward’s
	25	35	Each	Plastic pipet, 1 ml	Ward’s
	5	8	Each	Ring stand	Ward’s
	5	8	Each	Ring, 10cm	Ward’s
	5	8	Each	Rubber stopper, two holes, size 6	Ward’s
	20	30	Pair	Safety glasses	Ward’s
	40	60	Each	Test tubes	Ward’s
	5	8	Each	Thermometer	Ward’s
	10	15	Each	Weighing dish	Ward’s

CASE

TAA Teaching Timeline

IMPORTANT: This timeline is for planning and preparation purposes only. Refer to the plans, teacher notes and activities, projects, and problems while preparing for each lesson. This timeline is for a 45-50-minute class period. Adjust accordingly.

Day	Lesson	APP & CU	Teacher Presentation	Completion/ Observations	Assigned Homework	Advanced Preparation
1	1.1	Activity 1.1.1				Prepare 4 Bar Linkages for 1.1.2
2		Activity 1.1.2	Measurement Tools			
3						Gather example bolts for 1.1.3
4		Activity 1.1.3				Gather example components for 1.1.4
5		Activity 1.1.4				
6		Activity 1.1.5				Gather example belts, chains, and pulleys
7						
8		Activity 1.1.6	Drive Train Components			
9						Review **OSHA** website
10		Project 1.1.7				
11						
12						Contact Presenter with 1.2.1 Checklist
13		Lesson 1.1 CU				
14	1.2	Activity 1.2.1				Prepare student **PowerPortal** accounts
15		Activity 1.2.2				Review **Fluke** account setup
16		Activity 1.2.3		Fluke Lesson 1		
17				Fluke Lesson 2	Fluke Lesson 3–6	Print 1.2.4 Complaint Cards
18		Project 1.2.4	Completing an Order			
19				Work/Repair Order		
20		Project 1.2.5				
21						
22				Work/Repair Order		
23		Lesson 1.2 CU				Review VEX materials for 2.1.1
24	2.1	Activity 2.1.1			Pages 215–227	
25					Pages 253–262 and 274–276	Prepare dowels for 2.1.2
26		Activity 2.1.2	Clutches			
27						

Day	Lesson	APP & CU	Teacher Presentation	Completion/ Observations	Assigned Homework	Advanced Preparation
28						
29		Activity 2.1.3		Employability Eval.	Pages 242–249	Gather example bearings for 2.1.4
30		Activity 2.1.4	Bearings			
31		Project 2.1.5	Gears			
32						
33						
34						
35		Activity 2.1.6				
36						
37				Work/Repair Order		
38		Lesson 2.1 CU				
39	2.2	Activity 2.1.2			Pages 547–551	
40					Pages 283–288	
41		Activity 2.2.2				
42		Activity 2.2.3			Pages 755–761	
43						Gather tire cross sections for 2.2.4
44		Activity 2.2.4				Prepare containers for 2.2.5
45		Activity 2.2.5			Pages 591–597	
46						
47		Project 2.2.6				
48						
49		Lesson 2.2 CU		Work/Repair Order		Review how to use the equipment for 3.1.1
50	3.1	Activity 3.1.1				
51						Check the Apps needed for 3.1.2
52		Activity 3.1.2	Precision Systems			Arrange a visit to a dealership to view precision equipment
53						
54		Project 3.1.3	Precision Parts			
55						Set up John Deere accounts for 3.1.4
56		Activity 3.1.4	Guided Operation			
57						
58		Project 3.1.5				
59						Review DCU and electrical schematic for 3.1.6
60			Controlling with Precision		Breadboard Video	
61		Activity 3.1.6				

Day	Lesson	APP & CU	Teacher Presentation	Completion/ Observations	Assigned Homework	Advanced Preparation
62						Set up an outdoor area for 3.1.7
63		Activity 3.1.7				
64						
65		Lesson 3.1 CU				Download SMS software on to computers
66	3.2	Activity 3.2.1	Creating Field Boundaries Video			
67			Creating Soil Samples Video			
68		Activity 3.2.2	Interpolate Maps Interpolation Video			
69						
70			Prescription Maps		Prescription Video	
71		Activity 3.2.3				
72		Project 3.2.4				
73						
74		Lesson 3.2 CU				Review using Lobe application for 3.3.1
75	3.3	Actvitiy 3.3.1				
76		Activity 3.3.2				
77		Lesson 3.3 CU				
78	4.1		LunchBox Session© Basic Electrical Units and Series and Parallel Circuit Basics			
79		Activity 4.1.1				
80						
81		Activity 4.1.2	LunchBox Session© Diodes			Prepare tractor for 4.1.3
82						
83		Activity 4.1.3	YouTube video Electrical System Troubleshooting for a Farm Tractor			Create a fault in charging systems for Part Four
84		Activity 4.1.4				
85						
86		Activity 4.1.5	LunchBox Session© Variable Resistors			
87		Lesson 4.1 CU				
88	4.2	Activity 4.2.1	LunchBox Session© Interpreting Electrical Schematics			
89		Activity 4.2.2	LunchBox Session© Starting and Charging Systems			

Day	Lesson	APP & CU	Teacher Presentation	Completion/ Observations	Assigned Homework	Advanced Preparation
90						Prepare engines for 4.2.3
91		Activity 4.2.3				
92						
93		Activity 4.2.4	LunchBox Session© Relays			Gather control panel materials for 4.2.5
94		Project 4.2.5	LunchBox Session© Sensors, Transducers, & Transmitters			
95		Project 4.2.6				
96						
97						
98		Lesson 4.2 CU				
99	4.3	Activity 4.3.1	LunchBox Session© Open and Short Circuit Faults			
100		Project 4.3.2	Electrical Testing – Voltage Drop			
101				Work/Repair Order		
102		Activity 4.3.3				Gather materials for 4.3.5
103		Project 4.3.4	LunchBox Session© Electrical Connectors and Lunchbox Session: Basic Soldering			
104						
105						
106						
107		Problem 4.3.5				
108						
109						
110						
111						
112		Lesson 4.3 CU				Access PowerPortal Videos for 5.1.1
113	5.1	Activity 5.1.1	PowerPortal Videos			
114						
115		Activity 5.1.2				
116						Prepare coolants for 5.1.3
117		Activity 5.1.3				Prepare water pumps and radiator for 5.1.4
118						
119		Project 5.1.4				

Day	Lesson	APP & CU	Teacher Presentation	Completion/ Observations	Assigned Homework	Advanced Preparation
120						Prepare DEF for 5.1.5
121		Activity 5.1.5				
122						Gather engine components for 5.1.6
123		Project 5.1.6				
124				Work/Repair Order		
125		Lesson 5.1 CU				Prepare Arudinos with CAN Bus code for 5.2.1
126	5.2	Activity 5.2.1	LunchBox Session© Intro to CAN Bus			
127						Prepare Arudinos with CAN Bus code for 5.2.2
128		Activity 5.2.2				Connect with dealership for 5.2.3 fied trip
129		Project 5.2.3				
130						
131		Lesson 5.2 CU				Set up Amatrol Accounts for students
132	6.1		LunchBox Session© Fluid Power Basics	Hydraulic Power Systems Segments 1 and 2		
133		Activity 6.1.1				
134		Activity 6.1.2	LunchBox Session© Hydraulic Schematic Symbols	Amatrol® Hydraulic Power Systems Segments 3 and 4		
135						
136						Prepare pumps and plastic tubing for 6.1.3
137		Activity 6.1.3	LunchBox Session© Positive and Non-positive Pumping			
138						
139		Activity 6.1.4	LunchBox Session© Pressure and Flow			
140						
141		Activity 6.1.5	LunchBox Session© Pressure Parts 1–3			
142			LunchBox Session© Pressure Parts 4–5			
143		Lesson 6.1 CU				Prepare fluids for 6.2.1
144	6.2	Activity 6.2.1	LunchBox Session© Fluid Basics Part 1			Schedule tractor for 6.2.2 and 6.2.6
145			LunchBox Session© Fluid Basics Part 2			

Day	Lesson	APP & CU	Teacher Presentation	Completion/ Observations	Assigned Homework	Advanced Preparation
146		Activity 6.2.2	LunchBox Session© Fluid Power Safety			
147						
148		Activity 6.2.3	LunchBox Session© Introduction to Gear Pumps			
149			LunchBox Sessions© Introduction to Vane Pumps and Introduction to Piston Pumps			
150						
151		Activity 6.2.4				
152		Project 6.2.5	LunchBox Session© Hydrostatic Systems			
153						
154						
155		Activity 6.2.6	LunchBox Session© Hydraulic Steering			
156						
157		Lesson 6.2 CU				Gather cylinders, valves, and pumps for 6.3.1 and 6.3.2
158	6.3	Activity 6.3.1	LunchBox Sessions© Anatomy of a Cylinder and Directional Control Valves			
159						
160		Project 6.3.2				
161				Work/Repair Order		
162		Activity 6.3.3	LunchBox Sessions© Hydraulic Fittings: Threads and Quick Couplers: Maintenance and Faults			Prepare oil for 6.3.4
163						
164						
165		Project 6.3.4	LunchBox Session© Filtration and Contamination			
166				Work/Repair Order		
167		Lesson 6.3 CU				Prepare materials for 7.1.1 and 7.1.2
168	7.1	Project 7.1.1				
169						
170		Activity 7.1.2				

Day	Lesson	APP & CU	Teacher Presentation	Completion/ Observations	Assigned Homework	Advanced Preparation
171						
172				End of Course Assessment		
173				Foundational SAE Checklist		

Name____

CASE

Work/Repair Order Evaluation Rubric

Areas with Room for Improvement	Criteria	Areas that Meet or Exceed Expectations
	Grammar The work/repair order uses proper grammar throughout the document.	
	Concisely Written The student wrote the work/repair order concisely, using only necessary wording and jargon.	
	Correct Terminology The work/repair order uses the correct terminology to communicate parts, failures, and procedures during diagnosis and correction.	
	Professional The order is professional and appropriate to file with employers and provide to the customer. The complaint, cause, key part, correction, and confirm and all communicated clearly.	

Name____

CASE

Work/Repair Order Template

Customer Information			
Name (Last, First)		**Date**	
Equipment			
Serial Number			
Drive Time/Mileage			

Complaint (Concern)

What is the customer's complaint? How did you verify the complaint?

Cause

What are the symptoms of the component failure? What is the root cause?

Key Part(s)

Part Number	Part Name	Quantity

Correction

What steps did you take to repair the problem?

Confirm

What steps did you take to confirm operation? What was the outcome?

CASE

Lesson 1.1 Equipment Systems

Preface

Agricultural technicians use a combination of technical reading, mechanical skills, and technology to maintain and repair agricultural equipment for planting, harvesting, storing, and processing agricultural goods. Employers expect technicians to recognize the importance of safety and apply employability to skills. By practicing safety and employability skills in the classroom, students should improve their skills before moving into the workforce.

A technician must be familiar with the equipment used in their local area, as they vary across the United States because of diverse agricultural commodity production. Although agricultural equipment varies in size and purpose, they have similar drivetrains and safety equipment. Most equipment contains a driveshaft connected to power-take-off (PTO) via a universal joint (U-joint). The driveshaft powers a series of gears, chains, and belts found in the equipment. Technicians need to be aware of the powertrain's actions and motions to reduce the chance of injury.

Students begin the course by researching the types of equipment used in agriculture. Next, students make their first entry in a *Logbook*. Then they practice using their logbook while disassembling and assembling a universal joint. Next, students identify the powertrain components. Students complete the lesson by identifying safety hazards found on agricultural equipment.

Concepts	Performance Objectives
Students will know and understand	*Students will learn concepts by doing*
1. Agricultural equipment used by industry varies based on local crops and geographic location.	• Identify and describe the equipment used in the local area to produce and harvest crops. (Activity 1.1.1)
2. Technicians document plans and processes when servicing equipment.	• Organize notebooks to record coursework and projects. (Activity 1.1.2) • Practice recording assembly and disassembly procedures in a logbook. (Activity 1.1.2)
3. Technicians use tools to make precise measurements.	• Measure components using a dial caliper, dial indicator, torque wrench, and combination square. (Activity 1.1.2) • Use a micrometer to make precise measurements. (Activity 1.1.4)
4. A fastener’s strength and size vary based on its purpose.	• Identify bolt size, type, and grade. (Activity 1.1.3)
5. Power take-off (PTO) systems transfer power to agricultural implements.	• Disassemble and identify the components of a universal joint. (Activity 1.1.5)
6. Powertrain systems contain belts, chains, and gears to deliver power for work.	• Identify types of belts, chains, and gears on a piece of equipment. (Activity 1.1.6)
7. Guarding and shielding agricultural equipment prevent injury to an operator.	• Identify the safety hazards found in the internal motions of equipment. (Project 1.1.7)

National AFNR Common Career Technical Core Standards Alignment

Career Ready Practices
2. Apply appropriate academic and technical skills.
• CRP.02.02: Use strategic thinking to connect and apply technical concepts to solve problems in the workplace and community.
4. Communicate clearly, effectively and with reason.
• CRP.04.02: Produce clear, reasoned and coherent written and visual communication in formal and informal settings.
Agriculture, Food, and Natural Resources Career Cluster
3. Examine and summarize importance of health, safety, and environmental management systems in AFNR organizations.
• AG 3.1: Examine health risks associated with a particular skill to better form personnel safety guidelines.
• AG 3.6: Demonstrate methods to correct common hazards.
• AG.3.7: Demonstrate application of personal and group health and safety practices.
Power, Structural and Technical (AG-PST)
1. Apply physical science principles and engineering applications related to mechanical equipment, structures, and biological systems to solve problems and improve performance in AFNR power, structural, and technical systems.
• AG-PST 1.3: Investigate solutions to AFNR power, structural, and technical systems.
2. Operate and maintain mechanical equipment related to AFNR power, structural, and technical systems.
• AG-PST 2.3: Operate machinery and equipment while observing all safety precautions.

Next Generation Science Standards Alignment

Crosscutting Concepts	
Cause and Effect: Mechanism and Prediction	Events have causes, sometimes simple, sometimes multifaceted. Deciphering causal relationships, and the mechanisms by which they are mediated, is a major activity of science and engineering.
	• Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. • Cause and effect relationships can be suggested and predicted for complex natural and human designed systems by examining what is known about smaller scale mechanisms within the system. • Systems can be designed to cause a desired effect. • Changes in systems may have various causes that may not have equal effects.
Systems and System Models	A system is an organized group of related objects or components; models can be used for understanding and predicting the behavior of systems.
	• Systems can be designed to do specific tasks. • When investigating or describing a system, the boundaries and initial conditions of the system need to be defined and their inputs and outputs analyzed and described using models.

Common Core State Standards for English Language Arts

CCSS: English Language Arts Standards » Science & Technical Subjects » Grade 11-12	
Key Ideas and Details	• **RST.11-12.3 –** Follow precisely a complex multistep procedure when carrying out experiments, taking measurements, or performing technical tasks; analyze the specific results based on explanations in the text.
Craft and Structure	• **RST.11-12.4 –** Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to grades 11-12 texts and topics.
Integration of Knowledge and Ideas	• **RST.11-12.7 –** Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem. • **RST.11-12.9 –** Synthesize information from a range of sources (e.g., texts, experiments, simulations) into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible.
Range of Reading and Level of Text Complexity	• **RST.11-12.10 –** By the end of grade 12, read and comprehend science/technical texts in the grades 11-CCR text complexity band independently and proficiently.

CCSS: English Language Arts Standards » Writing » Grade 11-12

Production and Distribution of Writing	• **WHST.11-12.4 –** Produce clear and coherent writing in which the development, organization, and style are appropriate to task, purpose, and audience. • **WHST.11-12.6 –** Use technology, including the Internet, to produce, publish, and update individual or shared writing products in response to ongoing feedback, including new arguments or information.
Research to Build and Present Knowledge	• **WHST.11-12.7 –** Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation. • **WHST.11-12.8 –** Gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively; assess the strengths and limitations of each source in terms of the specific task, purpose, and audience; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and overreliance on any one source and following a standard format for citation. • **WHST.11-12.9 –** Draw evidence from informational texts to support analysis, reflection, and research.
Range of Writing	• **WHST.11-12.10 –** Write routinely over extended time frames (time for reflection and revision) and shorter time frames (a single sitting or a day or two) for a range of discipline-specific tasks, purposes, and audiences.

Essential Questions

1. Which agricultural products are grown in your area?
2. What types of equipment do local producers use for growing their crops?
3. What is the purpose of a logbook?
4. How does a logbook keep a technician organized?
5. How are bolts classified?
6. Why do technicians use micrometers when diagnosing problems?
7. What information do you record in a logbook?
8. How is power transferred from a tractor to an implement?
9. What are the advantages and disadvantages of a universal joint?
10. How is power transferred within an implement?
11. Where are belts, chains, gears, and pulleys found?
12. What are the advantages and disadvantages of belts, chains, gears, and pulleys?
13. What are the essential components of all machines and equipment?
14. Where is the risk of injury greatest when working on equipment?
15. How is equipment designed to reduce the risk of injury?

Key Terms

Bearing	**Bearing cup**	**Bending**
Bevel gear	**Cam gear**	**Combine**
Cross shaft	**Dial caliper**	**Drive gear**
Drive pully	**Driveshaft**	**Driven gear**
Driven pully	**Drivetrain**	**Flat-head screwdriver**
Forage harvester	**Gear**	**Guard**
Grease seal	**Grease zerk**	**Hay baler**

Implement	**In-running nip points**	**Logbook**
Micrometer	**Mower**	**Nonsynchronous drive**
Operating controls	**Planter**	**Point of operation**
Power-take-off	**Punching**	**Race**
Reciprocating	**Retaining ring**	**Rotating**
RPM	**Shearing**	**Sprocket**
Synchronous drive	**Technician**	**Tillage**
Timing belt	**Torque**	**Torque wrench**
Tractor	**Transversing**	**Universal joint (U-joint)**
V-belt	**Yoke**	

Day-to-Day Plans
Time: 13 days

*Refer to the Teacher Resources section for specific information on teaching this lesson, in particular **Lesson 1.1 Teacher Notes**, **Lesson 1.1 Glossary**, **Lesson 1.1 Materials**, and other support documents.*

Day 1:

- Present **Concepts**, **Performance Objectives**, **Essential Questions**, and **Key Terms** to provide a lesson overview.
- Provide students with a copy of **Activity 1.1.1 Local Equipment**.
- Students work individually to complete *Activity 1.1.1 Local Equipment*.

Day 2:

- Provide students with a copy of **Activity 1.1.2 Technical Records**, **Agriscience Notebook Cover Page**, **Agriscience Notebook Spine Template**, **Agriscience Notebook Table of Contents**, **SAE for All Checksheet**, **Logbook Guidelines**, and the **Logbook Evaluation Rubric**.
- Students complete Part Two of *Activity 1.1.2 Technical Records*.
- Provide students **Presentation Notes** pages to use throughout the presentation. Students record notes and add these pages to their *Agriscience Notebook*.
- Present PowerPoint® **Measurement Tools**.

Day 3:

- Students work in pairs to complete *Activity 1.1.2 Technical Records*.

Day 4:

- Provide students with a copy of **Activity 1.1.3 Bolt Size and Gauge**.
- Students work in pairs to complete *Activity 1.1.3 Bolt Size and Gauge*.

Day 5:

- Provide students with a copy of **Activity 1.1.4 Mic'd Up**.
- Students work in pairs to complete *Activity 1.1.4 Mic'd Up*.
- Students read pages 610–615 of *Heavy Equipment Power Trains and Systems.*

Day 6:

- Provide students with a copy of **Activity 1.1.5 Universal Connections**.

- Students work individually to complete Part One of *Activity 1.1.5 Universal Connections* by recording work in their logbooks.

Day 7:

- Students work in pairs to complete *Activity 1.1.5 Universal Connections.*

Day 8:

- Provide students **Presentation Notes** pages to use throughout the presentation. Students record notes and add these pages to their *Agriscience Notebook*.
- Present the PowerPoint® **Drive Train Components**.
- Provide students with a copy of **Activity 1.1.6 Combining Chains and Belts**.
- Students begin working in pairs on *Activity 1.1.6 Combining Chains and Belts*.

Day 9:

- Students work in pairs to complete *Activity 1.1.6 Combining Chains and Belts*.

Day 10:

- Provide students with a copy of **Project 1.1.7 Safety Precautions, Equipment Safety Checklist,** and **Project 1.1.7 Evaluation Rubric**.
- Students work individually to complete Part One of *Project 1.1.7 Safety Precautions*.
- Students work in pairs to start Part Two of *Project 1.1.7 Safety Precautions.*

Day 11:

- Students work in pairs to complete Part Two and Part Three of *Project 1.1.7 Safety Precautions*.

Day 12:

- Students work in pairs to present *Project 1.1.7 Safety Precautions*.
- Evaluate presentations using *Project 1.1.7 Evaluation Rubric*.

Day 13:

- Distribute **Lesson 1.1 Check for Understanding**.
- Students complete *Lesson 1.1 Check for Understanding* and submit for evaluation.
- Use **Lesson 1.1 Check for Understanding Key** to evaluate student assessments.

Instructional Resources

PowerPoint® Presentations

Measurement Tools

Drive Train Components

Student Support Documents

Lesson 1.1 Glossary

Presentation Notes

Activity 1.1.1 Local Equipment

Activity 1.1.2 Technical Records

Activity 1.1.3 Bolt Size and Gauge

Activity 1.1.4 Mic'd Up

Activity 1.1.5 Universal Connections

Activity 1.1.6 Combining Chains and Belts

Project 1.1.7 Safety Precautions

Logbook Guidelines

SAE for All Checksheet

Teacher Resources

Lesson 1.1 Equipment Systems PDF

Lesson 1.1 Teacher Notes

Lesson 1.1 Materials

Lesson 1.1 Check for Understanding

Answer Keys and Assessment Rubrics

Lesson 1.1 Check for Understanding Answer Key

Activity 1.1.3 Student Data Key

Activity 1.1.4 Student Measurements Key

Project 1.1.7 Evaluation Rubric

Logbook Evaluation Rubric

Student Project Development Template

Equipment Safety Checklist

Reference Sources

Belle, G., Felinski, D., Howe, S., Jordan, T., Norton, J., Sutton, M., Whitney, S. (n.d.). *Machine guarding etool*. Retrieved from **www.osha.gov/SLTC/etools/machineguarding/intro.html**

Dell, Timothy W. (2019). *Heavy equipment power trains and system, 1st edition.* Tinely Park, IL: The Goodheart-Willcox Company, Inc.

Herren, R. (2006). *Agricultural mechanics fundamentals and applications*. (5th ed.). Clifton Park, NY: Thomson Delmar Learning.

Koel, L., & Mazur, G. A. (2013). *Agricultural technical systems and mechanics*. Orland Park, IL: American Technical Publishers.

FFA Connections

The National FFA Organization provides students an opportunity to apply knowledge and skills learned in the CASE classroom. Students can receive proficiency awards for their Supervised Agricultural Experience (SAE) projects. FFA suggests related proficiency award areas throughout the course. Another FFA opportunity is the Agriscience Fair, where students propose, plan, conduct, and report research and product development. In addition, competitive **Career and Leadership Development Events** (CDEs and LDEs) allow students to actively explore agricultural careers. Each lesson suggests potential SAE, Agriscience Fair, CDE, and LDE connections to integrate into the course.

This lesson provides conceptual and procedural knowledge related to the following FFA awards, activities and educational resources.

- Agricultural Proficiency
    - **Agricultural Mechanics Repair and Maintenance –Placement**
    - **Agricultural Mechanics Repair and Maintenance –Entrepreneurship**
- Agriscience Fair
    - **Power, Structural and Technical Systems**
- Career Development Events
    - **Agricultural Technology & Mechanical Systems**

- Educational Resources
    - **SAE Idea Cards-Power, Structural and Technical Systems**
    - **Power, Structural and Technical System Careers**
    - **Power, Structural and Technical Systems Career Focus Area Resources**
    - Agricultural Mechanics (**Word)** (**PDF**)
    - Keegan Humm-SAE-Placement-Implement Dealership Lesson Plan (**Word**) (**PDF**)
    - Power Up Your Future with John Deere **(Word)**
    - Power, Structural and Technical Careers **(Word)**

Skills and knowledge from this lesson support the development and implementation of service-learning projects that address properly running equipment systems.

- **Service-Learning and Living to Serve Grants**
- Service-learning projects focused on equipment systems address the maintenance, repair and safety of agricultural equipment.
- Project ideas including conducting an agricultural equipment safety audit of local farms and businesses, refurbishing broken bicycles for donation or repairing lawn and garden equipment for community members.
- Living to Serve Grants provide funding to FFA chapters to support service-learning and community service projects.

For more information, visit the **National FFA Organization** website.

SAE for All

Supervised Agricultural Experience (SAE) activities are essential components of an effective agricultural education program. *Technical Application in Agriculture* lessons have SAE connections for experiential learning beyond the classroom walls to add relevance to their coursework.

Foundational SAE

All students in an agricultural education program are expected to have a Foundational SAE. Students completing the APP and extensions listed below will meet the Foundational SAE qualification for the Advanced (Grades 11-12) level. Students should place all documented evidence in the FFA/SAE section of their Agriscience Notebook along with the SAE for All Foundational Checksheet.

- Workplace Safety
    - Project 1.1.7 Safety Precautions
- Agricultural Literacy
    - Activity 1.1.1 Local Equipment

Access the **SAE for All Educator Resources** site for additional teacher and student resources.

Immersion SAE

Students interested in this lesson's topics should explore the following related Immersion SAEs. An immersion SAE is optional and replaces the agricultural literacy component of the Foundational SAE.

- Placement/Internship
    - **Implement Dealership Placement SAE | Keegan Humm**
    - **Agricultural Mechanics SAE | Jeremiah Hager**

For more information on the guiding principles for implementing SAE programs, visit the **SAE for All: Evolving Essentials** site.

Critical Thinking and Application Extensions

Explanation

1. Visit a local dealership and record the types of equipment sold and their purpose.

Application

1. Students will identify and measure belt and chain sizes on equipment and order replacement parts.
2. Tighten or realign a belt or chain on equipment.

CASE

Lesson 1.1 Teacher Notes

Use the following notes to teach the course.

- Students keep an *Agriscience Notebook* to record notes, experiences, thoughts, and other important information they acquire during this class. Students place all activity sheets and records of their work in the notebook.
- Make multiple copies of the **Presentation Notes** pages, found in the Teacher Resources, for students to take notes and record observations. Students keep *Presentation Notes* in their *Agriscience Notebook* for future reference.
- A *Lesson Materials* list is provided for each lesson to plan for the upcoming lesson. Items listed on the materials list are from various vendors; therefore, ensure that you have placed equipment and supply orders well in advance of instruction.
- The **Course Glossary** and individual lesson glossaries list all *Key Terms* identified in each lesson. Make the glossary or single lesson glossaries available to students in the classroom or instruct students to add them to their *Agriscience Notebooks*.

Lesson 1.1 Equipment Systems

In preparation for teaching this lesson, review Concepts, Performance Objectives, Essential Questions, and Key Terms, along with the PowerPoint® presentations. Review all activity, project, and problem directions, expectations, and work students will complete.

Students research, analyze, and record how agricultural equipment transfers power throughout a drivetrain. Students learn how to enter procedures in their *Logbooks* and use the *Equipment Safety Checklist* throughout this process.

PowerPoint® Presentations

Measurement Tools

Use this presentation to demonstrate how to use a dial caliper, torque wrench, dial indicator, and combination square for students. Students will use these tools to complete *Activity 1.1.2 Technical Records*.

Drive Train Components

This presentation provides students with background information on the types of chains, belts, and gears used in drivetrains. Students will use this information to complete *Activity 1.1.6 Combining Chains and Belts*.

Activities, Projects, and Problems

Activity 1.1.1 Local Equipment

Students work individually to define types of agricultural equipment, then identify the equipment found in their local area.

Teacher Preparation

Students need a device with internet access and the *Heavy Equipment Power Trains and Systems* textbook to find the information needed to complete the activity.

Student Performance

Students start the activity by defining the types of equipment used in agriculture. Next, students use a USDA resource to find the top five commodities grown in their state. Finally, students list and describe the equipment used to harvest the commodities grown in their state to complete the activity.

Results and Evaluation

Table 1 contains definitions for each equipment category.

Table 1. *Equipment Categories*

Tillage	**Tillage equipment cuts, agitates, stirs, and overturns the soil in preparation for seeding and controlling weeds.**
Planting and seeding	**Equipment designed to open a furrow for placing seed and closing the furrow after placing the seed.**
Mowers, cutters, conditioners	**Mowers and conditioners are designed for cutting and preparing a forage crop for harvest and storage.**
Rakes	**Windrow hay to combine into larger windrows or turnover for drying.**
Hay balers	**Picks up a swath of hay and pack it into a bale.**
Forage harvesters	**Harvest equipment cut and chop a forage crop.**
Combines	**Equipment that reaps plants and threshes the grain, separating the grain from the remainder of the plant.**
Tractors	**Tractors power and pull other types of equipment. Power is transferred through a hitch, power take-off, or hydraulics.**
Spreaders and Sprayers	**Spreaders and sprayers are applicators that treat fields for weeds or nutrition.**

Activity 1.1.2 Technical Records

Students prepare their *Agriscience Notebook* and *Logbook* for the course. They practice using the Logbook to assemble and disassemble a four-bar linkage.

Teacher Preparation

Part One

Prepare the appropriate quantity of binders, sheet protectors, tabs and labels, and notebooks, as well as paper copies (or electronic binder alternative) of the following documents.

The three-ring binders should have two-inch diameter rings, minimum.

- Clear-view covers will allow students to customize their covers and side bindings using the **Agriscience Notebook Cover Page Template** and the **Agriscience Notebook Spine Template**.
- The **Agriscience Notebook Table of Contents** provides a table of contents for the notebook.
- Students need ten tab dividers and label inserts to organize their *Agriscience Notebook*.
- Students will use the **SAE for All Checksheet** to keep records related to their SAE programs. Substitute these pages with local or state required paper or electronic SAE records.

Please contact the **National FFA Local Program Success** staff for assistance in providing FFA and SAE opportunities to your students.

Part Two

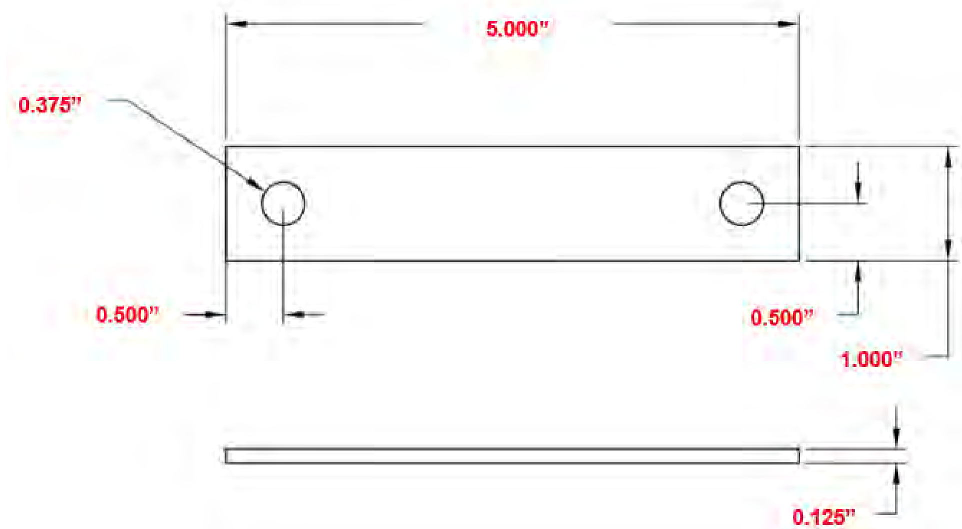
Students will need a blank *Logbook* and copies of the **Logbook Guidelines** and **Logbook Evaluation Rubric**.

Part Three
Present *Powertrain Components* before starting Part Three. Use ten four-bar linkages assembled by students During the *CASE Agricultural Power and Technology* course. If needed, use the drawings in the figures and listed materials below to construct each four-bar linkage. You can reuse the linkages each year after they are constructed.

Four-Bar Linkage Materials

- (3) $^{1}/_{8}$″x1″-9″ flat stock
- (1) $^{1}/_{8}$″x1″-5″ flat stock
- (4) $^{5}/_{16}$″-1″ low-grade UNC bolts
- (4) $^{5}/_{16}$″ UNC nuts
- (24) $^{5}/_{16}$″ flat washers

5″ Bar



9″ Bar

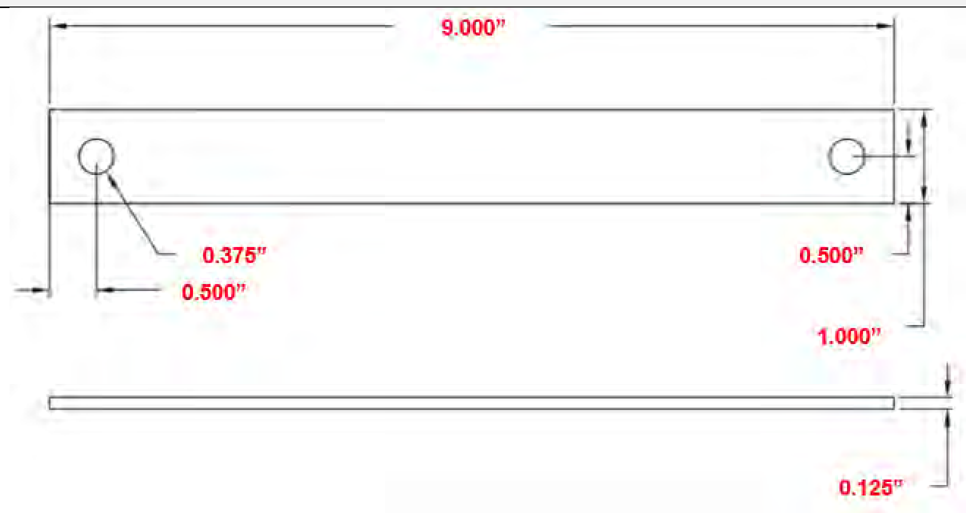


Figure 1. Bar Dimensions

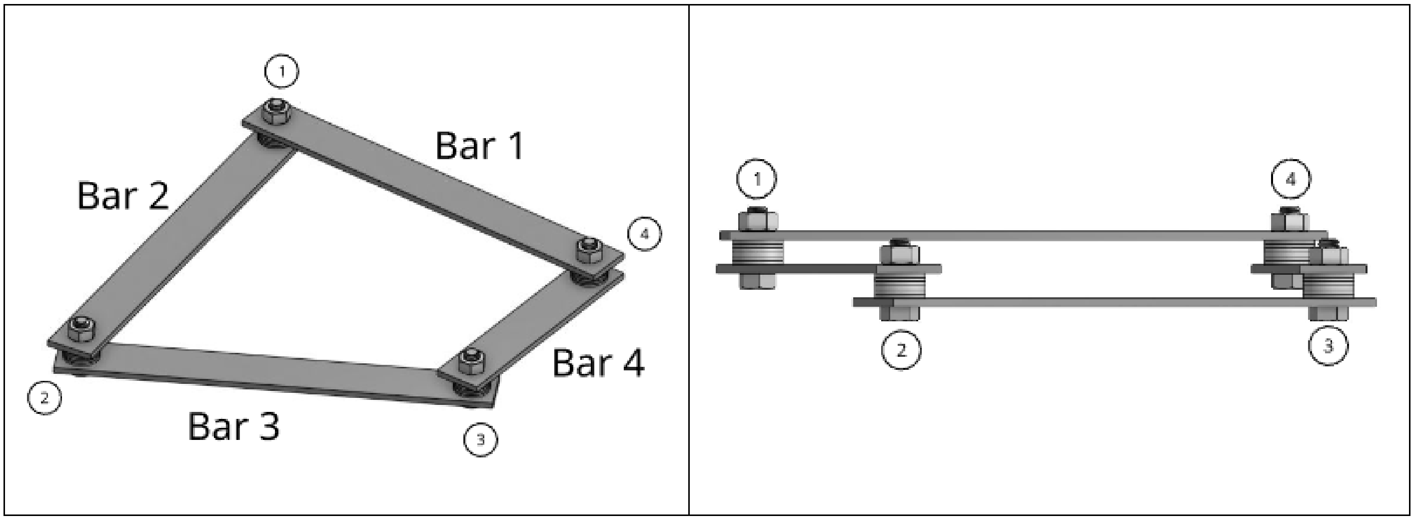


Figure 2. Linkage Bar assembly

Student Performance

Part One

Students assemble a binder with dividers and labeled tabs for each course Unit. Next, they insert a cover page and spine for the binder.

Part Two

Students set up a *Logbook* to record technician actions completed throughout the course. Use the *Logbook Guidelines* to assist students in preparing their notebooks. Students paste the guidelines page and *Logbook Evaluation Rubric* inside the notebook for future reference. Remind students during the initial activities and projects to record their actions in this notebook. Throughout the course, use the *Logbook Evaluation Rubric* to assess their entries.

Part Three

Students disassemble and assemble a four-bar linkage. They record each step and measurement in their Logbook while completing the task. An example of *Logbook* notes is included in Table 2.

Results and Evaluation

Make periodic checks and access progress of the student *Logbooks*. Due to various academic periods, you are encouraged to set up a formative assessment interval that fits your program's needs.

Table 2. *Example Logbook Notes*

Step	Hardware	Tools	Torque or Specification
Measure the movement of linkage and torque of bolts	*4 bar linkage*	*Vise* *½" combination wrench* *$^3/_8$" drive torque wrench* *½" socket* *Dial indicator*	*Movement – 0.015"* *Torque – 60 in-lbs*
Remove nuts from the four-bar linkage	*4 - 5/16" nuts*	*½" combination wrench* *$^3/_8$" drive socket wrench* *½" socket*	
Remove bolts and washers *Take measurements*	*4 – 5/16" bolts – 1"* *24 – $^5/_{16}$" flat washers* *1 – $^1/_8$"x1"-5" flat stock* *3 – $^1/_8$"x1"-9" flat stock*	*Combination square* *Dial Caliper*	*Flat stock with 3/8" holes*
Assembly			
Attach bolts and washers	*4 – 5/16" bolts – 1"* *24 – $^5/_{16}$" flat washers* *1 – $^1/_8$"x1"-5" flat stock*		

	3 – ⅛"x1"-9" flat stock		
Tighten nuts on bolts	*4 - 5/16" nuts*	*½" combination wrench* *⅜" drive torque wrench* *½" socket*	*20 in-lbs*

Activity 1.1.3 Bolt Size and Gauge

Students work in pairs to identify bolts by size, thread count, and strength.

Teacher Preparation

Gather 20 bolts of various sizes and gauges. Be sure to vary the grade along with metric and imperial measured bolts. Complete an **Activity 1.1.3 Student Data Key** to use as a key to review with students. Place the two bolts at ten stations for students to rotate through.

Student Performance

Students use a dial caliper to measure and identify bolt sizes. Then they find the markings to determine the gauge of each bolt. Students record their observations on *Activity 1.1.3 Student Data* sheet.

Results and Evaluation

Review the bolt sizes and gauges with students to ensure they have correctly identified them.

Activity 1.1.4 Mic'd Up

Students learn to use multiple types of micrometers and practice using them while measuring components.

Teacher Preparation

1. Review the **micrometer video** (**https://www.youtube.com/watch?v=vyT1gC9Ns4c**) if you are not familiar with using a micrometer.
2. Go to the **virtual micrometer website** (**https://www.stefanelli.eng.br/en/simulator-virtual-micrometer-tenths-thousandth-inch/**) to ensure the site is available for students.
3. Gather 15 mechanical components for students to measure with either a depth, inside or outside micrometer. Use a paint pen to mark where to measure each component.
    - Nine components to measure with an outside micrometer.
        - Three components for 0–1″ micrometer.
        - Three components for 1–2″ micrometer.
        - Three components for 2–3″ micrometer.
    - Three components to measure with an inside micrometer.
    - Three components to measure with a depth micrometer.
4. Measure each component before class and record them on **Activity 1.1.4 Student Measurement Key**.

Student Performance

Students begin the lesson by watching a video on how to use a micrometer. Next, they practice setting a virtual micrometer at a specific measurement. Then review the 15 components with the class and discuss with type and size of the micrometer to use for each. Separate the components into the following five stations with three components and the correct measurement tool.

- Three components and a 0–1″ outside micrometer.
- Three components and a 1–2″ outside micrometer.
- Three components and a 2–3″ outside micrometer.
- Three components and an inside micrometer.
- Three components and a depth micrometer.

Break the class into teams of three and assign each team one of the five stations. Students should measure each component and record their measurements on the student measurements sheet.

Results and Evaluation
Review the measurements with students to ensure they have correctly measured them.

Activity 1.1.5 Universal Connections

Students work in pairs to disassemble, measure, and reassemble a universal joint.

Teacher Preparation
Each pair of students needs a shop bench to complete this activity. Review the service manual for your specific universal joint and the **ball joint service kit** before starting the activity, as the universal joint components will vary. Be prepared to explain or demonstrate how to lubricate the joint using a grease gun at the end of the activity.

Student Performance
Students complete a reading the day before about universal joints. Students start a record in their Logbook for disassembling a universal joint during the first day of the activity. Students then disassemble the joint and record all actions in their *Logbook*. On the second day, students reassemble and lubricate the U-joint.

Results and Evaluation
Review student *Logbooks* to ensure they record all procedural steps. Answers to analysis questions are in Table 3.

Table 3. ***Analysis Questions and Potential Responses***

Q1	What would you inspect if a customer complains of the universal joint making noise while rotating?	*I would inspect where the yoke connects to the cross.*
Q2	Why is it important to measure the diameter of the journals on the cross?	*The diameter is the cross's area where the friction will cause wear, decreasing the diameter of the cups.*

Activity 1.1.6 Combing Chains and Belts

Students work with a partner to inspect powertrain components.

Teacher Preparation
1. Present *Powertrain Components* before the activity.
2. Gather three examples of pulleys, belts, chains, and sprockets for a total of 12 components. Have an example piece of equipment with belts and chains available for students to inspect.
    - Another option would be to set up an implement visit to inspect a piece of equipment.
3. Make copies of the equipment's user manual for students.

Student Performance
Students begin by identifying and measuring five power train components. Next, students view each component on equipment. They compare measurements to manual specifications and complete a physical inspection to determine if maintenance is needed. Finally, students record collected information and measurements on a student observation sheet.

Results and Evaluation
Motions and drivetrain types will vary based on the make and model of the implement. Review the observation sheet with students while referring to the service manual.

Project 1.1.7 Safety Precautions

Students review the common machine components, actions, and guards found on all equipment. Then they virtually observe equipment operating while completing a safety inspection.

Teacher Preparation
Print two copies of the *Equipment Safety Checklist* for each student. Review the OSHA website to familiarize yourself with the terminology students will research. You are responsible for understanding the equipment's safety features and instructing students about the safe operation. Have an example piece of equipment for students to inspect using the *Equipment Safety Checklist*.

Student Performance
Students use the **OSHA** website to review the terminology for evaluating equipment safety features. Next, students work in pairs to inspect an example piece of equipment using the *Equipment Safety Checklist*. Review the inspections with students. Next, assign students equipment to virtually inspect with the checklist. Then have student pairs present their safety information to the class. Students may choose the platform for presentations.

Results and Evaluation
Evaluate student presentations with **Project 1.1.7 Evaluation Rubric**. Students should keep their example *Equipment Safety Checklists* in the Safety section of their *Agriscience Notebook*.

Assessment

Lesson 1.1 Check for Understanding

Lesson 1.1 Check for Understanding is included for you to use as an assessment tool for this lesson. Use **Lesson 1.1 Check for Understanding Answer Key** for evaluation purposes.

Name____ CASE

Activity 1.1.1 Local Equipment

Purpose

Agricultural equipment can vary in size and scope, from a small utility tractor used at a golf course to a large combine harvesting hundreds of acres. As a technician, you need to be familiar with agricultural equipment used in your area. What types of equipment would you maintain if you were a technician where you live?

Producers use agricultural equipment to till the soil, plant crops, apply fertilizer and herbicides, and harvest. Tillage equipment prepares the soil for planting. Equipment used for planting places the seeds or seedlings in the soil at a specific rate. Application equipment directs herbicides to weeds and directs fertilizers to crops. Harvest equipment removes the crop from the field and separates plant parts. Finally, transport equipment delivers crop materials to storage or processing locations.

Which types of equipment do you expect to see in the field and at local dealerships in your area?

Materials

Per student:

- *Heavy Equipment Power Trains and Systems* text
- Device with internet access
- Pen

Procedure

Identify equipment used to produce crops grown near where you live.

Part One – Equipment Types

Describe each equipment category listed in Table 1 on *Activity 1.1.1 Student Observations*. Refer to Chapter 4 of *Heavy Equipment Power Trains and Systems.*

Part Two – State Commodities

1. In the *State* row in Table 2, write the state abbreviation for the state where you live.
2. Access the **USDA State Fact Sheets** (www.ers.usda.gov/data-products/state-fact-sheets).
3. Select your state.
4. Choose *Top Commodities, Exports, and Counties*.
5. Identify the top five commodities for your state. Then, record the commodities in Table 2.
6. Circle the commodity in Table 2 you wish to investigate production practices.

Part Three - Equipment

Identify two pieces of equipment used for producing your circled commodity for each equipment category. Use internet resources and the *Heavy Equipment Power Trains and Systems* Textbook. Record the equipment and describe what the equipment does in Table 3. Some equipment categories may be left blank depending on the selected commodity.

Conclusion

1. What is the relationship between local commodity production and equipment?

2. How does geographic location affect the types of equipment sold locally?

3. Based on your commodity research, what other types of equipment would you find in your area?

Name____

Activity 1.1.1 Student Observations

Table 1. ***Equipment Categories***

Tillage	
Planting and seeding	
Mowers, cutters, conditioners	
Rakes	
Hay balers	
Forage harvesters	
Combines	
Tractors	
Spreaders and sprayers	

Table 2. ***State Commodities***

State	
Commodities	
#1	
#2	
#3	
#4	
#5	

Table 3. ***Local Equipment***

Category	Equipment	Description
Tillage	• •	
Planting and seeding	• •	
Mowers, cutters, conditioners	• •	
Rakes	• •	
Hay balers	• •	
Forage harvesters	• •	
Combines	• •	
Tractors	• •	

Table 3. ***Local Equipment***

Category	Equipment	Description
Spreaders and sprayers	• •	

Name____ CASE

Activity 1.1.2 Technical Records

Purpose

Organization, sound records, and a professional work ethic are essential for reliable work in any technical work setting. Technicians accurately follow all written and oral instructions. They keep precise and detailed logs of all equipment servicing and maintenance while following safety protocols and maintaining professionalism.

Logbooks are an official record of all work a technician completes for employer and customer reference. Therefore, it is essential to use good record-keeping practices as a technician.

How will you keep records of your work in a *Logbook*?

Materials

Per student:

- (10) Tab dividers
- (10) Tab label inserts
- Two-inch, three-ring binder
- *Agriscience Notebook Cover Page*
- *Agriscience Notebook Spine* Template
- *Agriscience Notebook Table of Contents*
- *Logbook*
- *Logbook Evaluation Rubric*
- *Logbook Guidelines* page
- Pen, black or blue ink
- *Presentation Notes*
- Safety glasses
- *SAE for All Checksheet*

Per pair of students:

- Combination square
- Combination wrench $^{1}/_{2}$″
- Dial caliper, 6″/150mm
- Dial indicator
- Four-bar linkage
  - (4) Bolt, 5/16″-1″ low-grade UNC
  - Flat stock 1/8″x1″-5″
  - Flat stock 1/8″x1″-9″
  - Flat washer 5/16″
- Glue stick
- Socket $^{3}/_{8}$″ drive, $^{1}/_{2}$″
- Socket wrench $^{3}/_{8}$″ drive
- Torque wrench $^{3}/_{8}$″ drive, in-lb, beam
- Workbench with vise

Procedure

Set up your *Agriscience Notebook* and a *Logbook*. The *Agriscience Notebook* will be a portfolio for all course documents and records. Use the *Logbook* to record all actions completed in the lab or shop. Always keep these two items together. While completing the course, you will compile a portfolio of work.

Part One – Agriscience Notebook

1. Acquire a two-inch, three-ring binder from your teacher.
2. Write your name clearly on both the cover page and the spine label. Slide your cover page and the spine label into the appropriate positions on the outside of the binder.
3. Make labels for the tab dividers. Use the following list for section titles:
   - Records
   - 1. Equipment
   - 5. Diesel
   - 6. Fluid

- 2: Powertrains
- 3. Precision
- 4. Electrical
- 7. Field
- Reports
- Safety

4. Insert the *Table of Contents* at the front of the binder on the inside.
5. Place the *SAE for All Checksheet* in the *Records* section of your notebook. Add documents as you progress through the course. Your teacher will provide additional pages for local and state FFA program requirements.

Part Two – Logbook

1. Review the *Logbook Guidelines* and paste that page on the inside front cover of your notebook.
2. Review the *Logbook Evaluation Rubric* and paste that page on the inside front cover of your notebook.
3. Set up page 1 as the title page using a blue or black pen
    - Record the following on the title page.
        - Your name
        - Start date (Today's date)
        - Course name (*Agricultural Equipment Maintenance and Technology*)
4. Pages 2 through 6 will be the Table of Contents. Label each page accordingly.
5. Page 7 will be your first entry.

Part Three – Logbook Practice

Complete your first entry in your *Logbook* as you work with a partner to assemble and disassemble a four-bar linkage. Put on safety glasses before you begin.

1. On page 2 of the table of contents, record the activity title **Technical Records**, today's date, and the page number you will begin your documentation (page 7).
2. At the top of page 7, begin your first entry by recording the activity's title, **Technical Records**.
3. Record the following objective in your *Logbook*.
    - "Record the disassembly and assembly process of a four-bar linkage."
4. Record a table in your *Logbook* with headers, as seen in Table 1.
    - Record each step, including hardware and tools used in your *Logbook*.
    - Add a new row as you complete each step of the disassembly and assembly processes.

Table 1. *Example Logbook Notes*

Step	Hardware	Tools	Torque or Specification

5. Use Figure 1 as a guide to place the linkage in a vise and set up the dial indicator to measure the movement of a vertical bar in the linkage.
    - The dial indicator's plunger should be in contact with the end of a vertical bar.
6. Record the linkage movement in your *Logbook*.
7. Use the ½″ combination wrench and socket wrench to tighten the nuts from the four-bar linkage.
8. Use a beam torque wrench and ½″ combination wrench to measure the torque of each bolt.
9. Record the torque of each nut in your *Logbook*.
10. Use the ½″ combination wrench and socket wrench to remove the nuts from the four-bar linkage.

Figure 1. Dial Indicator

11. Disassemble the bars, bolts, and washers. Use a dial caliper and combination square to measure the specifications of each part. Include lengths, widths, thickness, and heights of the bars, bolts, washers, and nuts.
    - Record this step, the hardware, and the tools used in your *Logbook*.
    - Record the specifications for each part in your *Logbook*.
12. Sketch and record the components beneath the disassembly table in your *Logbook*.
13. Start a new table for reassembling the four-bar linkage.
14. Refer to Figure 2 to reassemble the four-bar linkage. Use the torque wrench to torque the two bolts connected to bar four to 100 in-lbs.
    - Use the dial indicator to measure the movement in the system.
    - Record the assembly steps in your *Logbook*.
15. Record answers to conclusion questions in your *Logbook*.

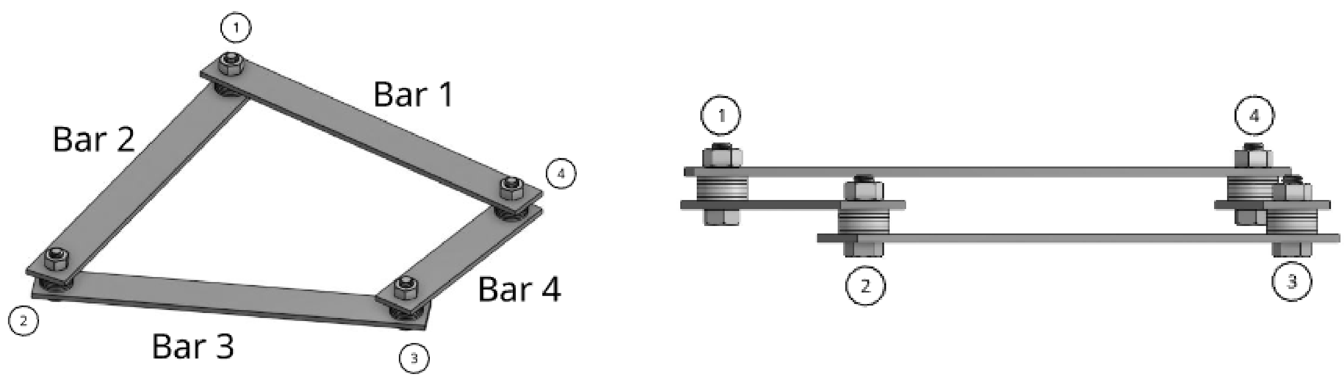


Figure 2. Linkage Bars

Conclusion

1. How do detailed records assist technicians?
2. What information should you record in your *Logbook*?
3. How will your records assist you when repairing equipment?

Name____

CASE

Activity 1.1.3 Bolt Size and Gauge

Purpose

A customer brings in an old tractor needing repair. The tractor has several seized bolts. After breaking the bolts loose, you identify the bolts as parts to replace. During the repair, you tighten the bolts to industry specifications. How do you ensure that you replaced the bolt correctly? Is the bolt strong enough for the stress applied? The industry identifies bolts by diameter, length, threads, and grades.

Looking through a tractor, you will find both SAE and metric bolts. Figure 1 shows an SAE bolt measured in inches, while Figure 2 is metric. Original Equipment Manufacture or OEMs identify bolts by diameter, threads, and length. The bolt shown in Figure 1 is identified as SAE 5/16" x 18 x 2". The metric bolt in Figure 2 is M5 x 0.8mm x 10mm. Notice that the hex head of each bolt is larger than the shaft. The SAE bolt head is ½," and the metric bolt head is 8mm. Technicians use a *Bolt Identification Process* to identify a bolt.

Bolt Identification Process

1. Quantify the bolt's diameter. Use a dial caliper to measure the width of the bolt, not the head. SAE bolts smaller than ¼" are sized with numbers such as 6, 8, and 10.
2. Measure the threads. Manufacturers quantify SAE threads by the number of threads per inch (TPI) and metric bolts by the pitch, or distance, between threads. Figure 1 shows how to measure one inch of the bolt and count the threads using a dial caliper. For metric bolts, use a dial caliper to measure the distance between two threads, as shown in Figure 2.
3. Size the bolt's length with a dial caliper. Measure from the bolt head's base to the bolt's end, as shown in Figures 1 and 2.

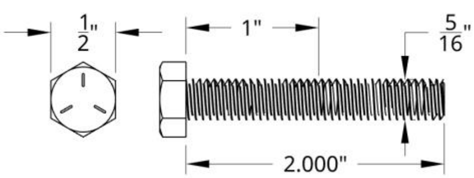


Figure 1. SAE 5/16" x 18 x 2" Bolt

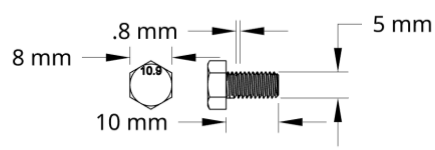
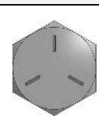


Figure 2. M5 x .8mm x 10mm Bolt

Why do bolts have different threads? The industry categorizes SAE threads as Unified Fine (UNF) or Unified Coarse (UNC) and metric bolts as standard, fine, or extra-fine. Finer thread bolts have a higher tensile strength than coarse threads. The bolt in Figure 1 is coarse. Figure 2 is standard threaded.

You may have noticed different markings on the bolt heads in Figures 1 and 2. Manufacturers mark bolts with raised numbers or dashes to indicate grades. Higher grade bolts can withstand additional stress. Agriculture and construction equipment can place much tension on a bolt. Engineers design equipment using bolts of varying grades to withstand stress. Table 1 summarizes the markings of SAE and metric bolts and their composition.

Table 1. *Bolt Grades*

SAE Grade 2	SAE Grade 5	SAE Grade 8	Metric Grade 8.8	Metric Grade 10.9
 Low carbon steel	 Medium carbon steel, tempered	 Medium carbon alloy steel, tempered	 Medium carbon steel, tempered	 Alloy steel, tempered

How will you identify bolt sizes using markings and a dial caliper?

Materials

Per pair of students:

- Dial caliper 6"/150mm
- *Heavy Equipment Power Trains and Systems* text

Per class:

- (20) Bolts, assorted type, size, threads, and grades

Per student:

- Clipboard
- Pen
- *Agriscience Notebook*

Procedure

Your teacher has arranged 20 bolts across the room. Work with a partner to identify the size and grade of each bolt.

1. Go to the station as directed by your teacher.
2. Examine the markings on top of the first bolt. Record your findings in Table 2 of the *Activity 1.1.3 Student Data* page.
    - Determine if the bolt is SAE or metric.
    - Determine the grade.
3. Use a dial caliper to record the bolt diameter, threads, and length—record in Table 2.
    - Review the process listed in the *Purpose*, as necessary.
4. Record the bolt size in Table 2. Use the diameter x thread x length format.
    - For SAE bolts smaller than ¼", refer to the *US Customary Bolt Sizes* chart on page 901 of your *Heavy Equipment Power Trains and Systems* text.
5. Review the thread sizes listed on pages 900–901 of your text. Record if the bolt is standard, fine, extra-fine, UNC, or UNF in Table 2.
6. Rotate through the remaining bolts as instructed by your teacher. Repeat Steps 2–5 with the remaining bolts.

Conclusion

1. How do you measure the length of the bolt?

2. How can you tell if a bolt is SAE or metric?

3. What is the difference between measuring threads in SAE and metric bolts?

Name____

Activity 1.1.3 Student Data

Table 2. ***Thread Count***

Bolt	SAE or Metric	Grade	Diameter	TPI or Pitch	Length	Size	Thread Type
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							
16							
17							
18							
19							
20							

CASE

Activity 1.1.3 Student Measurements Key

Table 2. ***Thread Count***

Bolt	SAE or Metric	Grade	Diameter	TPI or Pitch	Length	Size	Thread Type
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							
16							
17							
18							
19							
20							

Name____ **CASE**

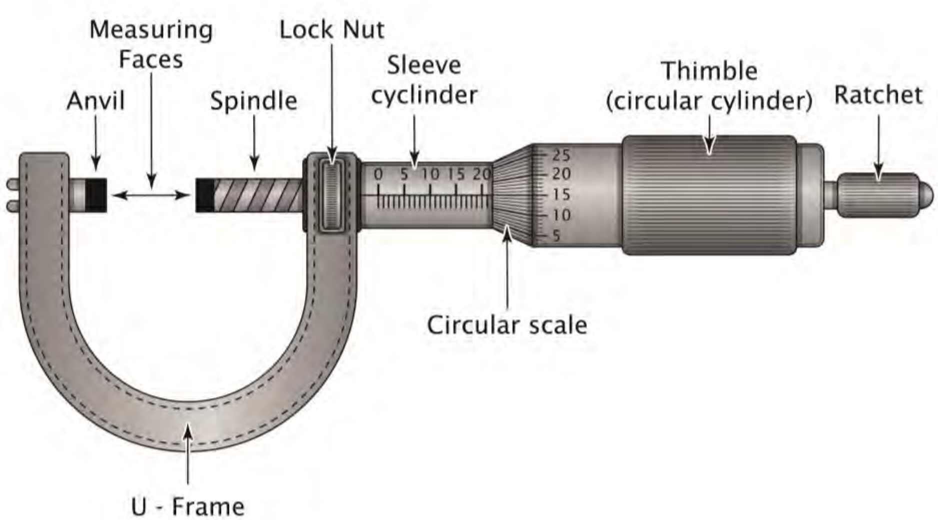
Activity 1.1.4 Mic'd Up

Purpose

OEMs manufacture mechanical components to an exact size. Over time, these components wear and break down, potentially causing mechanical failures. Technicians use precision measurement tools to determine if a component needs replacement. For example, when replacing an axle or bearing, a technician needs to know the precise size of each component to ensure the proper fit. How does a technician make precise measurements?

Technicians use micrometers to measure with accuracy to the nearest ten-thousandth of an inch with a standard micrometer or one-hundredth of a millimeter with a metric micrometer. They measure external dimensions and thicknesses with an outside micrometer. For measuring internal diameters and openings, they use a depth micrometer.

The micrometer components include the sleeve, rotating thimble, and ratchet, as seen in Figure 1. When using the micrometer, the technician rotates the micrometer's thimble until the spindle is near the component they are measuring. Then they use the ratchet for the final adjustment to prevent overtightening the thimble. Overtightening a thimble can cause false readings and affect the micrometer's calibration.



Narasingam/Shutterstock.com

Figure 1. Micrometer Parts

Once a technician has made the measurement and correctly fitted the micrometer to the component, they need to read it and record the measurement. A technician begins by reading the numbers on the sleeve, representing tenths of an inch and each line representing 0.025″. Next, the technician reads the lines on the thimble representing 0.001″. Finally, they find the line on the thimble that aligns with the vernier scale on the sleeve. Each line on the vernier scale represents 0.0001″. Figure 2 shous the vernier scale aligned at 2. A technician adds the four individual readings to find the measurement.

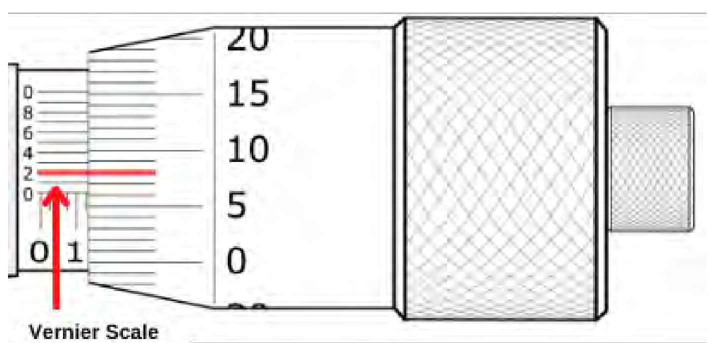


Photo from https://www.stefanelli.eng.br/en/simulator-virtual-micrometer-tenths-thousandth-inch/

Figure 2. Micrometer Reading

How will you make precise measurements with a micrometer?

Materials

Per student:

- Pen
- *Agriscience Notebook*

Per class:

- Depth micrometer
- Inside micrometer
- (15) Machine components
- Outside micrometer, 0–1″
- Outside micrometer, 1–2″
- Outside micrometer, 2–3″

Procedure

Part One – Review and Read

1. View the **micrometer video** (https://www.youtube.com/watch?v=vyT1gC9Ns4c).
2. Go to the **virtual micrometer website** (https://www.stefanelli.eng.br/en/simulator-virtual-micrometer-tenths-thousandth-inch/).
3. Turn the dial of the micrometer until the reading is 0.1428″.
4. Sketch the micrometer on *Activity 1.1.4 Student Measurements*.
5. Repeat steps 3–4 for the following measurements.
    - 0.5250″
    - 0.6891″
    - 0.1001″

Part Two – Component Measurements

1. Review the 15 mechanical components provided to the class.
2. Determine if you should use a depth, external or internal micrometer to measure the labeled part of the component.
3. Record the type of instrument you should use in Table 1.
    - Your teacher will sort the components into five stations based on the tool needed for making the measurement.
4. Go to your assigned station and work with your group to measure the three components. Record the measurements in Table 1.
5. Rotate to the next station when instructed by your teacher.
6. Compare your measurements to your teachers' *Official Measurements*.
    - Circle the correct measurements.
    - Draw a line through the measurements that are lower than the *Official Measurement*.
    - Place an X over the measurements that are lower than the *Official Measurement*.

Conclusion

1. Why do technicians need different types of micrometers?

2. Why does a technician need to use a micrometer instead of a ruler?

3. What factors impact a technician's accuracy when using a micrometer?

Name____

Activity 1.1.4 Student Measurements

0.1428″	**0.5250″**
0.6891″	**0.1001″**

Table 1. ***Component Measurements***

Number	Instrument	Measurement	Number	Instrument	Measurement
1			9		
2			10		
3			11		
4			12		
5			13		
6			14		
7			15		
8					

CASE

Activity 1.1.4 Student Measurements Key

Table 1. ***Component Measurements***

Number	Instrument	Measurement	Number	Instrument	Measurement
1			9		
2			10		
3			11		
4			12		
5			13		
6			14		
7			15		
8					

Name____

CASE

Activity 1.1.5 Universal Connections

Purpose

Tractors power many agricultural implements listed during *Activity 1.1.1 Local Equipment.* How does a tractor transfer power to an implement?

A tractor's power take-off (PTO) is one mechanism for transferring power to agricultural implements. A PTO driveshaft on a tractor is a short shaft with external splines. A universal joint with matching internal splines slides over the PTO driveshaft on the tractor to transfer power to the implement. Most PTO driveshafts are found at the tractor's rear and rotate clockwise at high speeds. PTOs with six splines rotate at 540 rpm, and PTOs with 20 or 21 splines have a speed of 1,000 rpm.

The universal joint connecting the implement's PTO shaft to the driveshaft allows the tractor to transfer power at angles. The universal joint consists of a cross shaft with two Y-shaped yokes connected, as seen at the ends of the driveshaft in Figure 1. Bearings between the cross shaft and yoke reduce the universal joint's friction.

Figure 1. Universal Joints and Shaft

What is the process for disassembling a universal joint? As a technician, what do you need to record when disassembling components for inspection?

Materials

Per pair of students:

- Ball joint service kit
- Ball-pean hammer
- Dial caliper 6″/150mm
- Flat-head screwdriver
- *Heavy Equipment Power Trains and Systems* text
- Markers/pens
- Needle nose pliers
- Paper plate
- Snap ring pliers
- Universal joint
- Universal joint service manual (optional)
- Vise, bench

Per student:

- Safety glasses
- Pen
- *Agriscience Notebook*
- *Logbook*

Per class:

- (2) Grease gun

Procedure

Work with a partner to disassemble a universal joint while documenting the process in your *Logbook*. Put on safety glasses before you begin.

Part One – Disassembly

1. On page 2 of the table of contents, record the activity's title *Universal Connections*, today's date, and the page number you will begin your documentation.
2. Start a new page in your *Logbook* by recording the activity's title, *Universal Connections*.
3. Record the following objective in your *Logbook*.
   - "Inspect the components of a universal joint."
4. Use pages 610–615 of *Heavy Equipment Power Trains and Systems* to draw and label the following parts in your *Logbook*.
   - Yoke
   - Cross shaft
   - Bearing cup
   - Circ clip or snap ring
   - Grease seal
   - Grease zerk
   - Needle bearings
   - Race
5. Put on your safety glasses.
6. Inspect and record the number of splines on the yoke.
   - Use the number of splines to find the rated speed and record it in your *Logbook*.
7. Record a table in your *Logbook* with headers, as seen in Table 1.
   - Add a new row as you complete each step of the disassembly and assembly processes.
   - If available, record the section, page, and figure number from the service manual related to each step as you disassemble the u-joint.

Table 1. *Example Logbook Notes*

Step	Hardware	Tools	Torque or Specification	Service Manual Info.		
				Sec.	Page	Fig.

8. Use a snap-ring pliers, needle-nose pliers, and a flat-head screwdriver to remove the four retaining rings from the universal joint cross.
9. Position the ball joint press around the drive shaft yoke as seen in Figure 2.
   - Remove the grease zerk if needed.
10. Tighten the jackscrew to expose the bearing cup inside of the yoke.
11. Separate the yoke from the cross shaft.
12. Remove the two exposed cups and needle bearings.
13. Repeat Steps 9–12 to remove the other yoke from the cross shaft.
14. Use a dial caliper to measure the outside diameter of each journal on the cross.
15. Record the diameters in your *Logbook*.

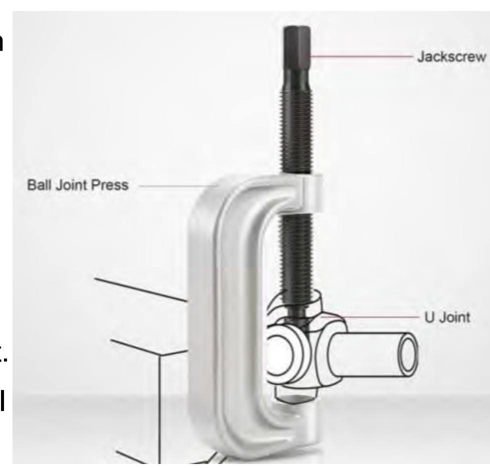


Figure 2. U-Joint Disassembly

16. Answer the analysis questions in your *Logbook*.

Q1 What would you inspect if a customer complains of the universal joint making noise while rotating?
Q2 Why is it important to measure the diameter of the journals on the cross?

Part Two – Assembly

Use the notes recorded in your *Logbook* to assemble the universal joint and record all steps in your *Logbook*. Next, use the grease gun to lubricate the universal joint, as demonstrated by your teacher. Finally, record the amount of grease added to the joint.

Conclusion

1. Why are universal joints an essential component for transferring power to agricultural equipment?
2. Other than connecting a tractor's power take-off to an implement, where else would you find a universal joint?
3. What would cause a universal joint to break? Why?

Name____

CASE

Activity 1.1.6 Combining Chains and Belts

Purpose

Many agricultural implements have drive trains with a complex system of belts, pulleys, and chains transferring power from the energy source to an output. Synchronous drivetrains contain gears, sprockets, and chains transferring power with no slippage between the parts. Gears interlock while a roller chain connects sprockets. In a synchronous drive system, gears or sprockets attached to the drive shaft of an energy input source turns the driven gears or sprockets to do work, which is the output.

Belt drives are nonsynchronous drive systems transferring energy between two or more shafts. A nonsynchronous drive system does not have positive engagements between the parts, which means the components can slip if resistance is greater than the friction between the belt and pulley. Machines require the correct amount of tension between the belt and pulley to function correctly. Belts slip on the pulley if the tension is too loose. Increasing the belt tension increases contact between the belt and the pulley to reduce slippage.

How does a technician find, identify, and replace a drive train component?

Materials

Per student:

- Combination square
- Dial caliper 6″/150mm
- *Heavy Equipment Power Trains and Systems* text
- Safety glasses
- String
- Tape measure, 25′
- *Agriscience Notebook*
- *Logbook*
- Pen

Per class:

- (10) Example equipment with user manual
- (10) Power train components

Procedure

Work with a partner to inspect example power train components. Then identify and inspect components on a piece of equipment. Put on safety glasses before you begin.

Part One – Component Inspection

Work with a partner to identify and measure five power train components provided by your teacher. Record the name of the part, measurements, wear, and maintenance information for each component in Table 2 on *Activity 1.1.6 Student Observations* sheet. Use a dial caliper, combination square, or measuring tape and string to make needed measurements. Refer to Table 1 to ensure you include all measurements.

Table 1. *Measurements and Specifications*

Belt	Pully	Chain	Sprocket
• Width • Depth • Belt Size	• Circumference • Pully diameter • Shaft diameter	• Pitch • Roller diameter • Chain size	• Number of teeth • Pitch • Shaft diameter

Part Three– Drive Train Information

1. Work with a partner to find the following components on the equipment assigned to you.
   - Pulley
   - V-Belt
   - Chain
   - Sprocket
2. Find the name and specifications for each component in the user manual and record them in Table 3.
3. Measure each component and record your measurements in Table 3.
4. Look for wear on each component and compare the measurements to the specifications and sizes when new.
5. Record any evidence of wear in Table 3.
6. Use the manual to determine how to maintain and lubricate each component.
7. Record maintenance information in Table 3.

Conclusion

1. What are the advantages of the chain-driven system?

2. What causes a belt to slip in a drive system?

3. How would a technician determine if a chain has stretched?

Name____

Activity 1.1.6 Student Observations

Table 2. ***Drive Train Components***

Component	Measurements	Wear Evidence	Maintenance

Table 3. ***Drive Train Maintenance***

Component	Name	Specification	Measurements	Wear Evidence	Maintenance
V-Belt					
Chain					
Pulley					
Sprocket					

Name____ **CASE**

Project 1.1.7 Safety Precautions

Purpose

Agricultural equipment presents injury risks due to quick movement and great force. However, if you are familiar with equipment components and safety hazards, you can safely repair and calibrate equipment.

The power source, point of operation, power transmission, and operating controls are fundamental components of most agricultural equipment. Mechanisms within the equipment can produce up to eight different motions and actions that could cause injury. These motions and actions occur in a wide variety of combinations in machines. Guards and shields prevent injuries caused by the movements and actions of the equipment. To be safe, technicians need to be familiar with the motions and guards of a machine.

What are the equipment components, and how can you determine if they are safe?

Materials

Per student:

- Device with internet access
- Presentation software
- Pen
- Safety glasses
- Clipboard
- *Project 1.1.7 Evaluation Rubric*
- (2) *Equipment Safety Checklist*
- *Agriscience Notebook*

Per class:

- Example equipment

Procedure

Complete Part One individually to better understand the hazards and essential safety features found on agricultural equipment. Then complete Parts Two and Three with a partner to analyze agricultural equipment. Put on safety glasses before you begin.

Part One – Actions and Motions

1. Obtain a device with internet access as instructed by your teacher.
2. Use **OSHA's Machine Guarding eTool: Introduction** (https://www.osha.gov/etools/machine-guarding/introductionl) to find the description of each equipment component.
3. Record the component and the description in Table 1 of *Project 1.1.7 Student Research*.
4. Using **OSHA's Machine Guarding eTool: Motions and Actions** (https://www.osha.gov/etools/machine-guarding/introduction/hazardous-motions-actions), identify the equipment motions or actions.
5. Sketch or describe each motion or action and explain its potential hazards in Table 2.
6. Use **OSHA's Machine Guarding eTool: Guards** (https://www.osha.gov/etools/machine-guarding/intuction/guards) to identify the types of guards and the advantages and limitations of each.
7. Record the advantages and limitations of each guard in Table 3.

Part Two – Safety Analysis

1. Obtain a copy of the *Equipment Safety Checklist* from your teacher.
2. Use the *Equipment Safety Checklist* to inspect the example equipment provided by your teacher.
3. Correct or add to your *Equipment Safety Checklist* as your teacher reviews the equipment inspection.
4. Your teacher will assign you and your partner one of the listed *Equipment and Suggested Video* to observe safety concerns.

Equipment and Suggested Video

- **Combine harvester** (www.youtube.com/watch?v=_z1UPnNf8nU)
- **Forage harvester** (www.youtube.com/watch?v=QwzKAaLn1TA)
- **Grain auger** (https://www.youtube.com/watch?v=PQ-ZB6zDz0g)
- **Grain cart** (www.youtube.com/watch?v=_U_JLWjmK6A&list=PLVsrA2gAIr0n1JBKswcJPARrUdpOaERJR)
- **Planter** (www.youtube.com/watch?v=GdLZTbcYpUE)
- **Robotic milker** (www.youtube.com/watch?v=6nWJYYCKnik)
- **Round baler** (www.youtube.com/watch?v=vYTcWhOmER4)
- **Tractor hitch** (www.youtube.com/watch?v=pQGwNXFz8OY)
- **Potato harvester** (https://www.youtube.com/watch?v=R70IQgU8PZQ)
- **Sugar cane harvester** (https://www.youtube.com/watch?v=-Kab9gWIgS8)

5. View the assigned video and analyze the equipment by completing an *Equipment Safety Checklist*.
   - You do not need to enter maintenance recommendations.

Part Three – Presentation

Prepare a presentation to introduce the class to what you learned. The presentation should include the following information and will be evaluated using *Project 1.1.7 Evaluation Rubric*.

- Type of equipment and purpose
- Location of power source, power transmission, operating controls, and points of operation
- Four actions or motions you observed and potential injuries for each
- Two types of guards and their locations

Place a copy of the *Equipment Safety Checklist* in the *Safety* section of your *Agriscience Notebook*.

Conclusion

1. What safety features do agricultural equipment have to protect you from injury?

2. What are the differences and similarities between the agricultural equipment presented?

3. How will you use the *Equipment Safety Checklist* as you complete this course?

Name____

Project 1.1.7 Student Research

Table 1. ***Fundamental Areas of a Machine***

Areas	Description
Point of Operation	
Power Transmission Device	
Operating Controls	

Table 2. ***Motions and Actions***

Motion/Action	Description/Sketch	Hazard

Table 3. ***Machine Guarding***

Guard Type	Advantages	Limitations

Name____

CASE

Project 1.1.7 Evaluation Rubric

Areas with Room for Improvement	Criteria	Areas that Meet or Exceed Expectations
	Equipment Type and Purpose Students describe the type of equipment and purpose, along with a brief overview of how the equipment works.	
	Operating Locations The presentation identifies the locations of power transmission, operating controls, point of operation.	
	Actions and Motions Students locate four different actions or motions and describe how that action or motion could cause injury.	
	Guards The presentation includes examples of two different types of guards found on the equipment.	
	Delivery Effectively and creatively delivers the information while staying on the topic and considering the audience. The group demonstrates all speaking skills, including voice, presence, power of expression, and effect.	
	Visual Aids Neat, accurate, and illustrative representations. All pictures/charts/graphs are clear and distinct. Text is of adequate size and font to read.	
	Participation Each partner completes assigned tasks and participates equally in the presentation.	

Name____

Lesson 1.1 Check for Understanding

1. Why should a technician be aware of local agricultural production?

2. Why do technicians need to record their work in a logbook?

3. How is a dial indicator different than a dial caliper?

4. List three tools used for precision measurements. Describe the application of each.

5. List the size and grade of the metric bolt shown in Figure 1.
    - Bolt Size:
    - Bolt grade:

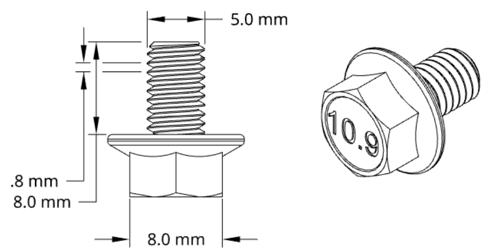


Figure 1. Metric Bolt

6. What is the advantage of using a universal joint to connect a driveshaft to a power take-off?

7. List an example of a synchronous or nonsynchronous drive system.
    - Synchronous -
    - Nonsynchronous -

8. Identify the point of operation and power transmission in Figure 2.
9. Circle three safety hazards in Figure 2.

Figure 2. Safety Hazard Identification

CASE

Lesson 1.1 Check for Understanding Answer Key

1. Why should a technician be aware of local agricultural production?

The equipment maintained by a local technician is specialized for the commodities grown in the area.

2. Why do technicians need to record their work in a logbook?

So technicians have a record of procedures and measurements of components they maintain and repair.

3. How is a dial indicator different than a dial caliper?

A dial indicator can measure the movement of a component while a dial caliper measures size.

4. List three tools used for precision measurements. Describe the application of each.

Answers may include:

Outside micrometer – Measures the outside diameter of machine components to the nearest 0.0001"
Inside micrometer – Measures the inside diameter of machine components to the nearest 0.0001"
Telescoping gauge – Gauges the inside diameter of machine components and measured with an outside micrometer
Depth micrometer – Measures the depth of machine components to the nearest 0.0001"
Dial caliper – Measures the outside diameter, internal diameter, and depth of machine components to the nearest 0.001"
Dial indicator – Measures the movement of a machine component

5. List the size and grade of the metric bolt shown in Figure 1.

- Bolt Size: **M5 x 0.8mm x 8mm**
- Bolt grade: **10.9**

Students may confuse the 8mm head diameter. This signifies the size of the socket required to drive the bolt.

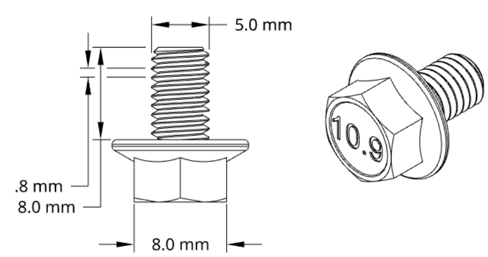


Figure 1. Metric Bolt

6. What is the advantage of using a universal joint to connect a driveshaft to a power take-off?

A universal joint allows power to be transferred at multiple angles instead of restricted to a straight line.

7. List an example of a synchronous or nonsynchronous drive system.

- **Synchronous – chain and sprocket**
- **Nonsynchronous – V-belt and pully**

8. Identify the point of operation and power transmission in Figure 2.
9. Circle three safety hazards in Figure 2.

Figure 2. Safety Hazard Identification

CASE

TAA Logbook Guidelines

General

- Record all entries in pen.
- Write clearly and neatly so others may follow or repeat your work.
- Do not erase, white-out, or otherwise obliterate the entry if you make a mistake. Instead, make a single line through the middle of the text.
- Attach supplemental documents to the appropriate page, such as graphs, charts, and pictures. Pasting with glue is acceptable. Tape and staples are not allowable.
- Do not skip pages in the notebook.
- If a page is only partially used, draw a line through the remainder of the page, sign, and date.
- Avoid abbreviations except for metric units.

Table of Contents

- Record all technical lab/shop activities, projects, or problems in the Table of Contents.
- Include the page number that activity, project, or problem starts on, the date, and the title.

Activities

- Title the top of the first page for an activity.
- Briefly describe the purpose or objective of the activity.
- Record all data tables, measurements, and answers to analysis questions.
- Note any reactions, conditions, or environmental factors influencing the activity results.

Projects and Problems

- Title the top of the first page of a project or problem.
- Briefly describe the purpose or objective of the activity.
- Record all data tables, measurements, and answers to analysis questions.
- Describe the procedures, materials, and quantities used for the project or problem even when following established procedures.
- Include solutions with sketches, criteria, and constraints when applicable.

Name____

CASE

Logbook Evaluation Rubric

Areas with Room for Improvement	Criteria	Areas that Meet or Exceed Expectations
	Organization Student records entry title, start date, and all correct page numbers in the Table of Contents. All entries are written in ink. Writing is clear and neat. No abbreviations beyond metric and English units are used. Graphs, charts, and pictures are directly related to the activity, project, or problem. Printed visuals are securely pasted in.	
	Page Numbering Student numbers every page at the top.	
	Entry Contents The title, description, procedures, materials, quantities, data tables, sketches, and answers to analysis and conclusion questions are recorded in detail when required.	
	Verification Blank space on any page has a slash, date, and signature. Any mistakes have a line drawn through them.	

Name____ CASE

Employability Evaluation Rubric

Areas with Room for Improvement	Criteria	Areas that Meet or Exceed Expectations
	Productivity and Accountability Routinely uses time-management skills to overcome obstacles and complete assigned tasks on time, and to set standards. The student also helps classmates manage time, overcome obstacles, and develop a shared sense of accountability among classmates to deliver work meeting high standards.	
	Initiative and Self Direction Routinely exhibits initiative and self-direction when completing tasks, asking questions as needed, and keeping the teacher informed of progress. Uses knowledge of self-motivation and self-regulation to motivate others and lead by example to complete assigned tasks.	
	Interpersonal Skills Understands teamwork and works well with others while respecting individual differences. Exercises leadership skills to improve team morale and resolves conflicts while still completing the tasks on time.	
	Communication The student communicates verbally and actively listens to classmates and teacher. They comprehend written material and convey written and verbal information in a clear, concise manner.	
	Skill Applications Uses pre-taught reading, writing, and mathematical strategies to complete assigned tasks without teacher assistance. Independently applies scientific and engineering procedures when needed.	
	Equipment Use Uses tools and equipment for their intended purpose using safe procedures and teaches others how to use the equipment.	
	Safety Wears proper PPE and works with classmates to ensure they are always safe. Informs classmates and teachers of near misses and potential accidents.	

Name____

CASE

Equipment Safety Checklist

Equipment Name:

Non-Mechanical Hazards

Is there a potential noise hazard?	**Yes**	**No**	If yes, what PPE is needed?
Does the equipment produce harmful substances?	**Yes**	**No**	If yes, what PPE is needed?

Mechanical Inspection

Power Sources			Power Transmission			Points of Operation		
Place a check by all observed sources:			Place a check by all observed components:			Describe the work observed at the operation points.		
Electrical	☐		Belt and pully	☐				
Mechanical (Power take-off)	☐		Chain and sprocket	☐				
Combustion engine	☐		Gears	☐				
Hydraulic	☐		Hoses	☐				
Pneumatic	☐		Cylinders and rods	☐				
Are all power sources connected properly?	**Yes**	**NO**	Are any power transmission components exposed?	**Yes**	**NO**	Is there point of operation safeguards for the equipment?	**Yes**	**NO**
Are all power sources safeguarded?	**Yes**	**NO**	Do any power transmission components need maintenance?	**Yes**	**NO**	Have safeguards been tampered with or removed?	**Yes**	**NO**
What maintenance do you recommend?			What maintenance do you recommend?			What maintenance do you recommend?		

Mechanical Hazards
Place a check by any motions or actions that are potential hazards for each equipment area. Record the type of guard preventing injury from that action or motion.

Action or Motion	**Power Source**		**Power Transmission**		**Point of Operation**	
		Type of Guard in Place		**Type of Guard in Place**		**Type of Guard in Place**
Rotating	☐		☐		☐	
In-Running Nip Points	☐		☐		☐	
Reciprocating	☐		☐		☐	
Transversing	☐		☐		☐	
Cutting	☐		☐		☐	
Punching	☐		☐		☐	
Shearing	☐		☐		☐	
Bending	☐		☐		☐	

**** Types of guards: Fixed, Interlocked, Adjustable, Self-adjusting***

Hazard Prevention

Where are the operating controls located?
How is the equipment isolated (locked out) from its energy source before a technician performs maintenance?
What hazards should the operator be aware of before using the equipment?
What PPE should an operator wear to prevent injuries from mechanical hazards?

CASE

Curriculum for Agricultural Science Education

Agricultural Equipment Maintenance and Technology

Drive Train Components

Unit 1 – Lesson 1.1 Agricultural Equipment

Belts and pulleys

- Change speed, torque, and direction.
- Equipment and systems include
  - Drive shafts
  - Rollers and rotors
  - Electrical systems
  - Pumps
  - Compressors
  - Conveyors

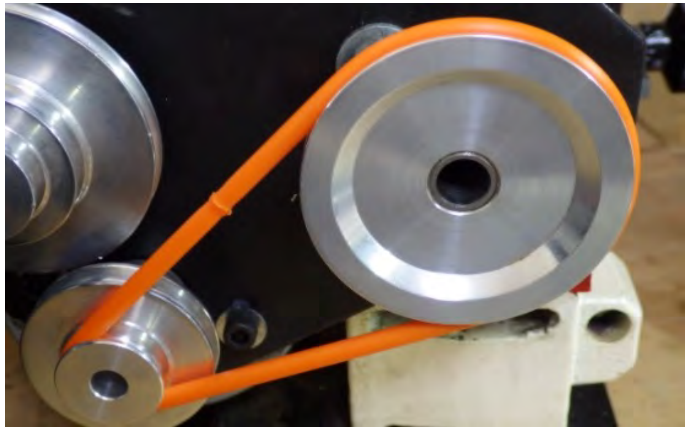
Example Belts and Pulleys

- Round belts
- Flat belts
- Timing belts
- V-belts

Belt Classification

Belts can be classified by their shapes.

- Flat belts consist of a flat strap
- Round belts have a round cross-section
- V Belts have a V shape

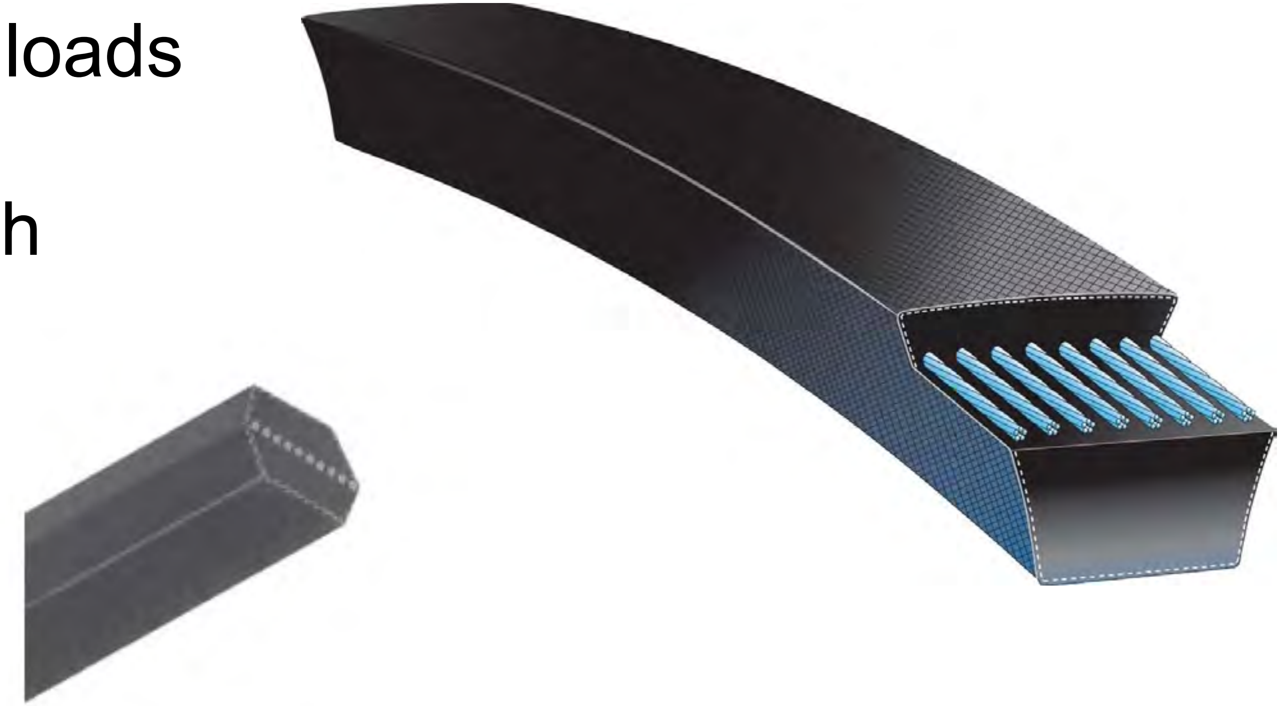


Timing Belts

- Toothed profile mates with grooves.
- Reduces slippage
- Synchronous engagement like a gear or chains.

V belts

- Wedge–shaped cross section.
- Joined V-belts carry higher loads and span greater distance.
- Double V design allows both sides to drive a pulley.



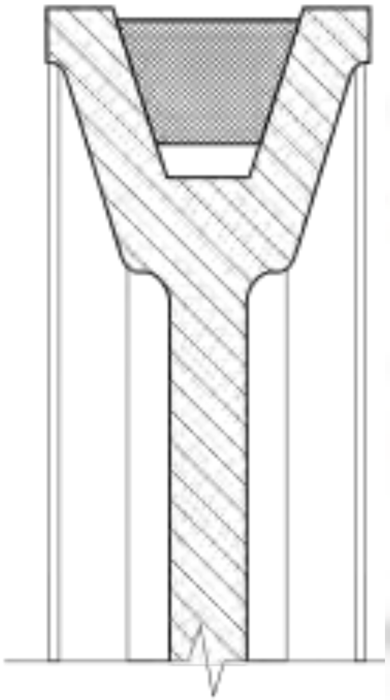
V-Belt Size and Identification

- Measure width and thickness
- Conventional V-belts have a set width and thickness
- Letter and numbers help identify specialty belts
  - H – Heavy Duty
  - L – Lightweight
  - X - Cogged

Conventional Belt Size	Belt Width	Thickness
A	½”	11/32”
B	5/8”	7/16”
C	7/8”	9/16”
D	1 ¼”	¾"
E	1 ½”	1”

Pulleys

- V belt wedge fits into pulley groove
- Fastened to shaft using a key or set screw
- Use a string or flexible tape to find the circumference
- Diameter measured where the belt meets the pulley
  - Find the diameter by dividing the circumference by pi
  - $D = C/\pi$



Belts and Pulley Maintenance

Misalignment

- Belts must be properly tensioned.
- Loose belts slip and can overheat break
- Tight belts stretch and place load on pulleys

Wear

- Worn shafts, pulleys, and bearings cause misalignment
- Misalignment causes wear
- Worn belts or pulleys will not wedge together causing slippage.

Chains and Sprockets

Chains on equipment do the following work:

- Convey product (move material).
- Time components
- Lift weight
- Transfer power

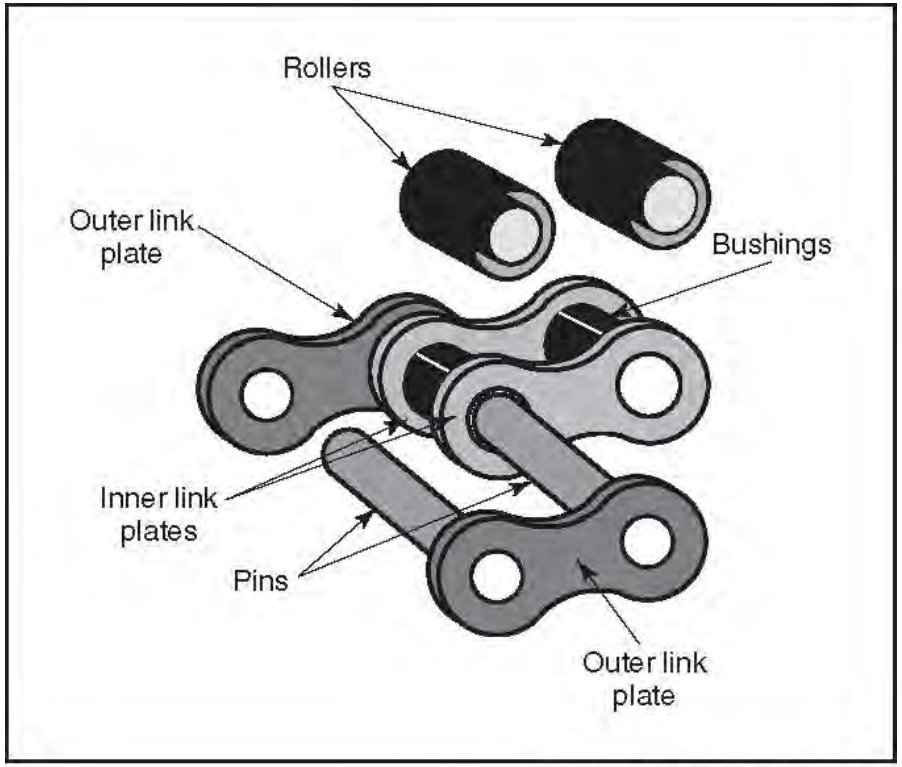
Example chain types

- Roller
- Rollerless
- Silent.
- Detachable link.

Roller Chain

A roller chain consists of the following components:

- Two inner link plates
- Two outer link plates (sidebars)
- Two bushings (sleeves)
- Two rollers
- Two pins



Chain Pitch

Distance from the center of one pin to the center of the next pin.

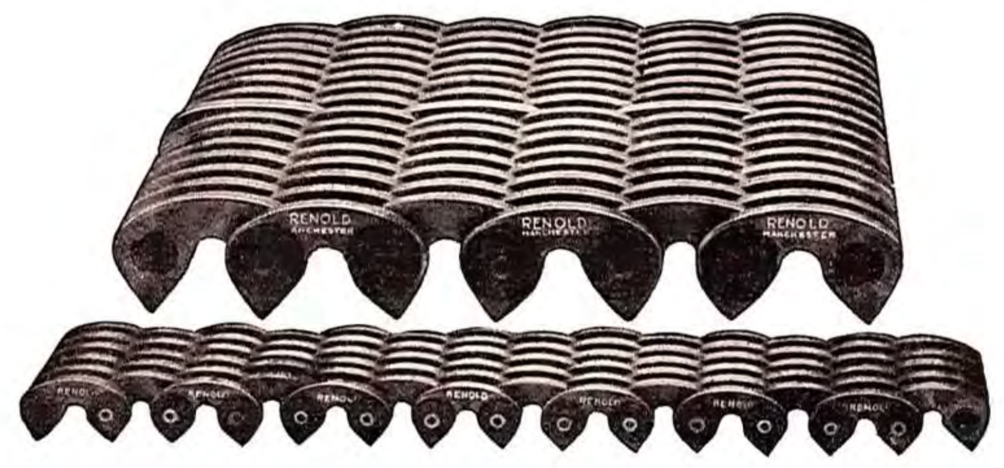
ANSI Roller Chain Sizes			
Chain Size	Pitch	Distance between Inner Link Plates, or Roller Width	Roller Diameter
40	0.5″ (12.7 mm)	0.313″ [5/16″] (7.950 mm)	0.312″ (7.92 mm)
50	0.625″ (15.875 mm)	0.376″ [3/8″] (9.550 mm)	0.4″ (10.160 mm)
60	0.75″ (19.050 mm)	0.5″ [1/2″] (12.700 mm)	0.469″ (11.910 mm)
80	1.0″ (25.4 mm)	0.626″ [5/8″] (15.900 mm)	0.625″ (15.880 mm)
100	1.25″ (31.750 mm)	0.754″ [3/4″] (19.150 mm)	0.75″ (19.050 mm)
120	1.5″ (38.100 mm)	1.006″ [1″] (25.550 mm)	0.875″ (22.230 mm)
140	1.75″ (44.450 mm)	1.004″ [1″] (25.500 mm)	1″ (25.400 mm)
160	2″ (50.800 mm)	1.25″ [1 1/4″] (31.750 mm)	1.125″ (28.580 mm)
180	2 1/4″ (57.150 mm)	1.406″ [1 13/32″] (35.710 mm)	1.406″ (35.710 mm)
200	2 1/2″ (63.500 mm)	1.50″ [1 1/2″] (38.100 mm)	1.562″ (39.680 mm)
240	3″ (76.200 mm)	1.89″ [1 7/8″] (48.00 mm)	1.875″ (47.630 mm)

Rollerless

Rollerless chain has the same appearance as roller chain, except it is missing the rollers.

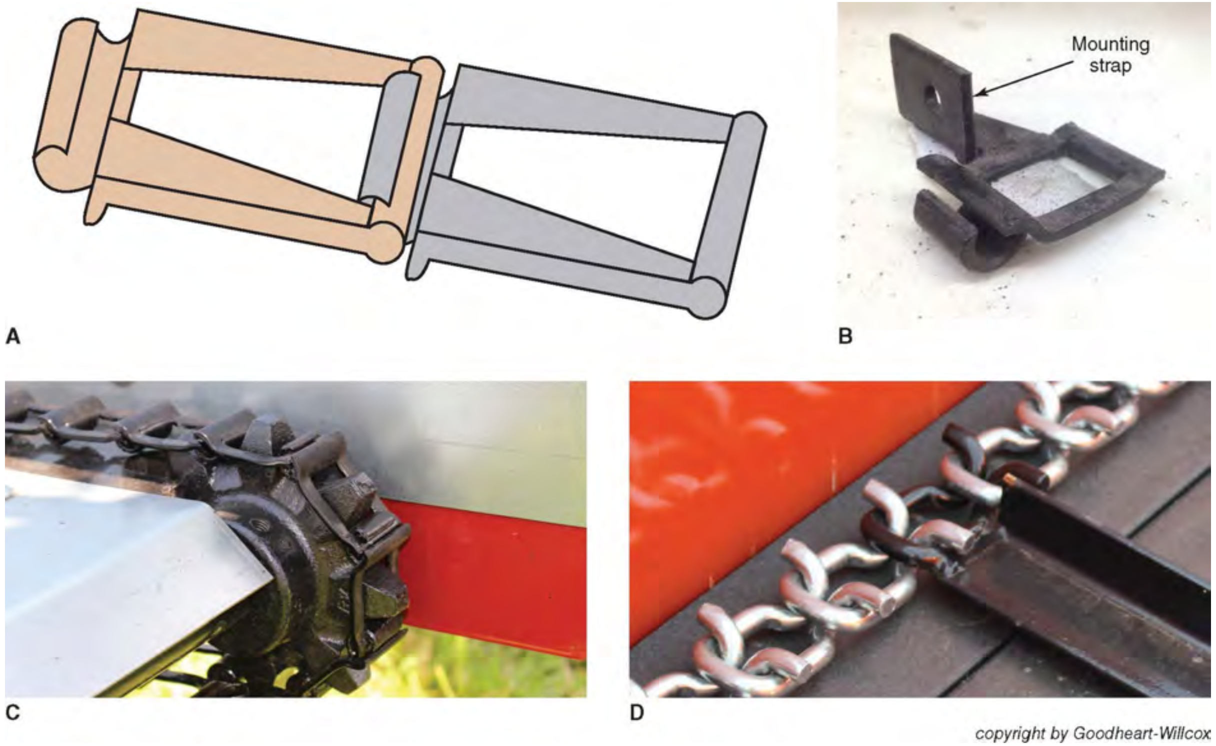
Silent Chain

- Link plates assembled with pins
- Used for timing chains



Detachable Link

- Low speed, low torque applications
- Driven in one direction



Sprockets

- Types
  - Driven, drive, idler
- Pitch circumference
  - teeth x pitch
  - 10 teeth x 1″ = 10″
- Pitch diameter
  - Pitch circumference/π
  - 10″/π = 3.18″
- Thickness

Chains and Sprocket Maintenance

Maintenance

- Chain lubrication
- Sprocket alignment
- Chain tension
  - Slight deflection on the slack side

Wear

- Poor lubrication causes metal to wear
- Worn shafts, sprockets, and bearings cause misalignment
- Chains will stretch and become loose over time

Presentation Review

- Mark or highlight three key points
- List two ideas or concepts related to previous knowledge.
- List questions you have about this topic.
- Keep notes organized and available for use throughout the course.

References

- Dell, Timothy W. (2019). *Heavy equipment power trains and system, 1st edition.* Tinely Park, IL: The Goodheart-Willcox Company, Inc.

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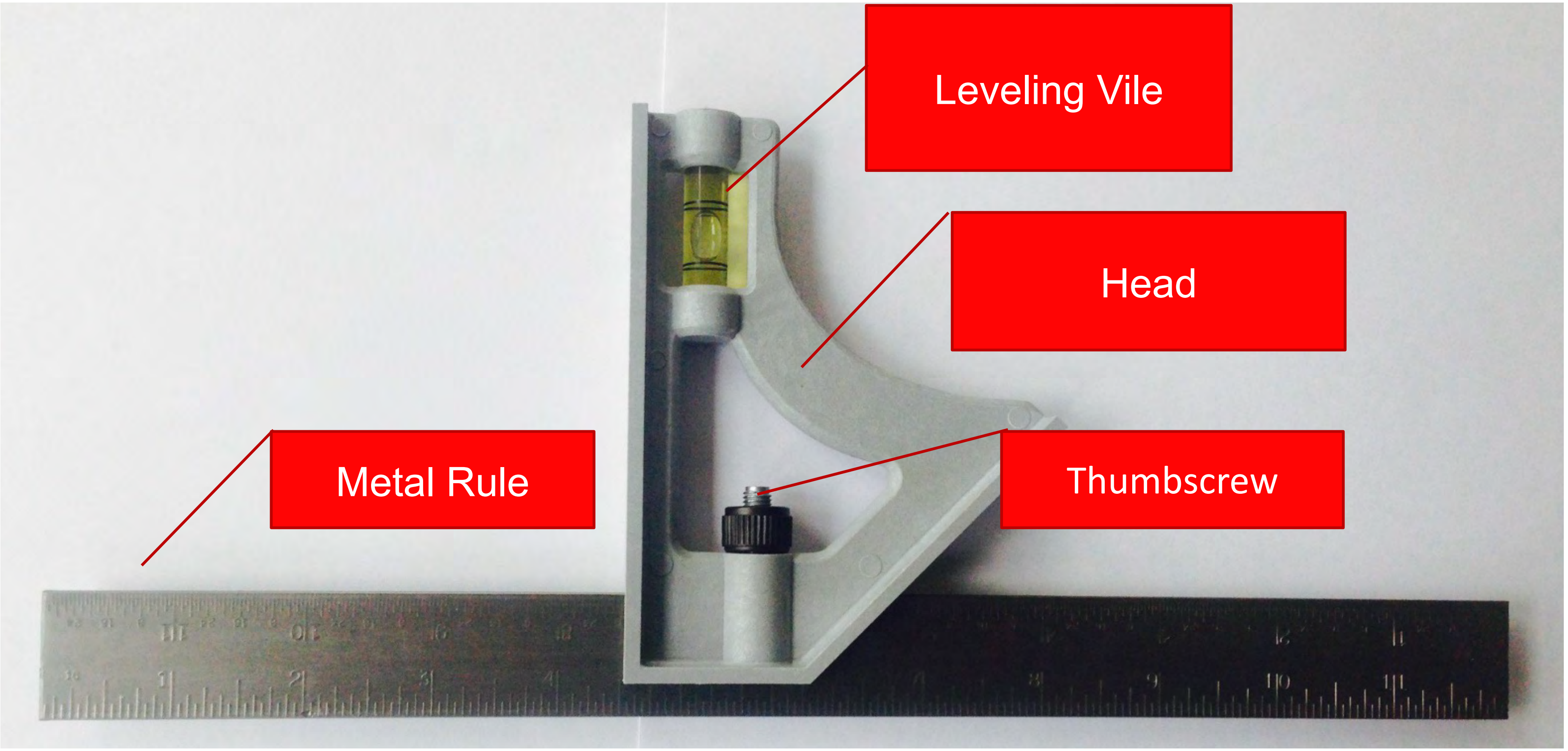
Curriculum for Agricultural Science Education

Agricultural Equipment Maintenance and Technology

Measurement Tools

Unit 1 – Lesson 1.1 Agricultural Equipment

Parts of a Combination Square



Combination Square

- 12″ metal rule that has an accuracy of 1/8″ - 1/16″.
- Sliding head can be locked along the rule with thumb screw.
- Used to lay out 90° and 45° angles.
- Used as a marking gauge by holding the head flush against material.

45° angle

90° angle

Caliper

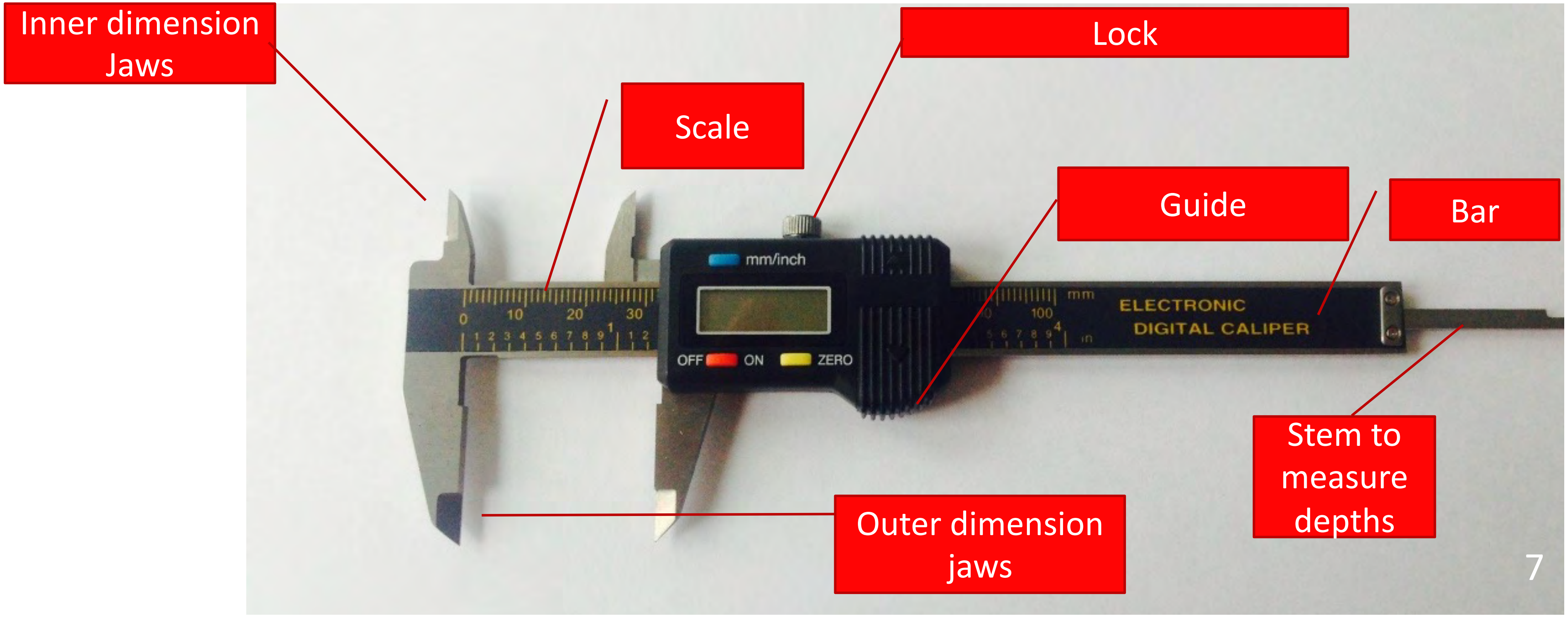
- Measure the inside or outside dimensions of an object between the jaws.
- Has a stem to measure the depth of an object.
- Used when a high degree of accuracy is needed.
- English or metric units.
  - Nearest 1/100″ or 1/1000″
  - Nearest 1/100mm

Types of Calipers

Digital Caliper

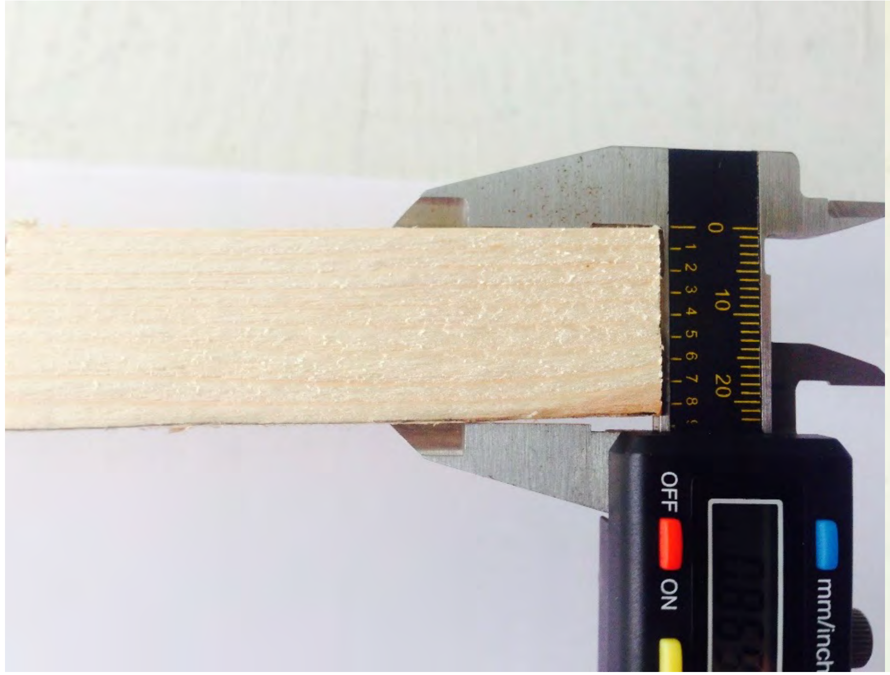
Dial Caliper

Parts of a Caliper



Jaw Placement

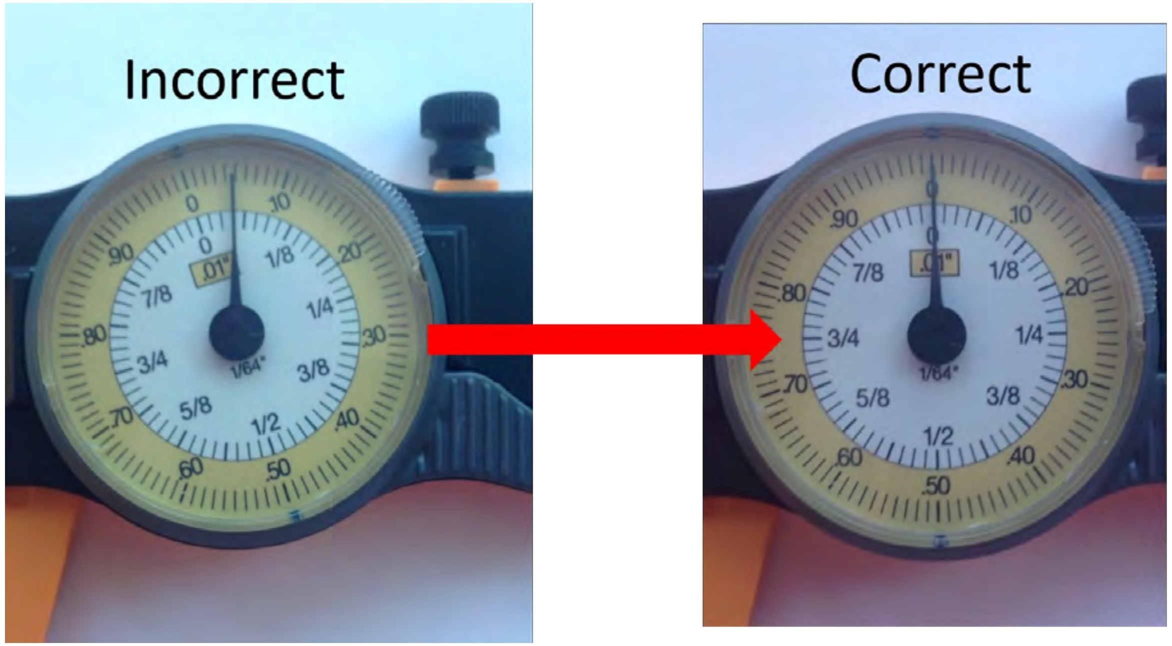
Outer Dimension



Inner Dimension

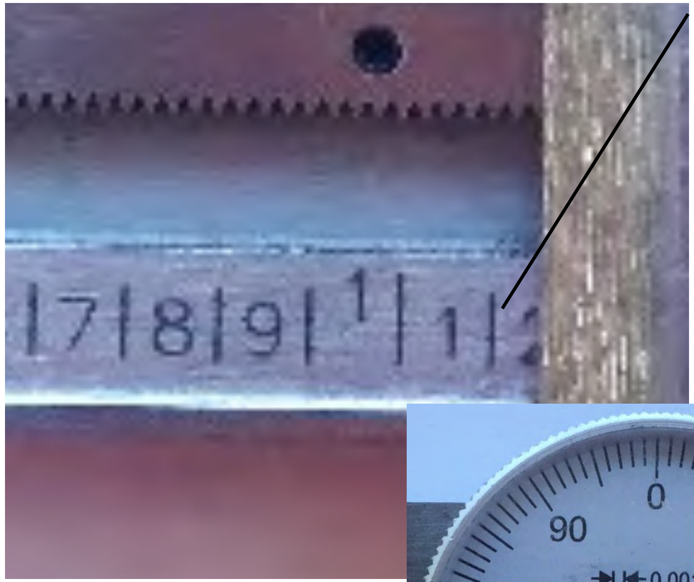
Reading a Dial Caliper

- Calibrate the caliper by turning the dial so the needle is aligned with the zero on the gauge when the jaws are closed.

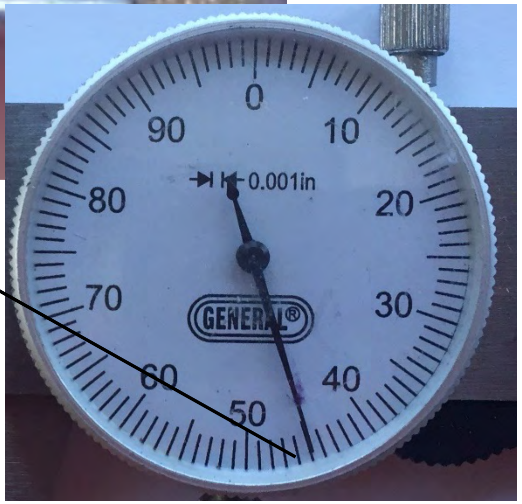


Reading a Dial Caliper

- Read the total number of inches and tenths visible using the scale on the bar.
- Read the hundredths and thousandths of an inch on the dial.
- Add the total together
  - 1.1 inch + 0.0.45 inch
  - 1.145 inches



1.1″



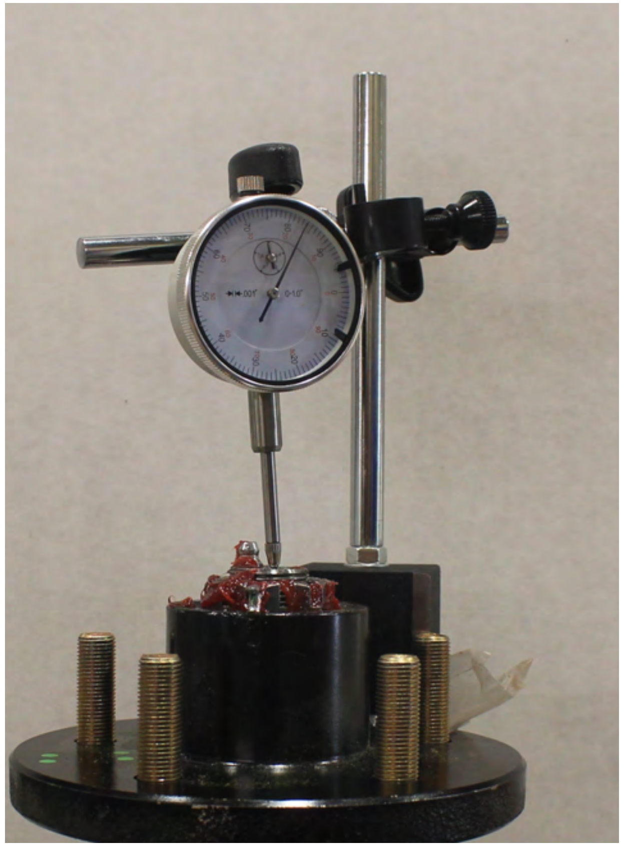
0.045″

Dial Indicators

- Measure travel or movement, including runout, endplay and backlash.
- Normal range of 1 inch.
- A standard dial indicator measures in thousandths of an inch (0.001″).
- Use a magnetic base or clamp to mount to a fixture.

Dial Indicator Procedure

1. Turn on magnetic base to connect to fixed location.
2. Place the plunger on the component you want to measure.
3. Move the component and record the maximum and minimum measurement on the dial indicator
4. Find the reading by subtracting the difference between the maximum and minimum.



Torque Wrench

Units

- Inch-pounds (in-lb)
- Foot-pounds (ft-lb)
- Newton – meters (N-m)

Using a Torque Wrench

Beam Torque Wrench

- Use to tighten bolts, not loosen.
- Calibrate to read zero with no torque applied.
- Use a slow, steady motion to tighten the bolt.
- Stop tightening once the flexible beam is pointing to the desired torque.

Click Torque Wrench

- Use to tighten bolts, not loosen.
- Set to the desired setting.
- Use a slow, steady motion to tighten the bolt.
- Stop tightening when the torque wrench clicks.

Presentation Review

- Mark or highlight three key points
- List two ideas or concepts related to previous knowledge.
- List questions you have about this topic.
- Keep notes organized and available for use throughout the course.

References

Ryan, V. (2009). *The digital caliper*. Retrieved from **http://www.technologystudent.com/e quip1/vernier1.htm**

CASE

Lesson 1.2 Technician Expectations

Preface

Technicians are in high demand in the agricultural equipment industry. They have the technical skills and mechanical knowledge to diagnose and repair agricultural equipment. Moreover, they are also required to have strong interpersonal and technical writing skills for employment. These skills allow dealerships to confidently employ a technician who will efficiently diagnose failures, show up to work daily, and communicate services to customers.

Technicians diagnose agricultural equipment using a standard diagnostic process. During the diagnostic process, technicians use the Five Whys method to define component failure symptoms further to isolate the root cause of a breakdown. A manufacturer's service manual helps guide the diagnostic and repair process. Technicians create picklists to communicate needed equipment that becomes part of a work/repair order. The Work/Repair Order is a document that lists the services rendered to the service desk for billing and further communication with the customer.

In this lesson, students visit an agricultural equipment dealer to observe a technician diagnose agricultural equipment and learn about technicians' interpersonal skills during the field experience. Then students learn the fundamentals of using a digital multimeter and work towards certification. They apply the diagnostic process to find the root cause of component failures. Finally, students complete a Work/Repair Order for a universal joint repair.

Concepts	**Performance Objectives**
Students will know and understand	*Students will learn concepts by doing*
1. Technicians follow a standard diagnostic procedure to inspect a problem, make repairs, and verify operation.	• Identify the parts of the six-step diagnostic process during a guest technician presentation. (Activity 1.2.1)
2. Agricultural equipment dealers prefer technicians with strong interpersonal skills.	• Identify interpersonal skills desired by ag equipment dealers. (Activity 1.2.1)
3. Technicians use digital service procedure manuals to diagnose and repair equipment.	• Create a picklist for equipment repair using a digital service manual. (Activity 1.2.2)
4. Technicians use a digital multimeter to diagnose and repair electrical systems.	• Test for voltage, resistance, and continuity in an electrical component using a digital multimeter. (Activity 1.2.3)
5. Technicians utilize written reports, such as work/repair orders, to communicate services provided to a customer.	• Write a work/repair order using technical writing. (Project 1.2.4) • Write a work/repair order for a universal joint repair. (Project 1.2.5)
6. Component failure analysis allows technicians to analyze root cause failures.	• Diagnose a failed universal joint and identify the root cause using the Five Whys method. (Project 1.2.5)
7. Technicians use service manuals to perform diagnostics and repairs on agricultural equipment, leading to a longer life in powertrain systems and reducing operation costs.	• Repair a universal joint and identify steps to verify operation using a manufacturer's service manual. (Project 1.2.5)

National AFNR Common Career Technical Core Standards Alignment

Career Ready Practices

1. Act as a responsible and contributing citizen and employee.

- CRP.01.01: Model personal responsibility in the workplace and community.
- CRP.01.02: Evaluate and consider the near-term and long-term impacts of personal and professional decisions on employers and community before taking action.

2. Apply appropriate academic and technical skills.

- CRP.02.01: Use strategic thinking to connect and apply academic learning, knowledge, and skills to solve problems in the workplace and community.
- CRP.02.02: Use strategic thinking to connect and apply technical concepts to solve problems in the workplace and community.

4. Communicate clearly, effectively and with reason.

- CRP.04.02: Produce clear, reasoned and coherent written and visual communication in formal and informal settings.

6. Demonstrate creativity and innovation.

- CRP.06.01: Synthesize information, knowledge, and experience to generate original ideas and challenge assumptions in the workplace and community.
- CRP.06.02: Assess a variety of workplace and community situations to identify ways to add value and improve the efficiency of processes and procedures.

8. Utilize critical thinking to make sense of problems and persevere in solving them.

- CRP.08.02: Investigate, prioritize, and select solutions to solve problems in the workplace and community.

9. Model integrity, ethical leadership, and effective management.

- CRP.09.01: Model characteristics of ethical and effective leaders in the workplace and community (e.g. integrity, self-awareness, self-regulation, etc.).
- CRP.09.02: Implement personal management skills to function effectively and efficiently in the workplace (e.g., time management, planning, prioritizing, etc.).

10. Plan education and career path aligned to personal goals.

- CRP.10.03: Develop relationships with and assimilate input and/or advice from experts (e.g., counselors, mentors, etc.) to plan career and personal goals in a chosen career area.

11. Use technology to enhance productivity.

- CRP.11.01: Research, select and use new technologies, tools, and applications to maximize productivity in the workplace and community.

Agriculture, Food, and Natural Resources Career Cluster

2. Evaluate the nature and scope of the Agriculture, Food & Natural Resources Career Cluster and the role agriculture, food and natural resources (AFNR) play in society and the economy.

- AG 2.1: Examine company performance and goals within AFNR organizations and the AFNR industry.
- AG 2.3: Explain the types of industries, organizations, and activities part of AFNR.

5. Describe career opportunities and means to achieve those opportunities in each of the AFNR career pathways.

- AG.5.1: Locate and identify career opportunities that appeal to personal career goals.

Agribusiness Systems Career Pathway (AG-BIZ)

2. Use record keeping to accomplish AFNR business objectives, manage budgets and comply with laws and regulations.

- AG-BIZ 2.2: Prepare and maintain all files as needed for effective record keeping practices.

Power, Structural and Technical (AG-PST)

2. Operate and maintain mechanical equipment related to AFNR power, structural, and technical systems.

- AG-PST 2.1: Maintain machinery and equipment by performing scheduled service routines.
- AG-PST 2.2: Perform service routines to maintain power units and equipment.
- AG-PST 2.3: Operate machinery and equipment while observing all safety precautions.

3. Service and repair mechanical equipment and power systems used in AFNR power, structural and technical systems.
• AG-PST 3.2: Service and repair power transmission systems following manufacturer's guidelines.

Next Generation Science Standards Alignment

Disciplinary Core Ideas	
Physical Science	
PS2: Motion and Stability: Forces and Interactions	
PS2.A: Forces and Motion	• Newton's second law accurately predicts changes in the motion of macroscopic objects. • Momentum is defined for a particular frame of reference; it is the mass times the velocity of the object. In any system, total momentum is always conserved. • If a system interacts with objects outside itself, the total momentum of the system can change; however, any such change is balanced by changes in the momentum of objects outside the system.
Engineering, Technology, and the Application of Science	
ETS1: Engineering Design	
ETS1.A: Defining and Delimiting Engineering Problems	• Criteria and constraints also include satisfying any requirements set by society, such as taking issues of risk mitigation into account, and they should be quantified to the extent possible and stated in such a way that one can tell if a given design meets them. • Humanity faces major global challenges today, such as the need for supplies of clean water and food or for energy sources that minimize pollution, which can be addressed through engineering. These global challenges also may have manifestations in local communities.
ETS1.B: Developing Possible Solutions	• When evaluating solutions, it is important to take into account a range of constraints including cost, safety, reliability and aesthetics and to consider social, cultural and environmental impacts. • Both physical models and computers can be used in various ways to aid in the engineering design process. Computers are useful for a variety of purposes, such as running simulations to test different ways of solving a problem or to see which one is most efficient or economical; and in making a persuasive presentation to a client about how a given design will meet his or her needs.

Science and Engineering Practices	
Asking Questions and Defining Problems	Asking questions and defining problems in 9–12 builds on K–8 experiences and progresses to formulating, refining, and evaluating empirically testable questions and design problems using models and simulations. • Ask questions that arise from careful observation of phenomena, or unexpected results · to clarify and/or seek additional information. · that arise from examining models or a theory, to clarify and/or seek additional information and relationships. · to determine relationships, including quantitative relationships, between independent and dependent variables. · to clarify and refine a model, an explanation, or an engineering problem. • Evaluate a question to determine if it is testable and relevant. • Ask questions that can be investigated within the scope of the school laboratory, research facilities, or field (e.g., outdoor environment) with available resources and, when appropriate, frame a hypothesis based on a model or theory. • Ask and/or evaluate questions that challenge the premise(s) of an argument, the interpretation of a data set, or the suitability of a design. • Define a design problem that involves the development of a process or system with interacting components and criteria and constraints that may include social, technical and/or environmental considerations.
Planning and Carrying Out Investigations	Planning and carrying out investigations in 9-12 builds on K-8 experiences and progresses to include investigations that provide evidence for and test conceptual, mathematical, physical, and empirical models. • Plan an investigation or test a design individually and collaboratively to produce data to serve as the basis for evidence as part of building and revising models, supporting explanations for phenomena, or testing solutions to problems. Consider possible confounding variables or effects and evaluate the investigation's design to ensure variables are controlled. • Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly. • Plan and conduct an investigation or test a design solution in a safe and ethical manner including considerations of environmental, social, and personal impacts. • Select appropriate tools to collect, record, analyze, and evaluate data.

	• Make directional hypotheses that specify what happens to a dependent variable when an independent variable is manipulated. • Manipulate variables and collect data about a complex model of a proposed process or system to identify failure points or improve performance relative to criteria for success or other variables.
Analyzing and Interpreting Data	Analyzing data in 9–12 builds on K–8 experiences and progresses to introducing more detailed statistical analysis, the comparison of data sets for consistency, and the use of models to generate and analyze data. • Analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in order to make valid and reliable scientific claims or determine an optimal design solution. • Apply concepts of statistics and probability (including determining function fits to data, slope, intercept, and correlation coefficient for linear fits) to scientific and engineering questions and problems, using digital tools when feasible. • Consider limitations of data analysis (e.g., measurement error, sample selection) when analyzing and interpreting data. • Compare and contrast various types of data sets (e.g., self-generated, archival) to examine consistency of measurements and observations. • Evaluate the impact of new data on a working explanation and/or model of a proposed process or system. • Analyze data to identify design features or characteristics of the components of a proposed process or system to optimize it relative to criteria for success.
Obtaining, Evaluating, and Communicating Information	Obtaining, evaluating, and communicating information in 9–12 builds on K–8 experiences and progresses to evaluating the validity and reliability of the claims, methods, and designs. • Critically read scientific literature adapted for classroom use to determine the central ideas or conclusions and/or to obtain scientific and/or technical information to summarize complex evidence, concepts, processes, or information presented in a text by paraphrasing them in simpler but still accurate terms. • Compare, integrate and evaluate sources of information presented in different media or formats (e.g., visually, quantitatively) as well as in words in order to address a scientific question or solve a problem. • Gather, read, and evaluate scientific and/or technical information from multiple authoritative sources, assessing the evidence and usefulness of each source. • Evaluate the validity and reliability of and/or synthesize multiple claims, methods, and/or designs that appear in scientific and technical texts or media reports, verifying the data when possible. • Communicate scientific and/or technical information or ideas (e.g. about phenomena and/or the process of development and the design and performance of a proposed process or system) in multiple formats (including orally, graphically, textually, and mathematically).

Crosscutting Concepts	
Cause and Effect: Mechanism and Prediction	Events have causes, sometimes simple, sometimes multifaceted. Deciphering causal relationships, and the mechanisms by which they are mediated, is a major activity of science and engineering.
	• Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. • Cause and effect relationships can be suggested and predicted for complex natural and human designed systems by examining what is known about smaller scale mechanisms within the system. • Systems can be designed to cause a desired effect. • Changes in systems may have various causes that may not have equal effects.

Common Core State Standards for English Language Arts

CCSS: English Language Arts Standards » Science & Technical Subjects » Grade 11-12	
Key Ideas and Details	• **RST.11-12.1 –** Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account. • **RST.11-12.2 –** Determine the central ideas or conclusions of a text; summarize complex concepts, processes, or information presented in a text by paraphrasing them in simpler but still accurate terms. • **RST.11-12.3 –** Follow precisely a complex multistep procedure when carrying out experiments, taking measurements, or performing technical tasks; analyze the specific results based on explanations in the text.
Craft and Structure	• **RST.11-12.4 –** Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to grades 11-12 texts and topics.

	• **RST.11-12.5 –** Analyze how the text structures information or ideas into categories or hierarchies, demonstrating understanding of the information or ideas. • **RST.11-12.6 –** Analyze the author's purpose in providing an explanation, describing a procedure, or discussing an experiment in a text, identifying important issues that remain unresolved.
Integration of Knowledge and Ideas	• **RST.11-12.7 –** Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem. • **RST.11-12.8 –** Evaluate the hypotheses, data, analysis, and conclusions in a science or technical text, verifying the data when possible and corroborating or challenging conclusions with other sources of information. • **RST.11-12.9 –** Synthesize information from a range of sources (e.g., texts, experiments, simulations) into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible.
Range of Reading and Level of Text Complexity	• **RST.11-12.10 –** By the end of grade 12, read and comprehend science/technical texts in the grades 11-CCR text complexity band independently and proficiently.

CCSS: English Language Arts Standards » Writing » Grade 11-12	
Text Types and Purposes	**WHST.11-12.1 –** Write arguments focused on discipline-specific content. • **WHST.11-12.1.C –** Use words, phrases, and clauses as well as varied syntax to link the major sections of the text, create cohesion, and clarify the relationships between claim(s) and reasons, between reasons and evidence, and between claim(s) and counterclaims.
Production and Distribution of Writing	• **WHST.11-12.6 –** Use technology, including the internet, to produce, publish, and update individual or shared writing products in response to ongoing feedback, including new arguments or information.
Research to Build and Present Knowledge	• **WHST.11-12.8 –** Gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively; assess the strengths and limitations of each source in terms of the specific task, purpose, and audience; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and overreliance on any one source and following a standard format for citation.

Essential Questions

1. How do technicians diagnose failures in agricultural equipment?
2. What interpersonal skills do technicians need?
3. How are reference numbers used in illustrated parts manuals?
4. What are the advantages of a digital service manual?
5. Why is the work/repair order a critical component of a technician's job?
6. How does a technician communicate services to a customer?
7. How can a technician use a digital multimeter to test electrical circuits?
8. How does questioning help diagnose the root cause?
9. How does a service manual help a technician find the cause, correct the problem, and confirm the repair?

Key Terms

Aftermarket	**Ampere (Amp)**	**Cause**
Circ cup	**Closed circuit**	**Confirm**
Continuity	**Complaint**	**Components**
Component failure	**Current**	**Diagnostic process**
Digital multimeter	**Five Whys**	**Illustrated parts list**
Interpersonal skills	**Key part**	**Needle roller bearing**

Original Equipment Manufacturer (OEM)	**Ohm**	**Ohm's Law**
Open circuit	**Part number**	**Pick List**
Qualified person	**Reference number**	**Resistance**
Root cause	**Service desk**	**Service manuals**
Snap ring	**Symptom**	**Volt**
Work/Repair Order		

Day-to-Day Plans
Time: 10 days

*Refer to the Teacher Resources section for specific information on teaching this lesson, in particular **Lesson 1.2 Teacher Notes**, **Lesson 1.2 Glossary**, **Lesson 1.2 Materials**, and other support documents.*

Day 1:

- Present **Concepts**, **Performance Objectives**, **Essential Questions**, and **Key Terms** to provide a lesson overview.
- Provide the local dealership with copies of the **Activity 1.2.1 Presenter Checklist**.
- Provide students with a copy of **Activity 1.2.1 Field Experience** and **Employability Evaluation Rubric**.
- Students individually complete Part One and Part Two of *Activity 1.2.1 Field Experience* during a field trip to a local agriculture equipment dealer.
- Students answer Part Three analysis questions in their *Logbook*.
- Evaluate student behavior and work using the *Employability Evaluation Rubric*.

Day 2:

- Provide students with a copy of **Activity 1.2.2 Digital Navigation** and **PowerPortal** access.
- Students work individually to complete *Activity 1.2.1 Digital Navigation* and submit a pick list from the PowerPortal.

Day 3:

- Provide students with a copy of **Activity 1.2.3 Digital Multimeter Operation**.
- Students sign up and enroll at **Fluke** for the *Digital Multimeter Basics* course.
- Students work individually to complete the *Course Introduction* and *Lesson 1: Multimeter Orientation*.
- Students work individually to begin *Lesson 2: Around the Dial*.
- Students work in pairs to complete *Activity 1.2.3 Digital Multimeter Operation* using a digital multimeter.

Day 4:

- Students continue working individually on the *Fluke Digital Multimeter Basics* course and complete *Lesson 2: Around the Dial*.
- Students work in groups to complete *Activity 1.2.3 Digital Multimeter Operation* using a digital multimeter.
- **Homework:** Student complete *Fluke Digital Multimeter Basics* Lessons 3-6 to complete their certification.

Day 5:

- Provide students **Presentation Notes** pages to use throughout the presentation Students record notes and add these pages to their *Agriscience Notebook*.
- Present PowerPoint® **Completing an Order**.

- Provide students with a copy of **Project 1.2.4 Communicating Services**, **Work/Repair Order Template**, and the **Work/Repair Order Rubric.**
- Students work in a group to complete Parts One and Two of *Activity 1.2.4 Communicating Services*.
- Assign each group a workstation with a **Project 1.2.4 Complaint Card** and broken pump.

Day 6:

- Students work individually to complete Parts Three and Four of *Activity 1.2.4 Communicating Services*.
- Evaluate student *Work/Repair Orders* using the *Work/Repair Order Rubric*.

Days 7 – 9:

- Provide students with a copy of **Project 1.2.5 The Five Whys**, a *Service Manual*, the *Work/Repair Order Template*, and the *Work/Repair Order Rubric*.
- Students work in pairs to identify a component failure in a universal joint, then correct and confirm the repair of the universal joint.
- Students work individually to complete a *Work/Repair Order Template*.
- Evaluate student work/repair orders using the *Work/Repair Order Rubric*.

Day 10:

- Distribute **Lesson 1.2 Check for Understanding**.
- Students complete *Lesson 1.2 Check for Understanding* and submit for evaluation.
- Use **Lesson 1.2 Check for Understanding Key** to evaluate student assessments.

Instructional Resources

PowerPoint® Presentations

Completing an Order

Student Support Documents

Lesson 1.2 Glossary

Presentation Notes

Activity 1.2.1 Field Experience

Activity 1.2.2 Digital Navigation

Activity 1.2.3 Digital Multimeter Operation

Project 1.2.4 Communicating Services

Project 1.2.5 The Five Whys

Teacher Resources

Lesson 1.2 Technician Expectations PDF

Project 1.2.4 Complaint Cards

Activity 1.2.1 Presenter Checklist

Lesson 1.2 Teacher Notes

Lesson 1.2 Materials

Lesson 1.2 Check for Understanding

Answer Keys and Assessment Rubrics

Lesson 1.2 Check for Understanding Answer Key

Employability Evaluation Rubric

Work/Repair Order Evaluation Rubric

Student Project Development Template

Work/Repair Order Template

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FFA Connections

This lesson provides conceptual and procedural knowledge required for participation in the following FFA activities:

- Agricultural Proficiency
  - **Agricultural Mechanics Repair and Maintenance –Placement**
  - **Agricultural Mechanics Repair and Maintenance –Entrepreneurship**
- Agriscience Fair
  - **Power, Structural and Technical Systems**
- Career Development Events
  - **Agricultural Technology & Mechanical Systems**
- Educational Resources
  - **SAE Idea Cards-Power, Structural and Technical Systems**
  - **Power, Structural and Technical System Careers**
  - **Power, Structural and Technical Systems Career Focus Area Resources**
  - Agricultural Mechanics (**Word)** (**PDF**)
  - Keegan Humm-SAE-Placement-Implement Dealership Lesson Plan (**Word**) (**PDF**)
  - Power, Structural and Technical Careers **(Word)**

Skills and knowledge from this lesson support the development and implementation of service-learning projects that address technician expectations.

- **Service-Learning and Living to Serve Grants**
- Service-learning projects focused on diagnosing agricultural equipment.
- Project ideas include hosting a spring tune-up or winterization event for local community members for lawnmowers and other equipment or refurbishing broken bicycles for donation.
- Living to Serve Grants provide funding to FFA chapters to support service-learning and community service projects.

For more information, visit the **National FFA Organization** website.

SAE for All

Foundational SAE

All students in an agricultural education program are expected to have a Foundational SAE. Students completing the APP and extensions listed below will meet the Foundational SAE qualification for the *Advanced (Grades 11-12) level*. Students should place all documented evidence in the *FFA/SAE* section of their *Agriscience Notebook* along with the *SAE for All Foundational Checksheet*.

- Career Exploration and Planning
    - Find three job openings for technicians. Record the job description, salary, benefits, and education requirements for each job opening.
- Employability Skills for College and Career Readiness
    - Fluke Certificate: Digital Multimeter Basics
    - Project 1.2.5 The Five Whys

Immersion SAE

Students interested in this lesson's topics should explore the following related Immersion SAEs. An immersion SAE is optional and replaces the agricultural literacy component of the Foundational SAE.

- Placement/Internship
    - **Implement Dealership Placement SAE | Keegan Humm**
    - **Agricultural Mechanics SAE | Jeremiah Hager**

For more information on the guiding principles for implementing SAE programs, visit the **SAE for All: Evolving Essentials** site.

Critical Thinking and Application Extensions

Interpretation

1. Students evaluate a work/repair order from a local dealership.

Perspective

2. Students research how the retirement of the baby boomer population is creating a high demand for agricultural equipment technicians.

Lesson 1.2 Teacher Notes

Lesson 1.2 Technician Expectations

In preparation for teaching this lesson, review Concepts, Performance Objectives, Essential Questions, and Key Terms, along with the PowerPoint® presentations. Review all activity, project, and problem directions, expectations, and work students will complete.

Students use a diagnostic process to find the cause of a complaint, correct, and confirm the operation during this lesson. They apply the Five Why method to discover the root cause of a component failure. To complete the lesson, students document the complaint, cause, key part, correct, and confirmation in a work/repair order while repairing a universal joint.

PowerPoints®

Completing an Order

Share the presentation to provide background knowledge related to work/repair orders. Explain each work/repair order step and provide examples to students. Technical writing is a highly desired skill set among technician hires.

Activities, Projects, and Problems

Activity 1.2.1 Field Experience

Students observe a technician using the diagnostic process during a field trip to a local agricultural equipment dealer. They also learn about needed interpersonal skills from the dealer manager or Human Resources (HR) department.

Teacher Preparation

Contact an agricultural equipment dealership to set up a tour for your students. Provide the **Activity 1.2.1 Presenter Checklist** to the dealership to guide them on presentation content. There are two portions of the tour, a technician diagnosing and repairing equipment. The technician needs to show every part of the diagnosis, correction, and confirmation. However, they can lead students through some portions to save time. Part Two requires a presentation by HR.

Student Performance

Part One

Students record the technician's objective and what the technicians did during each diagnostic step.

Part Two

Students listen to a presentation from HR or the dealership manager related to technicians' interpersonal skills. Finally, students compare these skills to the skills assessed by their teacher using the **Employability Evaluation Rubric**.

Part Three

Students answer analysis questions by reviewing Parts One and Two.

Results and Evaluation

Evaluate student behavior during the field experience using the *Employability Evaluation Rubric*. Potential answers for Part Three analysis questions are listed in Table 1.

Table 1. ***Analysis Questions and Potential Responses***

Q1	How did the technician use the symptoms to isolate the cause?	*Answers will vary.*
Q2	Which tools or equipment did the technician need during diagnosis?	*Answers will vary.*
Q3	Which recommended repairs were directly related to the main complaint?	*Answers will vary.*
Q4	Which recommended repairs were secondary to the main complaint?	*Answers will vary.*
Q5	How did the technician verify the operation?	*Answers will vary.*
Q6	What skills are most desirable by the employer?	*Dealerships typically look for employees who will show up to work on time, are dependable, and follow through. In addition, local employers may have shared other, more specific skills.*
Q7	How are these interpersonal skills similar or different from employment in other agricultural fields?	*Several careers require interpersonal skills. Responsibility is a highly desirable trait by employers in all areas. Technicians may require less empathy but more flexibility than other career paths.*

Activity 1.2.2 Digital Navigation

Students will use a digital service database, the PowerPortal, to search for parts and create a Pick List for necessary parts.

Teacher Preparation

Provide each student with a technician account for **PowerPortal** (www.thepowerportal.com).

1. Log into the PowerPortal.
2. Click on the **Power Channel** tab.
3. Click on **Technician Accounts** on the top menu bar.
4. Type the first name, last name, and email address of each student, as shown in Figure 1. Click **Submit**.
5. Continue submission for each student.

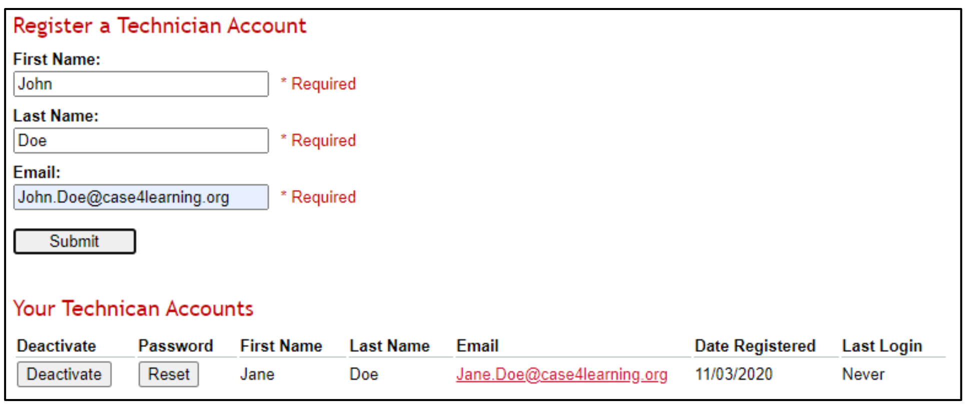

Figure 1. PowerPortal Technician Accounts

Student Performance

Students read through the overview of a diagnostic process listed in the procedure. Next, students use the list of recommended repairs and the model number to record the needed parts. Then students use an illustrated parts diagram from the PowerPortal to confirm a reference number and obtain a part number, part name, and the quantity needed. Finally, students use eParts to create a pick list to submit to their teacher. Ideally, a technician would only do one of these methods. The procedure shows students both methods to help master the skill.

Results and Evaluation

Students record assembly information in their *Logbook* in Table 2. Figure 2 shows a sample Pick List for Part Three.

Table 2. ***Assembly Information***

Part Two Step 5	Record the bolt grades and sizes needed in your Logbook.	*Two, 3/8”-16 x 0.75” Bolts, Grade 5*
Part Two Step 5	Find the torque specifications in the manual for the bolt(s) that will be removed or replaced. Then, record the specifications in your *Logbook*.	*30 ft-lbs or 40.8 newton-meters*
Part Three Step 2	Record the needed assembly information missing from the eParts section.	*Torque specifications*

Working Pick List: Andrews, Norma. 54' Snapper ZTR. 09/01/2020

Catalog	Part Number	Description	Price	Quantity
Accessories & Attachments	771148	SCREW, 3/8-16 X .75 GR 5		2
Accessories & Attachments	771221	SPACER, Shoulder		2
Accessories & Attachments	771220	WASHER, Wave		2
Accessories & Attachments	771219	BEARING, Ball		4
Accessories & Attachments	771214	WASHER, 1.010X1.560X.060		2
Accessories & Attachments	771325	SPRING, 1.25 OD X 1.751, Extension		1
Accessories & Attachments	771388	V-BELT, B Sec X 148.25 LG		1

Figure 2. Example Pick List

Activity 1.2.3 Digital Multimeter Operation

Students complete the first two of six Fluke Digital Multimeter Basics course lessons. During this activity, students apply their knowledge using a digital multimeter.

Teacher Preparation

Gather fifteen electrical components for students to practice measuring voltage, resistance, and continuity. Set up three stations of five components. Example components at each station include the following.

- Voltage – Batteries of various sizes and types
- Resistance – Wires, resistors, motors, and pumps
- Continuity – Switches turned (on and off), motors, wires, fuses

Then obtain working KidWind pumps, size D batteries, alligator clips, battery cases, and digital multimeters for each group of four students for Part Two.

Student Performance

Students complete the first two lessons in the *Fluke Digital Multimeter Basics* course. Next, students practice their skills by measuring the continuity, voltage, and resistance of electrical components while working in pairs. Each pair of students will need a digital multimeter. Then they apply the skills by measuring pump component voltage, resistance, and continuity. Finally, students measure the current in a working pump while under no load (not pumping water) and under load (pumping water). They will observe a higher current draw when the pump is under load.

Results and Evaluation

Potential answers to analysis questions are in Table 3. Example data readings are in Table 4. Assign students to complete lessons 4–6 of the *Fluke Digital Multimeter Basics* course as homework. Upon completing the Fluke course, students should add the certification to the *Records* section of their *Agriscience Notebook*.

Table 3. *Analysis Questions and Potential Responses*

Part One Analysis Questions

Q1	What is the difference between mΩ, Ω, and MΩ?	*Each is an expression of the number of Ohms in a circuit. mΩ, or milliohm, is 0.001Ω (one-thousandth). A MΩ, or megaohm, is 1,000,000Ω.*
Q2	Inspect your multimeter. What is the best range to select from testing a circuit with an expected voltage of 12V?	*Answers will vary based on the digital multimeter.* *For the most reading with the most resolution, turn the dial to the range right above the expected voltage (for example, 20V).*
Q3	Inspect your multimeter. Under what applications would you change the test lead among red input jacks?	*Answers will vary based on the digital multimeter.* *Multimeters will have one black COM (common) input jack and two to three red input jacks. The extra jacks are for testing amperage within a circuit.* *Some multimeters use a clamp to measure current.*
Q4	What could happen when testing a circuit if the red lead is plugged into the wrong input jack?	*The reading will be wrong. Additionally, the digital multimeter may blow a fuse, malfunction, or cause injury to the operator.*
Q5	Which lead do you connect to the circuit first?	*Black lead*
Q6	Which lead do you disconnect from the circuit first?	*Red lead*
Q7	What is the relationship between resistance and conductance?	*The higher the resistance (Ω), the lower the conductance (nS).*
Part Three Analysis Questions		
Q8	Why do technicians test for resistance in wires that have continuity?	*The digital multimeter tests for continuity by sending a small amount of current through the positive lead. Continuity implies there is a connection. However, a poor connection or broken wire could have a greater resistance and change machine performance, despite having continuity.*
Q9	What is the total resistance in the circuit? (pump + black wire + red wire)	*Example: 1.1Ω + 1.2Ω + 7.6Ω = 9.9Ω*
Q10	Use Ohm's law to calculate the amperage (current) in the pump while running. Show your work in your *Logbook*.	*Current = Voltage/Resistance* *Current = 1.5 Volts / 9.9 Ohms* *Current = 0.15 Amperes*
Q11	Why is the amperage measured different than the amperage calculated?	*The resistance may change when electrical current is flowing through a circuit.*

Table 4. *Example Digital Multimeter Readings*

Continuity (•))) Readings	Yes or No
Pump	**Yes**
Red cable with alligator clips	**Yes**
Black cable with alligator clips	**Yes**
Battery case without battery	**No**
Voltage (V) Readings	**Volts**
Battery out of the case	**1.57 V**
Battery inside case	**1.58 V**
Between leads on the pump (while running)	
Resistance (Ω) Readings	**Resistance**
Black cable with alligator clips	**1.1 Ω**
Red cable with alligator clips	**1.2 Ω**
Between leads on the pump (while not running)	**7.6 Ω**
Current (I) Readings	**Amperage**
Assembly without the battery	**0 Amperes**
Assembly with the battery under no load	**0.1 Amperes**

Assembly with the battery under load	

Project 1.2.4 Communicating Services

Students bridge what they learned during *Activity 1.2.1 Field Experience* to document the process using a Work/Repair Order. They work in a group of four to diagnose a pump failure and then work individually to write a repair order.

Teacher Preparation

Use Table 5 to prepare stations with failed pumps. At each station, provide **Project 1.2.4 Complaint Cards** for each student.

Table 5. ***Diagnostics Set Up***

Station	Cause	Example Tools
Complaint Card #1 Mark Marion brought in this pump on September 20th. He claims the pump was working well upon purchase three years ago. This summer, Mark started using the pump again. He noticed the pump ran slower than when he initially purchased it but still used it. Now the pump has no power and will not pump water.	**Corroded battery terminals:** Add electrical tape or shrink-wrap to the battery's terminals to simulate battery corrosion.	• Digital multimeter
Complaint Card #2 Grace Worland brought in this pump on August 12th. She used the pump for six years and would rather repair it if the repair cost is less than the replacement. When she used it last, it leaked like a sieve. Grace did not attempt any repairs to the pump before bringing it in.	Hose has small holes and abrasions. Poke several holes with a needle or small nail into the hose.	• New plastic tubing • Hot glue gun • Pliers
Complaint Card #3 Ron Nashua bought this pump last week, and it is still under warranty. He was using his battery for the system. Ron was using the pump to remove excess floodwaters, and the pump worked sporadically, sometimes not pumping at all.	**Electrical short:** Place the alligator clips on the battery in position, so they touch to short the electrical circuit. Another solution is to connect the two cables with another cable at the terminal (electricity follows the path of least resistance and not the pump).	• Digital multimeter

Student Performance

During Part One, students record information from *Completing an Order* PowerPoint® presentation. During Part Two, students identify the complaint and the cause of the failure at their assigned pump. They will correct and confirm that the pump operates. A work/repair order will be completed by each student individually using the **Work/Repair Order Template**. Students trade their work/repair order with another student to be peer-edited with a *Work/Repair Order Evaluation Rubric* to complete Part Three. Students complete the order to satisfy the *Work/Repair Evaluation Order Rubric* criteria during Part Four.

Results and Evaluation

Evaluate students' work/repair orders using the **Work/Repair Order Evaluation Rubric**. Potential answers to analysis questions are shown in Table 6.

Table 6. ***Analysis Questions and Potential Responses***

Q1	Which components of a work/repair order does a technician complete before fixing the problem?	*Complaint, Cause, and Key Part(s)*
Q2	What portion(s) of the work/repair order communicate parts replaced?	*Essential Part(s)*

Project 1.2.5 The Five Whys

Students use a service manual to diagnose, repair, and confirm component failure. During diagnosis, students employ the Five Whys process of root cause diagnosis.

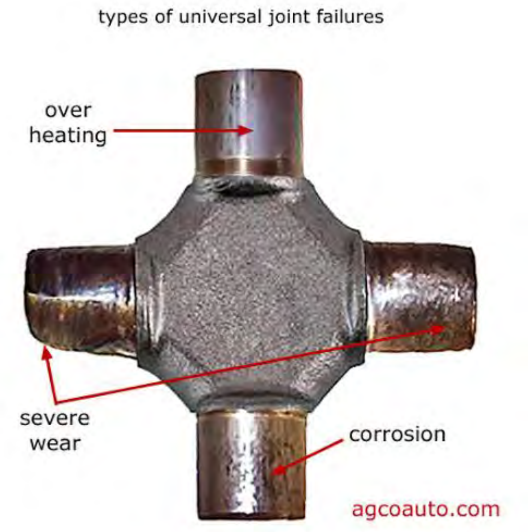

Figure 3. Universal Joint Failures

Teacher Preparation

Obtain used universal joints with failures and parts to repair them and pages from the service manual corresponding with diagnosis and repair. An example service manual can be found **here**. Figure 3 shows an example of universal joint failures. Another component option would be basic sprockets, chains, belts, and pulleys from equipment. Have a customer name, the type of equipment the component is from, and the equipment serial number to provide to the students.

Student Performance

Part One

Using the Five Whys process, students use a service manual to inspect a universal joint and diagnose the component failure by writing the questions in their *Logbook*. Students write the answer to each question using a red pen.

Part Two

Students repair the component using a cross-repair kit. They first list the procedures used to repair and reassemble the universal joint using the service manual. Once the instructor has approved the work/repair order process, students can move forward with the repair.

Part Three

Students use their *Logbook* notes to complete a *Work/Repair Order Template* for this repair. They list the steps a technician would take to confirm operation on the component as if it was attached to agricultural equipment. Students submit the *Work/Repair Order Template* as directed by their instructor to complete the project

Results and Evaluation

Evaluate students using the **Work/Repair Order Evaluation Rubric**.

Assessment

Lesson 1.2 Check for Understanding

Lesson 1.2 Check for Understanding is included for you to use as an assessment tool for this lesson. Use **Lesson 1.2 Check for Understanding Answer Key** for evaluation purposes.

Name____

CASE

Activity 1.2.1 Field Experience

Purpose

Benjamin Franklin's essay, *Advice to a Young Tradesman,* advised young people entering a business. His first advice was, "Remember that time is money." This advice remains wise in the agricultural equipment industry yet today. Technicians must be mindful of the time spent diagnosing problems with equipment to maximize the shop's profitability and minimize the customer's expense.

Technicians use a standardized, systematic process to find a problem, make repairs, and confirm the proper operation. Below is the six-step Technicians Diagnostic Process used in this class. While each employer might follow a different version of the steps listed, they all follow the same fundamental process.

Technicians Diagnostic Process

1. **Verify customer complaint:** The technician verifies they have enough information from the customer complaint to solve the problem. The technician will operate the equipment to identify the customer's concern during this step.
2. **Identify the symptoms:** Every problem has key symptoms. Identifying the symptoms of a problem will help determine the cause. Service manuals include flow charts that help technicians match key symptoms to the problem.
3. **Isolate the cause:** Determine which equipment components are causing the problem. Then, inspect the equipment for subsidiary repairs to prevent the issue from reoccurring.
4. **List recommended repairs:** Submit a list of the repairs to the service desk to share with the customer. Includes any added repairs the technician suggests to the customer.
5. **Repair the cause:** Repair the equipment as confirmed by the customer.
6. **Verify proper operation:** Test the equipment to ensure that the repair(s) solved the customer's problems or concerns.

Besides diagnostic skills, employers look for other applied knowledge, relationship, and workplace skills. For example, workers need to apply reading, writing, and mathematics they learned in school on the job. Employees with effective relationships provide input, resolve conflicts, and lead the team to task completion. Workplace skills on the job include safety, equipment use, time management, and accountability.

How do technicians use the diagnostic process and workplace skills to communicate with their customers?

Materials

Per student:

- Clipboard
- Safety glasses
- Closed-toed shoes
- Pen
- *Agriscience Notebook*
- *Employability Evaluation Rubric*

Procedure

Visit an equipment dealership to observe how a technician diagnoses a problem, then listen to a member of the Human Resources (HR) department speak about employee expectations. Follow the procedure to obtain information from the speakers. Wear your safety glasses and closed-toed shoes during your visit.

Part One – Technician Diagnostics

Observe the technician as they diagnose the equipment. During each step of the diagnostic process, record the technician's objective and what the technician did during each step in Table 1 of *Activity 1.2.1 Student Observation*.

Part Two – Employability

1. A representative from Human Resources (HR) will present the interpersonal skills necessary for technicians. Listen to the presentation.
2. Review the *Employability Evaluation Rubric*.
3. Place a star beside the common topics presented by HR.
4. List and describe three new skills presented by HR on the back or the *Employability Evaulation Rubric.*

Part Three – Wrap Up

Review your notes from Parts One and Two, then answer the *Part Three Analysis Questions* .

Conclusion

1. Why is a standard diagnostic process used in technical fields?
2. How can this diagnostic process be applied to other industries?
3. Why are interpersonal skills desirable from employers?

Name____

Activity 1.2.1 Student Observations

Table 1. *Diagnostic Process*

Diagnostic Process	Technician Objective	What did the technician do?
Verify the customer complaint		
Identify the symptoms		
Isolate the cause		
List recommended repairs		
Repair the cause		
Verify proper operation		

Part Three Analysis Questions

Q1 How did the technician use the symptoms to isolate the cause?

Q2 What tools or equipment did the technician need during diagnosis?

Q3 Which recommended repairs were directly related to the main complaint?

Q4 Which recommended repairs were secondary to the main complaint?

Q5 How did the technician verify the operation?

Q6 What skills are most desirable by the employer?

Q7 How are these interpersonal skills similar or different from employment in other agricultural fields?

Activity 1.2.1 Field Experience Presenter Checklist

Thank you!

Thank you for providing this experience for our students! Today's field experience will allow students to observe a technician diagnosing and repairing agricultural equipment (or a component). Students will also hear about the interpersonal (personal, 21st Century, etc.) skills expected of your employees. These presentations are part of our first lesson in a series on technician expectations. Below are guidelines for the technician and Human Resources to follow. Please feel free to add any pointers or extra material pertinent to your business.

Technician Checklist

Concept: Technicians follow a standard diagnostic procedure to inspect a problem, make repairs, and verify proper operation.

Lead students through the diagnostic process in troubleshooting, repairing, and confirming a repair in agricultural equipment.

- Note: The equipment can be ready for repair and has already been through the diagnostic process. However, please lead students through the process you went through.
- Please discuss your role during each diagnostic step and talk the students through the technical skills conducted during that process.
- The diagnostic process taught is the following six-step sequence:
  - Verify the customer complaint
  - Identify the symptoms
  - Isolate the cause
  - List recommended repairs
  - Repair the cause
  - Verify proper operation

Human Resources Checklist

Concept: Agricultural equipment dealers need technicians with strong interpersonal skills.

Please discuss the following in your presentation:

- How you evaluate your employees
- Desired interpersonal skills of employees
- Base education and technical skill requirements

Any information on future employment or apprenticeships is appreciated.

Requested Materials

In this class, students will be developing a technician portfolio. We are requesting example resources to align the curriculum to local industry needs. The following are forms that would be helpful, if possible:

- Work/repair order forms
- Blank employment evaluations

Name____

CASE

Activity 1.2.2 Digital Navigation

Purpose

Technicians utilize resources, such as service manuals, to diagnose and repair equipment correctly on the first attempt. Agricultural equipment manufacturers produce service manuals to communicate servicing procedures, maintenance, and product repairs. These manuals are not provided to the public but to the dealers that service equipment. Publishers sell aftermarket service manuals with torque specifications, part illustrations, and wiring diagrams to the general public.

Technical writers categorize service manuals and illustrate parts lists by machine components, such as transmission or engine accessories. Illustrated parts diagrams show an exploded view of a machine component, as seen in Figure 1. Technicians cross-reference the part reference numbers to a table with a specific part name, part number, and the quantity needed to compile a picklist

Dealers rely upon pick lists for parts. When technicians identify the parts needed, they create a pick list for two purposes. First, the service desk can give the customer a quote for the total bill for the repairs. Secondly, the pick list streamlines finding parts in the warehouse. The pick list and service manuals are often available to dealers on a digital platform.

How does a technician use a logbook to reference service manuals and picklists?

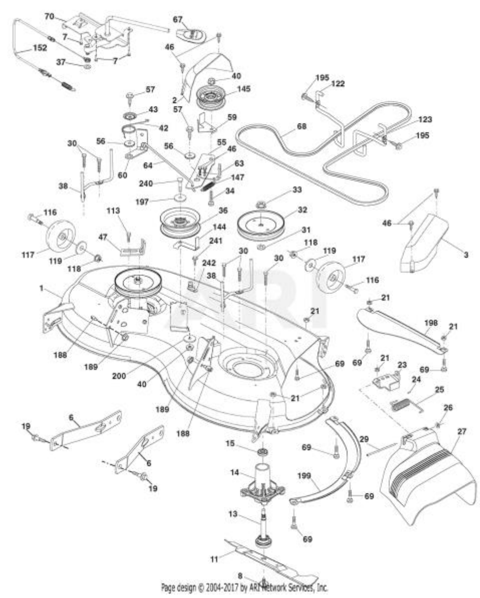

Figure 1. Illustrated Parts

Materials

Per student:

- Device with internet access
- PowerPortal access
- Pen
- *Agriscience Notebook*
- *Logbook*

Procedure

Use the PowerPortal database to search for service information on a Snapper 54" Zero Turn mower (Model #2691573). The lawnmower was brought into your shop on September 1st by a customer named Norma Andrews. Table 1 shows a briefing of a technician's diagnostic process leading up to the repairs. Follow the procedure to find the parts needed and create a pick list for the service desk.

Part One – Digital Database Search

1. Record the username and password for your PowerPortal account in your *Logbook*.
2. Log in to **PowerPortal** (www.thepowerportal.com**)** using the information provided by your teacher.
3. Select **Snapper** in the top menu tab.
4. Select **Model Search** and type the model number *2691573*.
5. Select **2691573-00**.
6. Scroll down the screen and open the *Illustrated Parts List*.

Part Two – Diagnostic Search

1. Review Table 1 to determine the parts needed to repair the mower. List the parts in your *Logbook*.

Table 1. ***Snapper 54" ZT Mower Diagnostics***

Complaint from the service desk	• The front left wheel seized up. The customer tried lubrication. • The mower deck runs slower than normal and does not operate under a load.
Verify the customer complaint	• The front left wheel is completely seized. • The front right wheel is also under a lot of friction. • The mower deck will not operate properly when mowing grass.
Identify the symptoms	• The front axles are rusted. • The mower deck receives power from the engine. The belt around the mower deck pulleys is not tight.
Isolate the cause	• V Belt on the mower deck need is stretched and slipping. The extension spring is stretched. • Front wheels bearings have corroded. The left wheel is seized completely.
List recommended repairs	• Front axles: Remove and replace all spacers, screws, bolts, washers, and bearings attaching the wheel to the yoke and the yoke to the frame on both sides. Clean corrosion off the frame and add copper anti-seize to the frame before reassembly. • Replace V-Belt and extension spring on the mower deck.

2. Determine which *Model Components* listed in the *Table of Contents* contain the needed parts.
3. Record the Model Components in your Logbook.
4. Make a table similar to Table 2 in your *Logbook*.

Table 2. ***List of Parts***

Part Name	Reference Number	Part Number	Quantity Needed

5. Review the parts diagrams for each *Model Component* to find the part(s). Then, for each part, record the *Part Name*, *Reference Number, Part Number,* and *Quantity Needed* in your *Logbook* table.
   - Have your teacher check your list of parts.
6. Review hardware and torque information.
   - Scroll to the page after the diagrams.
   - Record the bolt/screw grades and sizes needed in your *Logbook*.

- Find the torque specifications in the manual for the bolt(s) on the front wheel assembly that will be removed or replaced. Then, record the specifications in your *Logbook*.

Part Three – Pick List

1. Access the **eParts catalog** (https://eparts.thepowerportal.com/scripts/EmpartISAPI.dll?MF) in the PowerPortal by clicking on **Snapper** > **Parts** > **eParts**.
2. Enter the model number of the lawnmower and select the correct mower listed.
3. Select a mower component used in Part Two to access an interactive parts manual.
4. Use the part reference numbers in your *Logbook* to find each part.
5. Record the part number, description, and quantity needed on *Activity 1.2.2 Pick List*.
6. Record your name, equipment, and date on the pick list. (LastName, FirstName. EquipmentServiced, MM/DD/YYYY).
    - Example: Smith, Terry. John Deere 2510, 10/10/2020
7. Submit the pick list to your teacher.

Conclusion

1. What are the advantages of a digital service portal?

2. How is a pick list used in agricultural equipment repair?

3. Why are reference numbers used on illustrated parts diagrams?

Name____

Activity 1.2.2 Pick List

Name	
Equipment	
Date	

Part Number	Description	Quantity

Name____ **CASE**

Activity 1.2.3 Digital Multimeter Operation

Purpose

Employers in agricultural equipment services employ technicians with strong foundational skills. OSHA declares that a qualified person has foundational knowledge of using a digital multimeter when testing electrical circuits. A digital multimeter is a tool that can collect two or more quantities. Basic multimeters can quantify voltage, current, and resistance. More complex multimeters can collect measurements such as capacitance and temperature. Technicians use the digital multimeter to test electrical components and troubleshoot problems that cause an increase or decrease in electrical current.

The flow of electrical current in a wire can be compared to water flow in a hose. The greater the flow, the more quickly the hose fills a bucket with water. A spray nozzle on the end of a hose slows the flow but increases water pressure. You can increase the pressure or voltage of electricity in the same way. The thickness and length of the wire are two factors that influence the resistance in a circuit. The formula for Ohm's Law, as shown in Figure 1, represents the indirect relationship between resistance and electrical current when the voltage is constant. As resistance increases, voltage decreases.

$$\text{volts (V)} = \text{current (A)} \times \text{resistance } (\Omega)$$

Figure 1. Ohm's Law

Technicians start the electrical troubleshooting process by checking components for continuity, which is a complete path for electrical current to flow. An open circuit has no continuity or an infinite amount of resistance. A closed circuit has continuity with resistance having a numerical value.

How can the resistance of a wire influence equipment performance? How can technicians use digital multimeters to confirm continuity?

Materials

Per class:

- (10) Digital multimeter (DMM)
- (15) Electrical components

Per group of four students:

- Battery case, D size
- Battery, D size
- Beaker, 600ml
- Digital multimeter (DMM)
- Water pump
- Water
- Wire with alligator clips, black
- Wire with alligator clips, red

Per student:

- Device with internet access
- Headphones
- Safety glasses
- Pen
- *Agriscience Notebook*
- *Logbook*

Procedure

Complete Lessons One and Two of the Fluke *Digital Multimeters Basics* course to learn about digital multimeter operation. Next, utilize this information to complete a diagnostic review of a working Kidwind Pump. Wear your safety glasses throughout this activity.

Part One – Digital Multimeter Training

1. Go to the **Digital Multimeter Basics Online Course** (https://www.fluke.com/en-us/learn/online-courses/digital-multimeter-basics-online-course) page.
2. Scroll down and select **Get this Course**.
3. Select *Course Introduction* and complete the tutorial.
   - Use headphones to listen to the tutorial.
4. Select *Lesson 1: Multimeter Orientation*, complete the tutorial, and review questions.
5. Obtain a digital multimeter and answer the *Lesson 1 Analysis Questions* on *Activity 1.2.3 Student Review* sheet.
6. Select *Lesson 2: Around the Dial*, complete the tutorial, and answer the *Lesson 2 Analysis Questions*.

Part Two – Multimeter Practice

1. Go to one of the following stations with your assigned partner as instructed by your teacher.
   - Voltage (1–5)
   - Resistance (1–5)
   - Continuity (1–5)
2. Use a digital multimeter to measure the voltage, resistance, or continuity of the numbered electrical components at your station.
3. Record your measurements on *Activity 1.2.3 Student Review* sheet.
4. Rotate to the other stations when instructed by your teacher.
5. Check your results as your teacher discusses the measurement of each component.

Part Three – Application of Skills

1. Obtain a pump, battery case, D-size battery, and wires with alligator clips from your instructor.
2. Use a digital multimeter to measure the continuity, voltage, and resistance of the components listed in Table 1.
   - Use the skills obtained during the Fluke training.
3. Assemble the pump and multimeter, as shown in Figure 2.
   - Do not install the battery
4. Use the digital multimeter to measure the electrical current with no battery and record it in Table 1.
5. Place the battery into the case.
6. Find and record the electrical current of the assembly with the battery under no load in Table 1.
7. Place the pump in a 600ml beaker of water.
8. Find and record the electrical current of the assembly with the battery under load in Table 1.
9. Answer *Part Two Analysis Questions*.

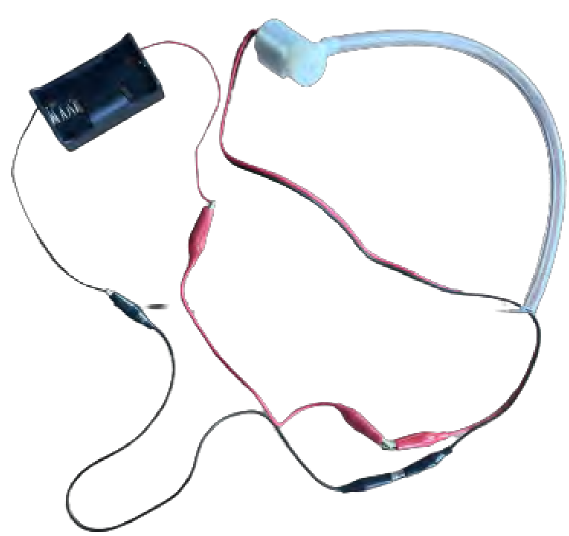

Figure 2. Pump Assembly

Conclusion

1. How can technicians use a digital multimeter to test an electrical circuit?

2. When would a technician use a digital multimeter during the diagnostic process?

3. Why is the range and units of a digital multimeter essential for the technician to understand?

Name____

Activity 1.2.3 Student Review

Lesson 1 Analysis Questions

Q1 What is the difference between mΩ, Ω, and MΩ?

Q2 Inspect your multimeter. What is the best range to select from testing a circuit with an expected voltage of 12V?

Q3 Inspect your multimeter. Under what applications would you change the test lead among red input jacks?

Q4 What could happen when testing a circuit if you plug the red lead into the wrong input jack?

Lesson 2 Analysis Questions

Q5 Which lead do you connect to the circuit first?

Q6 Which lead do you disconnect from the circuit first?

Q7 What is the relationship between resistance and conductance?

Part Two – Multimeter Practice

Table 1. ***Electrical Measurements***

Voltage	Resistance	Continuity
1.	1.	1.
2.	2.	2.
3.	3.	3.
4.	4.	4.
5.	5.	5.

Part Three – Application of Skills

Table 2. ***Digital Multimeter Readings***

Continuity (•)))) Readings	Yes or No
Pump	
Red wire with alligator clips	
Black wire with alligator clips	
Battery case without battery	
Voltage (V) Readings	**Volts**
Battery out of the case	
Battery inside case	
Resistance (Ω) Readings	**Resistance**
Black wire with alligator clips	
Red wire with alligator clips	
Between leads on the pump	
Current (I) Readings	**Amperage**
Assembly without the battery	
Assembly with the battery under no load	
Assembly with the battery under load	

Part Three Analysis Questions

Q8 Why do technicians test for resistance in wires that have continuity?

Q9 What is the total resistance in the circuit (pump + black wire + red wire)?

Q10 Use Ohm’s law to calculate the amperage (current) in the pump while running? Show your work.

Q11 Why is the amperage measured different than the amperage calculated?

Name____ CASE

Project 1.2.4 Communicating Services

Purpose

A technician's primary role in the agricultural equipment industry is to repair equipment brought into a dealership. When customers bring equipment into a dealership, a complaint or concern is filed and provided to the technician. The technician's role is to find the problem, correct it, and communicate how they fixed it to the customer and the billing office. Communication includes the labor hours used and the parts replaced. Technicians use a *Work/Repair Order* to communicate these services to all parties involved.

The components of a work or repair order include the customer's complaint (or concern), the cause of the problem, the correction made, and a confirmation that the equipment is properly working. These sections are commonly referred to in the agricultural equipment and automotive industries as "The Four Cs." Typically, dealerships add a section to their order that communicates key parts replaced when repairing the equipment. Each work/repair order section aligns to a diagnostic step, as shown in Figure 1.

Diagnostic Process		Work/Repair Order
1. Verify the customer complaint	→	Complaint
2. Identify the symptoms 3. Isolate the cause	→	Cause
4. List recommended repairs	→	Key Part
5. Repair the cause	→	Correction
6. Verify proper operation	→	Confirm

Figure 1. Diagnostic Process and Work/Repair Order

The technician's repair is unfinished until they submit a complete work/repair order. An incomplete or untimely order limits the dealer's ability to bill the customer properly. However, a proper order gives the customer confidence that their money is well spent on the services rendered.

How does a technician communicate repairs made on equipment to customers? How do technicians utilize a work/repair order?

Materials

Per group of four students:

- Battery case, D size
- Battery, D size
- Beaker, 600ml
- Digital multimeter (DMM)
- Graduated cylinder, 250ml
- Materials, tools, and equipment to diagnose and fix the pump
- Plastic hose, clear, ¼″ I.D., 12″
- Water
- Water pump
- (2) Wire with alligator clips

Per student:

- Safety glasses
- Device with word processing and internet access
- Pen
- *Activity 1.2.4 Complaint Card*
- *Work/Repair Order Template*
- *Work/Repair Order Rubric*
- *Agriscience Notebook*
- *Logbook*

Procedure

Determine the components of a *Work/Repair Order*, then follow the steps, filling in the Four Cs to diagnose the cause to repair the pump. The pump assembly might look familiar if you completed the CASE *Agricultural Power and Technology* course. Wear your safety glasses.

Part One – Work/Repair Order

Use your presentation notes from the *Completing an Order* PowerPoint® presentation to complete Table 1 and answer the analysis questions on *Project 1.2.4 Student Review* sheet.

Part Two – Identify Complaint/Cause

1. Acquire an assembled pump and *Complaint Card* from your instructor.
2. Read the *Complaint Card*.
3. Summarize the complaint in the *Work/Repair Order Template*.
4. Connect the red lead to the battery case's positive (+) terminal.
5. Diagnose the cause of the pump failure and record it in the work/repair order.
6. Identify the key part that needs repaired or replaced in the work/repair order.
7. Describe the procedure used to correct the failure in the work/repair order.
8. Test the pump again to confirm it works and the customer complaint has been satisfied. Write your confirmation in the work/repair order.
9. Trade your *Work/Repair Order* with a classmate as instructed by your teacher.

Part Three – Evaluate Work/Repair Order

Evaluate your classmate's *Work/Repair Order* using the *Work/Repair Order Rubric*. Record constructive and helpful comments for your classmate to edit their *Work/Repair Order.*

Part Four – Edit Work/Repair Order

Independently edit your *Work/Repair Order Template* and confirm that it meets the rubric's criteria. Then, submit your *Work/Repair Order* as instructed by your teacher.

Conclusion

1. How does a work/repair order communicate services rendered to the customer?

2. Why is a technician's job not done until the paperwork is submitted?

3. Why are proper vocabulary and technical terminology essential when writing work/repair orders?

Name____

Project 1.2.4 Student Review

Table 1. *Work/Repair Orders*

Term	Description	Example
Complaint		
Cause		
Key Part		
Correction		
Confirm		

Analysis Questions

Q1 Which components of a *Work/Repair Order* does a technician complete before fixing the problem?

Q2 What portion(s) of the *Work/Repair Order* communicate parts replaced?

Project 1.2.4 Complaint Cards

Complaint Card #1

Mark Marion brought this pump to the shop on September 20th. He stated that the pump worked well upon purchase when he used it three years ago. This summer, Mark started using the pump again. He noticed the pump ran slower than when he initially purchased it but still used it. Now the pump has no power and will not pump water.

Complaint Card #2

Grace Worland brought in this pump on August 12th. When she used it last, it leaked like a sieve. Grace did not attempt any repairs to the pump before bringing it in. She used the pump for six years and would rather repair it if the repair cost is less than replacement.

Complaint Card #3

Ron Nashua bought this pump last week, and it is still under warranty. He was using his battery for the system. Ron was using the pump to remove excess floodwaters, and the pump worked sporadically, sometimes not pumping at all.

Name____

CASE

Project 1.2.5 The Five Whys

Purpose

Several components work together for agricultural equipment to function. When one component fails, the equipment cannot operate efficiently or shuts down altogether. Behind every failed component is a root cause. Technicians use the diagnostic process to help determine the root cause, repair it, and verify operation. The "Five Whys" is a widely-used method in finding the root cause. The Five Whys technique's objective is to repeatedly ask "Why?" to determine the root cause. Each why aims to explore the answer to the previous question. Figure 1 shows an example of the Five Whys technique.

Problem	The lawnmower will not start.
Why… won't the mower start?	The engine isn't getting fuel.
Why… is the engine not getting fuel?	The carburetor jets and fuel ports are gummed up.
Why… is the carburetor gummed up?	The gasoline separated and varnished the carburetor.
Why… did the gasoline separate?	The gasoline was old.
Why… was the gas old?	The consumer stored the mower with gasoline in it over the winter months.

Figure 1. Five Whys

Technicians often use service manuals to help determine the cause and effect relationship between symptoms and failures. For example, following the process shown in Figure 1, a technician might determine that the root cause was old gasoline. Recommended repairs could include cleaning the carburetor, adding fresh fuel, and noting in the work/repair order that the customer should remove fuel before storage. The manufacturer's service manual would include information for the technician on how to service the carburetor, including parts, exploded part diagrams, and torque specifications for fasteners.

How can the Five Whys method of questioning help technicians further define problems in agricultural equipment?

Materials

Per pair of students:

- Mechanical and precision tools
- (2) Paper plate
- Service manual
- Universal joint

Per class:

- (2) Grease gun

Per student:

- Pen
- Pen, red
- Safety glasses
- *Agriscience Notebook*
- *Logbook*
- *Work/Repair Order Rubric*
- *Work/Repair Order Template*

Procedure

Use the diagnostic process and the Five Whys method to determine the root cause of a universal joint failure. Then, use a service manual to complete a work/repair order for the job. Be sure to wear your safety glasses and tie back long hair.

Part One – Component Failure Analysis

1. Put on safety glasses and tie back long hair.
2. Locate the illustrated parts diagram for the universal joint in the service manual.
3. Record the customer information in your *Logbook*.
   - Your teacher will provide you with the customer's name, type of equipment, and serial number.
   - Customer complaint: The component makes a clunking sound and vibrates when operating.
4. Inspect the universal joint to verify the customer complaint.
5. Follow the Five Whys process to identify symptoms and isolate the cause of the component failure.
   - In your *Logbook*, record your first question: Why is the component making a clunking sound or vibrating when operating?
   - Record the answer for the *why* using a red pen.
6. Use the service manual to inspect the universal joint further.
   - Continue with four additional questions and answers to identify symptoms and isolate the cause.
   - Set any parts removed during diagnosis onto paper plates.
7. Document the *Cause* in the *Work/Repair Order Template*.
8. List the recommended repairs in the *Key Parts* section of the work/repair order.
   - Include part number, name, and quantities needed.

Part Two – Service the Repair

1. Use a table similar to Table 1 to record a procedure for repairing the universal joint in your *Logbook*. Utilize information from the service manual.

Table 1. *Example Logbook Notes*

Step	Hardware	Tools	Torque or Specification	Service Manual Info.		
				Sec.	Page	Fig.

2. Receive instructor validation of your repair procedure before proceeding to Step 3.
3. Repair the universal joint and record the following specifications in your *Logbook*.
   - Diameter of the original bearing cups
   - Diameter of the worn bearing cups
4. Record any changes to the correction procedure in the *Logbook*.

Part Three – Document and Verify Operation

Refer to your *Logbook* to complete a work order for an employer and customer.

1. Record the *Customer Information* and *Complaint*.
2. Refer to the Five Whys answered in your *Logbook* to enter the *Cause*.

3. Record all key parts you replaced.
4. Use your procedure to summarize your repair in the *Correction* section.
5. Record the steps a technician should follow to verify operation in the *Confirm* section.
6. Submit your *Work/Repair Order* as instructed by your teacher.

Conclusion

1. Why is the Five Whys method used to determine the root cause?
2. How is the Five Whys method helpful when using the diagnostic process?
3. What are some limitations of the Five Whys method?

CASE

Curriculum for Agricultural Science Education

Agricultural Equipment Maintenance and Technology

Completing an Order

Unit 1 – Lesson 1.2 Technician Expectations

Work/Repair Order

Standard method to communicate a service

- Required by all OEM’s (Original Equipment Manufacturer for warranty repairs.
- Bridges the technician to the customer through the service desk.
- The job is not done until the work order is done.

Components of an Order

- Customer information
- Complaint (concern)
- Cause
- Key part(s)
- Correction
- Confirmation

Name

CASE

Work/Repair Order Template

Customer Information			
Name (Last, First)		Date	
Equipment			
Serial Number			
Drive Time/Mileage			

Complaint (Concern)

What is the customer's complaint? How did you verify the complaint?

Cause

What are the symptoms of the component failure? What is the root cause?

Key Part(s)

Part Number	Part Name	Quantity

Correction

What steps did you take to repair the problem?

Confirm

What steps did you take to confirm operation? What was the outcome?

Customer Information

- Name
- Contact information
- Equipment information
  - Model
  - Serial number
  - Miles and/or hours

Complaint (Concern)

A customer's complaint on a machine or part.

- A complaint must be filed for warranty work to be fulfilled on orders.
- Must be specific.

Cause

What caused the failure.

- Include:
  - How and where the part failed.
  - Test results
- Words to avoid:
  - Broken
  - Bad

Key Part(s)

Describe parts to replace:

- Part Name
- Part Number
- Quantity

Correction

Record what was done to repair the unit.

Record all pertinent information:

- Time to fix (decimal hours)
- Difficulties (example, seized bolt)
- Any cleaning of equipment
- Error codes
- Readings from diagnostic tests

Example Correction:

3/26 3.80 Hours: Pulled codes. Checked to make sure starter was free. Couldn’t turn over with crank pulley. Pulled plug out of bell housing. Tried to turn over with ring gear and boring tool. Pulled turbo lines. Everything was full of oil.

Confirmation

Verifying the repair by operating equipment and documenting the operation.

- Note: failure to record the confirmation of repair can reduce payments from OEMs on warranty work.

Presentation Review

- Mark or highlight three key points
- List two ideas or concepts related to previous knowledge.
- List questions you have about this topic.
- Keep notes organized and available for use throughout the course.

References

- Herren, R. V., & Donahue, R. L. (2000). *Delmar's agriscience dictionary with searchable CD-ROM*. Albany, NY: Delmar.
- Shade Tree Speed Shop. The Four C's of Automotive Repair. Retrieved from https://shadetreespeedshop.com/the-four-cs-of-automotive-repair/.

Name____

CASE

Lesson 1.2 Check for Understanding

1. Match the description of a small engine repair to its step in the diagnostic process.

______	Verify customer complaint	A.	Remove the carburetor and clear the block.
______	Identify the symptoms	B.	The pilot jet is plugged with old gas.
______	Isolate the cause	C.	The engine surges while running.
______	List recommended repairs	D.	The engine runs without surging.
______	Repair the cause	E.	The pilot jet was cleaned with a wire drill bit.
______	Verify proper operation	F.	The engine is running lean. Engine power is inconsistent.

2. List two interpersonal skills needed of technicians.

3. List three components of a pick list.

4. A work/repair order includes the following components, in order:
   a) Key Part, Complaint, Confirm, Cause, Correction
   b) Complaint, Cause, Key Part, Correction, Confirm
   c) Cause, Complaint, Concern
   d) Complaint, Cause, Correction, Confirm

5. Write an example sequence of a Five Why analysis for the listed problem.

Problem: The student was late for the bus.	
Question	**Answer**

6. List three types of information a technician would reference from a service manual when repairing a universal joint.

CASE

Lesson 1.2 Check for Understanding Answer Key

1. Match the description of a small engine repair to its step in the diagnostic process.

C	Verify customer complaint	A.	Remove the carburetor and clear the block.
F	Identify the symptoms	B.	The pilot jet is plugged with old gas.
B	Isolate the cause	C.	The engine surges while running.
A	List recommended repairs	D.	The engine runs without surging.
E	Repair the cause	E.	The pilot jet was cleaned with a wire drill bit.
D	Verify proper operation	F.	The engine is running lean. Engine power is inconsistent.

2. List two interpersonal skills needed of technicians.

Answers could include dependability, teamwork, flexibility, active listening, and responsibility

3. List three components of a Pick List.

Part Number, Part Name, Quantity

4. A work/repair order includes the following components, in order:

   a) Key Part, Complaint, Confirm, Cause, Correction
   b) Complaint, Cause, Key Part, Correction, Confirm
   c) Cause, Complaint, Concern
   d) Complaint, Cause, Correction, Confirm

5. Write an example sequence of a Five Why analysis for the listed problem.

Each question should start with why and should be answered. The next question should refer to the previous question's answer. Students can arrive at different end root causes. Refer to the example in Project 1.3.3.

6. List three types of information a technician would reference from a service manual when repairing a universal joint.

Answers may include illustrated parts diagrams, part numbers, torque specifications, service procedures, and service diagnostics.

CASE

Lesson 2.1 Drive Train Components

Preface

Engines and motors provide a limited amount of energy to a drivetrain. Drive train systems contain clutches, gears, sprockets, and bearings that transfer energy throughout the equipment to do work. Clutches engage the rotary power from the source to the drive train. Clutches use a mechanical or electromagnetic plate to engage and disengage a system of gears and sprockets.

Gear systems consist of drive, idler, and driven gears. Drive gears are closest to the energy source, and driven gears complete the work. Idler gears placed between drive and driven gears can change the system's speed. Gear speed is measured in revolutions per minute (rpm). The teeth ratio of the gears in the system affects the driven speed measured in revolutions. There is an indirect relationship between driven gear size and the gear’s rpm. As the diameter of the driven gear increases, the rpm decreases. An idler pulley in a compound system of gears reduces the speed at a greater rate.

Agricultural equipment uses a combination of gears designed for specific processes. Worm gears and bevel gears change the direction of the driven shaft by 90 degrees. Other gear systems, such as cams and rack and pinions, change rotary motion to linear motion. Technicians set the backlash or spacing between gears to ensure a proper fit in function when they interlock.

Moving components have bearings that reduce friction and increase the efficiency of the equipment. Friction and antifriction bearings are between the spindle and the gear, sprocket, or wheel that rotates around it. Friction bearings are fixed spacers such as a bushing, while antifriction bearings consist of rotating balls, rollers, or needles.

During this lesson, students construct a model transmission and drive train. Next, students adjust the backlash for a drive train. Then they make a model of a friction clutch and adjust an electromagnetic clutch. Students complete the lesson assembling a model drive train and completing a work order for a worn drive train.

Concepts	**Performance Objectives**
Students will know and understand	*Students will learn concepts by doing*
1. Gears change a drive train’s speed and torque.	• Construct a drive train and measure speed. (Activity 2.1.1) • Measure a drive train’s torque. (Activity 2.1.3)
2. Clutches engage and disengage torque from the power input to the power output.	• Identify clutch systems & components present on agricultural equipment. (Activity 2.1.2) • Adjust and test the settings for an electromagnetic clutch. (Activity 2.1.2)
3. Bearings reduce friction to increase efficiency in power train systems.	• Identify and select bearing types used in drive train systems. (Activity 2.1.4)
4. Technicians set and adjust gears to work effectively.	• Disassemble gearbox, identify components and inspect for wear and backlash. (Activity 2.1.5)

5. A drive train uses a combination of components to change the direction and speed of moving parts in a system.	• Construct a drive train modeling agricultural equipment. (Project 2.1.6)

National AFNR Common Career Technical Core Standards Alignment

Career Ready Practices
2. Apply appropriate academic and technical skills.
• CRP.02.01: Use strategic thinking to connect and apply academic learning, knowledge, and skills to solve problems in the workplace and community.
• CRP.02.02: Use strategic thinking to connect and apply technical concepts to solve problems in the workplace and community.
4. Communicate clearly, effectively and with reason.
• CRP.04.02: Produce clear, reasoned and coherent written and visual communication in formal and informal settings.
Power, Structural and Technical (AG-PST)
1. Apply physical science principles and engineering applications related to mechanical equipment, structures, and biological systems to solve problems and improve performance in AFNR power, structural, and technical systems.
• AG-PST 1.2: Use hand and power tools commonly required in power, structural, and technical systems
• AG-PST 1.3: Investigate solutions to AFNR power, structural, and technical systems.
• AG-PST 1.4: Design or modify equipment, structures, or biological systems to improve performance of an AFNR enterprise or business unit.
2. Operate and maintain mechanical equipment related to AFNR power, structural, and technical systems.
• AG-PST 2.1: Maintain machinery and equipment by performing scheduled service routines.
• AG-PST 2.2: Perform service routines to maintain power units and equipment.
3. Service and repair mechanical equipment and power systems used in AFNR power, structural and technical systems.
• AG-PST 3.4: Service and repair steering, suspension, traction, and vehicle performance systems by checking performance parameters.
• AG-PST 3.6: Service electrical systems by troubleshooting from schematics.

Next Generation Science Standards Alignment

Disciplinary Core Ideas	
Physical Science	
Engineering, Technology, and the Application of Science	
ETS1: Engineering Design	
ETS1.B: Developing Possible Solutions	• Both physical models and computers can be used in various ways to aid in the engineering design process. Computers are useful for a variety of purposes, such as running simulations to test different ways of solving a problem or to see which one is most efficient or economical; and in making a persuasive presentation to a client about how a given design will meet his or her needs.

Science and Engineering Practices	
Asking Questions and Defining Problems	Asking questions and defining problems in 9–12 builds on K–8 experiences and progresses to formulating, refining, and evaluating empirically testable questions and design problems using models and simulations. • Define a design problem that involves the development of a process or system with interacting components and criteria and constraints that may include social, technical and/or environmental considerations.
Developing and Using Models	Modeling in 9–12 builds on K–8 experiences and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed world(s). • Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system.
	Planning and carrying out investigations in 9-12 builds on K-8 experiences and progresses to include investigations that provide evidence for and test conceptual, mathematical, physical, and empirical models.

Planning and Carrying Out Investigations	• Select appropriate tools to collect, record, analyze, and evaluate data.
Analyzing and Interpreting Data	Analyzing data in 9–12 builds on K–8 experiences and progresses to introducing more detailed statistical analysis, the comparison of data sets for consistency, and the use of models to generate and analyze data. • Analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in order to make valid and reliable scientific claims or determine an optimal design solution.
Using Mathematics and Computational Thinking	Mathematical and computational thinking in 9-12 builds on K-8 and experiences and progresses to using algebraic thinking and analysis, a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms, and computational tools for statistical analysis to analyze, represent, and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions. • Use mathematical, computational, and/or algorithmic representations of phenomena or design solutions to describe and/or support claims and/or explanations. • Apply techniques of algebra and functions to represent and solve scientific and engineering problems. • Use simple limit cases to test mathematical expressions, computer programs, algorithms, or simulations of a process or system to see if a model "makes sense" by comparing the outcomes with what is known about the real world. • Apply ratios, rates, percentages, and unit conversions in the context of complicated measurement problems involving quantities with derived or compound units (such as mg/mL, kg/m3, acre-feet, etc.).
Constructing Explanations and Designing Solutions	Constructing explanations and designing solutions in 9–12 builds on K– 8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories. • Design, evaluate, and/or refine a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations.
Obtaining, Evaluating, and Communicating Information	Obtaining, evaluating, and communicating information in 9–12 builds on K–8 experiences and progresses to evaluating the validity and reliability of the claims, methods, and designs. • Communicate scientific and/or technical information or ideas (e.g. about phenomena and/or the process of development and the design and performance of a proposed process or system) in multiple formats (including orally, graphically, textually, and mathematically).
Crosscutting Concepts	
Patterns	Observed patterns in nature guide organization and classification and prompt questions about relationships and causes underlying them.
	• Mathematical representations are needed to identify some patterns. • Empirical evidence is needed to identify patterns.
Cause and Effect: Mechanism and Prediction	Events have causes, sometimes simple, sometimes multifaceted. Deciphering causal relationships, and the mechanisms by which they are mediated, is a major activity of science and engineering.
	• Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. • Cause and effect relationships can be suggested and predicted for complex natural and human designed systems by examining what is known about smaller scale mechanisms within the system. • Systems can be designed to cause a desired effect. • Changes in systems may have various causes that may not have equal effects.
Systems and System Models	A system is an organized group of related objects or components; models can be used for understanding and predicting the behavior of systems.
	• Systems can be designed to do specific tasks. • Models (e.g., physical, mathematical, computer models) can be used to simulate systems and interactions—including energy, matter, and information flows—within and between systems at different scales. • Models can be used to predict the behavior of a system, but these predictions have limited precision and reliability due to the assumptions and approximations inherent in models.

Common Core State Standards for High School Mathematics

Modeling standards are indicated by the star symbol (*) throughout other conceptual categories.

CCSS: Conceptual Category – Number and Quantity

Quantities	*Reason quantitatively and use units to solve problems.

CCSS: Conceptual Category – Algebra	
Creating Equations	*Create equations that describe numbers or relationships.
Reasoning with Equations and Inequalities	Understand solving equations as a process of reasoning and explain the reasoning. Solve equations and inequalities in one variable.

Common Core State Standards for English Language Arts

CCSS: English Language Arts Standards » Science & Technical Subjects » Grade 11-12	
Craft and Structure	• **RST.11-12.4 –** Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to grades 11-12 texts and topics.
Integration of Knowledge and Ideas	• **RST.11-12.7 –** Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem. • **RST.11-12.9 –** Synthesize information from a range of sources (e.g., texts, experiments, simulations) into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible.
Range of Reading and Level of Text Complexity	• **RST.11-12.10 –** By the end of grade 12, read and comprehend science/technical texts in the grades 11-CCR text complexity band independently and proficiently.

CCSS: English Language Arts Standards » Writing » Grade 11-12	
Text Types and Purposes	**WHST.11-12.2 –** Write informative/explanatory texts, including the narration of historical events, scientific procedures/experiments, or technical processes. • **WHST.11-12.2.A –** Introduce a topic and organize complex ideas, concepts, and information so that each new element builds on that which precedes it to create a unified whole; include formatting (e.g., headings), graphics (e.g., figures, tables), and multimedia when useful to aiding comprehension. • **WHST.11-12.2.B –** Develop the topic thoroughly by selecting the most significant and relevant facts, extended definitions, concrete details, quotations, or other information and examples appropriate to the audience's knowledge of the topic. • **WHST.11-12.2.E** – Provide a concluding statement or section that follows from and supports the information or explanation provided (e.g., articulating implications or the significance of the topic).
Production and Distribution of Writing	• **WHST.11-12.4 –** Produce clear and coherent writing in which the development, organization, and style are appropriate to task, purpose, and audience.
Research to Build and Present Knowledge	• **WHST.11-12.7 –** Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation. • **WHST.11-12.9 –** Draw evidence from informational texts to support analysis, reflection, and research.
Range of Writing	• **WHST.11-12.10 –** Write routinely over extended time frames (time for reflection and revision) and shorter time frames (a single sitting or a day or two) for a range of discipline-specific tasks, purposes, and audiences.

Essential Questions

1. What types of motions are in a drive train?
2. How do gears affect the direction, speed, and movement of equipment?
3. How can an operator quickly engage and disengage high-powered equipment?
4. What mechanisms does equipment have to prevent damage to equipment using high torque?
5. How is friction reduced in a machine?
6. What causes friction to occur in equipment?
7. What factors impact wear and damage to gears, bearings, and clutches?
8. How does bearing installation affect performance?

9. Why are precision measurement tools used when repairing equipment?
10. How can a technician determine how a drive train failed?

Key Terms

Angular load	**Antifriction bearing**	**Axial load**
Ball-bearing	**Bearing**	**Bore**
Busching	**Cage**	**Clutch**
Clutch disc	**Clutch shaft**	**Compound gears**
Electromagnetic clutch	**Feeler gauge**	**Flywheel**
Friction bearing	**Friction clutch**	**Friction plate**
Gear ratio	**Gear reduction**	**Gearbox**
Helical gear	**Herringbone gear**	**Idler gear**
Journal	**Pressure plate**	**Pinion gear**
Rack gear	**Radial load**	**Roller bearing**
Sealed bearing	**Single-pole switch**	**Spur gear**
Tapered roller bearing	**Telescoping gauge**	**Torque**
Transmission	**Worm gear**	

Day-to-Day Plans
Time: 15 days

*Refer to the Teacher Resources section for specific information on teaching this lesson, in particular **Lesson 2.1 Teacher Notes**, **Lesson 2.1 Glossary**, **Lesson 2.1 Materials**, and other support documents.*

Day 1:

- Present **Concepts**, **Performance Objectives**, **Essential Questions**, and **Key Terms** to provide a lesson overview.
- Provide students with a copy of **Activity 2.1.1 Manual Transmission**.
- Students work in teams of three to begin *Activity 2.1.1 Manual Transmission*.
- Assign students to read pages 215–227 of *Heavy Equipment Power Trains and Systems*.

Day 2:

- Review pages 215–227 of *Heavy Equipment Power Trains and Systems* with students.
- Students work in teams to complete *Activity 2.1.1 Manual Transmission*.
- Assign students to read pages 253–262 and 274–276 of *Heavy Equipment Power Trains and Systems*.

Day 3 – 4:

- Review pages 253–262 and 274–276 of *Heavy Equipment Power Trains and Systems* with students.
- Provide students *Presentation Notes* pages to use throughout the presentation to record notes and reflections. Students add these pages to their *Agriscience Notebook*.
- Present PowerPoint® **Clutches**.

- Students take notes using the *Presentation Notes* pages provided by the teacher.
- Provide students with a copy of **Activity 2.1.2 Clutch Performance**.
- Students begin working on *Activity 2.1.2 Clutch Performance*.

Day 5:

- Students work in groups to complete *Activity 2.1.2 Clutch Performance*.

Day 6:

- Provide students with a copy of **Activity 2.1.3 Speed and Torque**.
- Students work in teams of three to complete *Activity 2.1.3 Speed and Torque*.
- Assign students to read pages 242–249 of *Heavy Equipment Power Trains and Systems*.

Day 7 – 8:

- Review pages 242–249 of *Heavy Equipment Power Trains and Systems* with students.
- Provide students *Presentation Notes* pages to use throughout the presentation to record notes and reflections. Students add these pages to their *Agriscience Notebook*.
- Present PowerPoint® **Bearings**.
- Students take notes using the *Presentation Notes* pages provided by the teacher.
- Provide students with a copy of **Activity 2.1.4 Bearing Selection**.
- Students work in pairs to complete *Activity 2.1.4 Bearing Selection*.

Day 9:

- Provide students **Presentation Notes** pages to use throughout the presentation to record notes and reflections. Students add these pages to their *Agriscience Notebook*.
- Present PowerPoint® **Gears**.
- Students take notes using the *Presentation Notes* pages provided by the teacher.
- Provide students with a copy of **Project 2.1.5 Machine Gears**, **Employability Evaluation Rubric**, and **Project 2.1.5 Evaluation Rubric**.

Day 10 – 12:

- Students work in groups on *Project 2.1.5 Machine Gears*.
- Use *Project 2.1.5 Evaluation Rubric* to evaluate Project 2.1.5 Machine Gears.

Day 13 – 14:

- Provide students with a copy of **Activity 2.1.6 Worn Gears**, **Work/Repair Order Template**, and **Work/Repair Order Evaluation Rubric**.
- Students work in groups to complete *Activity 2.1.6 Worn Gears*.
- Students work individually to complete and submit a Work/Repair Order Template.
- Use the *Work/Repair Order Evaluation Rubric* to assess student work/repair orders.

Day 15:

- Distribute **Lesson 2.1 Check for Understanding**.
- Students will complete *Lesson 2.1 Check for Understanding* and submit it for evaluation.
- Use **Lesson 2.1 Check for Understanding Key** to evaluate student assessments.

Instructional Resources

PowerPoint® Presentations

Bearings

Clutches

Gears

Student Support Documents

Lesson 2.1 Glossary

Presentation Notes

Activity 2.1.1 Manual Transmission

Activity 2.1.2 Clutch Performance

Activity 2.1.3 Speed and Torque

Activity 2.1.4 Bearing Replacement

Project 2.1.5 Machine Gears

Activity 2.1.6 Worn Gears

Teacher Resources

Lesson 2.1 Drive Train Components PDF

Lesson 2.1 Teacher Notes

Lesson 2.1 Materials

Lesson 2.1 Check for Understanding

Answer Keys and Assessment Rubrics

Lesson 2.1 Check for Understanding Answer Key

Project 2.1.5 Evaluation Rubric

Employability Evaluation Rubric

Work/Repair Order Evaluation Rubric

Student Project Development Template

Work/Repair Order Template

Reference Sources

Curriculum for Agricultural Science Education. (2019). Mechanical systems in agriculture. Lexington, KY: Author.

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Fullbay. (2021). *Preload vs endplay*. Retrieved from **https://www.fullbay.com/blog/preload-vs-endplay/#:~:text=Preload%20settings%20on%20a%20bearing,a%20small%20amount%20of%20clearance**

Herren, R. (2006). *Agricultural mechanics fundamentals and applications*. (5th ed.). Clifton Park, NY: Thomson Delmar Learning.

Koel, L., & Mazur, G. A. (2013). *Agricultural technical systems and mechanics*. Orland Park, IL: American Technical Publishers.

SKF. (2017). *Bearing damage and failure analysis*. Lansdale, PA: Author.

Yanik, Kevin. (2017) *Determining typed of bearing damage*. Cleveland, OH: Pit and Quarry.

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FFA Connections

This lesson provides conceptual and procedural knowledge required for participation in the following FFA activities:

- Agricultural Proficiency
  - **Agricultural Mechanics Repair and Maintenance –Placement**
  - **Agricultural Mechanics Repair and Maintenance –Entrepreneurship**
- Agriscience Fair
  - **Power, Structural and Technical Systems**
- Career Development Events
  - **Agricultural Technology & Mechanical Systems**
- Educational Resources
  - **SAE Idea Cards-Power, Structural and Technical Systems**
  - **Power, Structural and Technical System Careers**
  - **Power, Structural and Technical Systems Career Focus Area Resources**
  - Agricultural Mechanics (**Word)** (**PDF**)
  - Keegan Humm-SAE-Placement-Implement Dealership Lesson Plan (**Word**) (**PDF**)
  - Power, Structural and Technical Careers **(Word)**

Skills and knowledge from this lesson support the development and implementation of service-learning projects that address drive train components.

- **Service-Learning and Living to Serve Grants**
- Service-learning projects focused on diagnosing equipment with drive train components.
- Project ideas include diagnosing and fixing lawnmowers, ATVs and other equipment for local community members.
- Living to Serve Grants provide funding to FFA chapters to support service-learning and community service projects.

For more information, visit the **National FFA Organization** website.

SAE for All

Immersion SAE

Students interested in this lesson's topics should explore the following related Immersion SAEs. An immersion SAE is optional and replaces the agricultural literacy component of the Foundational SAE.

- Placement/Internship
  - **Implement Dealership Placement SAE | Keegan Humm**
  - **Agricultural Mechanics SAE | Jeremiah Hager**

For more information on the guiding principles for implementing SAE programs, visit the **SAE for All: Evolving Essentials** site.

Critical Thinking and Application Extensions

Explanation

1. Students will create an identification chart for bearings found on selected agricultural equipment.

Application

2. Students will measure and adjust the backlash of gears, sprockets, and pulleys on equipment.

CASE

Lesson 2.1 Teacher Notes

Lesson 2.1 Drive Train Components

In preparation for teaching this lesson, review Concepts, Performance Objectives, Essential Questions, and Key Terms, along with the PowerPoint® presentations. Also, review all activity, project, and problem directions, expectations, and work students will complete.

Students begin the lesson assembling drive trains composed of gears and sprockets and observe how they function. Next, they construct a model clutch and adjust an electromagnetic clutches air gap. Then students identify bearings. Finally, students complete the lesson by assembling a model drive train

PowerPoints®

Bearings

Use the presentation to provide background knowledge related to types of bearings and their makeup.

Clutches

Present information to students on the types of clutches found in a drive train and the purpose of each.

Gears

This presentation contains background knowledge of gear types found in a drive system.

Reading Discussion

Chapter 7, pages 215–227

Use the questions below to facilitate a class discussion on Day 2 pertaining to the reading assignment for this lesson. Encourage student participation and assess student understanding of materials based on discussion.

- What types of gears do equipment use?
- What is a gear ratio?
- How does a sliding gear transmission work?

Chapter 8, pages 253–262 and 274–276

Use the questions below to facilitate a class discussion on Day 6 pertaining to the reading assignment for this lesson. Encourage student participation and assess student understanding of materials based on discussion.

- How does a traction clutch work?
- How are clutches used for operating power take-off?
- What is a multiple-disc clutch?
- How is electrical current used to operate an electromagnetic clutch?

Chapter 7, pages 242–249

Use the questions below to facilitate a class discussion on Day 8 pertaining to the reading assignment for this lesson. Encourage student participation and assess student understanding of materials based on discussion.

- What is the purpose of a bearing?
- What types of loads affect bearing performance?
- How does a ball bearing compare to a roller bearing?
- What types of tools does a technician use to remove and replace bearings?
- How are endplay and preload measured when installing a bearing?

Activities, Projects, and Problems

Activity 2.1.1 Manual Transmission

Students work in teams of three to construct a three-speed transmission with compound gears. Then, they calculate the gear reductions in the system.

Teacher Preparation

VEX Material Preparation

Students use materials from VEX to construct their systems. Develop a storage system for the materials to fit your storage needs. Small plastic bins with dividers, such as tackle and lure boxes, work well for organizing small pieces. Use a large toolbox for each to store the plastic containers. Provide each team with a **VEX EDR Booster Kit guide**. They use the guide as a part reference for this activity.

Transmission

Use the instructions from Part One of the activity to assemble an example gearbox for students to view. The transmission assembled during the activity needs to be square with tight fasteners to prevent the gears from binding. Caution students to keep hands, fingers, and objects away from moving parts when they turn on and off the system. The system needs to be held down at the outer edges of the C frame when it is running to prevent it from sliding off the workbench or table.

Student Performance

Part One

Students assemble a frame, motor, and gears to make a gear system. The system will include a drive axle with three different sized gears, an idler axle with three different sized gears, and a driven axle with a single sized gear. The drive axle and driven axle are fixed in place during the entire activity. The idler axle will slide back and forth to change the connected gears in the system.

Part Two

Students attach a battery to power the system. Students use wire pin leads for connecting power to the motor to prevent a short circuit and potential electrical fire. Students turn the power on and off by disconnecting the red wire from the battery.

Students place a piece of masking tape on the wheel tread to count revolutions. Next, students calculate the gear ratio for the first gear combination. Then the partners work together to find the rpm of the gear combination by turning on the system and counting wheel revolutions for 15 seconds. They multiply the number of revolutions made in 15 seconds by four to find the rpm. Students repeat calculations and measurements for two more gear combinations. Finally, students complete the activity by answering analysis questions.

Results and Evaluation

Table 1 contains example data, and Table 2 has potential answers to analysis questions.

Table 1. *Example Data*

Gear Settings	Drive Teeth	Idler Teeth	Driven Teeth	Gear Reduction	Wheel Revolutions per 15 sec.	Wheel rpm
1^{st} Gear Setting	12	60	60	5	9	36
2^{nd} Gear Setting	36	36/60	60	1	25	100
3^{rd} Gear Setting	60	12/60	60	0.2	125	500

Table 2. ***Analysis Questions and Potential Responses***

Q1	What are the gear combinations that can drive the wheel?	*12-60-60* *36-36/60-60* *60-12/60-60*
Q2	Predict the speeds of each combination by ranking them from fastest to slowest.	*Answers will vary.*

Activity 2.1.2 Clutch Performance

Students work in groups of four to construct a clutch model and adjust the air gap settings on an electromagnetic clutch.

Teacher Preparation

Discuss the assigned reading from chapter 8 with students. Then present *Clutches* before starting this activity. Cut 1" dowels six inches in length for students to use as a clutch shaft. Acquire new and worn clutch discs from a local dealer for students to inspect. Students use the electrical starter board, wires and alligator clips, and 12V power supply from the EETC board for this activity. Print copies of the **clutch manual** for each group.

Student Performance

Part One

Students use sandpaper discs, paper plates, and wooden dowels to construct model clutches with various amounts of friction. Students observe how the force applied to the plates and the friction between the plates impact how well the clutch can engage a drive train.

Part Two

Provide each group of students with three clutch discs to observe. Students will note evidence of damage, potential causes and complaints, and identify each disc as new, used, or needing replacement.

Part Three

Students start by sketching the parts of an electromagnetic clutch and measuring the air gap. Then they wire the clutch and use an electrical switch to engage and disengage the pulley. Next, students change the air gap and observe how it impacts the clutch's functionality.

Results and Evaluation

Students should understand how a friction and electromagnetic clutch function. Use Table 3 to assess students' answers to the analysis questions.

Table 3. ***Analysis Questions and Potential Responses***

Q1	What happens if an operator does not apply enough pressure to the clutch pedal?	*The clutch will slip, and the discs will wear and not engage the drive train.*
Q2	What will happen to the clutch disc if a technician misadjusts it, so it is always partially engaged?	*The clutch will slip, and the discs will constantly wear when not engaging the drive train.*
Q3	What evidence did you see of the model clutch slipping?	*The sandpaper is worn and scratched.*
Q4	Which clutch component do you believe a technician will need to replace most often? Why?	*Clutch discs because they are the engage point that may slip.*

Q5	How does the rotor engage the pulley?	*The rotor has an electromagnet that connects to the pulley when an electrical current flows through the rotor.*
Q6	Why is the air gap setting necessary on an electromagnetic clutch?	*If the air gap is too large, there is insufficient magnetic strength to engage the pulley.*
Q7	What would happen if the air gap setting was less than the recommended size?	*The rotor and pulley may always be in contact, causing the drive train to be partially engaged at all times.*

Activity 2.1.3 Speed and Torque

Students work individually to calculate the linear speed of the wheel on a transmission. Then they work in teams to measure the torque of each gear ratio.

Teacher Preparation

Students use the transmission constructed during the previous activity. Students use a toggle switch to turn the system on and off quickly. The clutch will slip under the lowest gear ratio. Letting the clutch slip too long will cause it to wear out very quickly. Instruct students to be prepared to shut down the system when the clutch slips.

Student Performance

Part One

Students begin calculating the linear speed of the wheel for each of the gear ratios calculated during *Activity 2.1.1 Manual Transmission*. The speed is calculated in miles per hour. They answer analysis questions after making calculations.

Part Two

Students attach a string and cup to the wheel driven by the gearbox. Then they rotate the wheel so the string is at the top and pulling down on the wheel. Next, students add washers to the cup until the weight causes the wheel to rotate or they have added all washers. They then turn the system on to see if it has enough torque to lift the washers. Finally, students weigh the washers and calculate the torque placed on the system in inch-pounds.

Results and Evaluation

The wheel's diameter is 4 inches, and the circumference is 12.56″(4π). Example calculations for Part One and Part Two are in Table 4. Use example responses in Table 5 to guide students through analysis questions.

Table 4. ***Part One Example Calculations***

Speed Calculations			
Reduction	**rpm**	**Speed Inches per Minute**	**Speed Miles per Hour**
5	20	$\frac{Distance}{Time} = \frac{20\ revolutions}{minute} \times \frac{12.56in}{1\ revolution}$ $\frac{Distance}{Time} = \frac{251.2in}{minute}$	$\frac{251.2in}{minute} \times \frac{1ft}{12in} \times \frac{1\ mile}{5280ft} \times \frac{60\ minutes}{1\ hour}$ $\frac{Distance}{Time} = \frac{0.24miles}{hour}$

1	100	$\frac{\text{Distance}}{\text{Time}} = \frac{\text{100 revolutions}}{\text{minute}} \times \frac{\text{12.56in}}{\text{1 revolution}}$ $\frac{\text{Distance}}{\text{Time}} = \frac{\text{1256in}}{\text{minute}}$	$\frac{\text{1256in}}{\text{minute}} \times \frac{\text{1ft}}{\text{12in}} \times \frac{\text{1 mile}}{\text{5280ft}} \times \frac{\text{60 minutes}}{\text{1 hour}}$ $\frac{\text{Distance}}{\text{Time}} = \frac{\text{1.18miles}}{\text{hour}}$
0.2	500	$\frac{\text{Distance}}{\text{Time}} = \frac{\text{500 revolutions}}{\text{minute}} \times \frac{\text{12.56in}}{\text{1 revolution}}$ $\frac{\text{Distance}}{\text{Time}} = \frac{\text{6280in}}{\text{minute}}$	$\frac{\text{6280in}}{\text{minute}} \times \frac{\text{1ft}}{\text{12in}} \times \frac{\text{1 mile}}{\text{5280ft}} \times \frac{\text{60 minutes}}{\text{1 hour}}$ $\frac{\text{Distance}}{\text{Time}} = \frac{\text{5.94miles}}{\text{hour}}$

Torque Calculations

Reduction	rpm	Washers	Weight Newtons	Torque Newton-meters
5	20	40	1.6 lbs	**Torque = 1.6 lbs x 2 in.** **Torque = 3.2 in.-lbs**
1	100	30	1.2 lbs	**Torque = 1.2 lbs x 2 in.** **Torque = 2.4 in.-lbs**
0.2	500	3	0.12 lbs	**Torque = 0.12 x 2 in.** **Torque = 0.24 in.-lbs**

Table 5. ***Analysis Questions and Potential Responses***

Q1	How do gear reductions affect linear speed?	*Gear reductions can increase or decrease the speed of the driven axle and wheel.*
Q2	What would happen to the system's speed if the wheel were smaller? Why do you believe so?	*The speed would decrease because the circumference of the wheel is lower.*
Q3	How could you increase the system's speed without changing the gear ratios?	*Increase the diameter of the wheel to increase the circumference and total distance the wheel travels during each revolution.*
Q4	How does a compound gear design affect torque?	*Compound gears can increase the torque of a system.*
Q5	What is the relationship between speed and torque in a gear system?	*As torque increases, the speed decreases.*

Activity 2.1.4 Bearing Replacement

Students observe and measure different types of bearings. Then they use the bearing information to find replacements.

Teacher Preparation
Discuss the assigned reading from chapter 7 with students. Then present *Bearings* before starting this activity. Student pairs will need an example of a friction, ball, and roller bearing for this activity. Acquire used samples from a local dealer or supplier.

Student Performance
Part One
Students clean all bearings with a rag. Then they use a dial caliper to measure the dimensions of each bearing. Students record all dimensions and note any damage to the bearings in their *Logbooks*.

Part Two
Students find replacements for each bearing they inspected and make a pick list for new bearings.

Results and Evaluation
Students submit their pick list in their *Logbooks* at the end of the activity. Review student sketches and measurements and compare them to the picklist to determine if students have selected the correct replacement bearings.

Project 2.1.5 Machine Gears

Students research the components that drive the internal components of a chosen implement. Then they work in teams to construct a model simulating rotary and linear movements found in the system.

Teacher Preparation
Discuss the assigned reading from chapter 7 with students. Then present *Gears* before starting this project. Students will need access to gears, fasteners, and structural components, along with bevel gears and worm gears ordered from VEX. Have storage containers available for students to organize and store parts during the assembly process.

Students may need cutting and measuring tools to construct their designs. Seven hacksaws, a metal chop saw, and seven combination squares should be ample for this project.

If students struggle with research and design, play one of the following videos to show how the threshing system in the combine works and discuss it as an example.

- John Deere S series combine: **https://www.youtube.com/watch?v=FDjGx-94yao**
- Crop flow animation: **https://www.youtube.com/watch?v=fVwnJKZgiP4**

Be prepared to use **Employability Evaluation Rubric** to assess student work habits as they complete the project.

Student Performance
Students individually research the components in their chosen system while recording in their *Logbook*. Then students work with teammates to design and construct a system model. The model system should meet the following criteria.

- Driven by a universal joint connected to the transmission constructed during *Activity 2.1.1 Manual Transmission*.
- Use one motor to supply the power
- A minimum of four motion variations simulated
  - Three rotary motions
  - One linear motion
- Gear ratios and speeds calculated

They sketch the design and record all gear ratios and speeds in their *Logbooks*. Students use VEX components to construct their models. Inspect the model for the following before allowing students to operate on their own.

- Students can turn the model on and off.
- The model has no interfering parts
- Students securely fastened all components.

Students should disassemble models and store all materials as the teacher sees fit.

Students turn in a completed model with their *Logbooks* for assessment. *Logbooks* should include research, sketches, gear ratios, and mathematical calculations.

Results and Evaluation
Designs for this project will vary. The assigned project is the construction of a machine simulating and not performing a task. Students may need to use a hacksaw to cut structural metal parts to size for this activity. Use **Project 2.1.5 Evaluation Rubric** to assess student models and the **Employability Evaluation Rubric** to evaluate student work. Inspect all assemblies before students operate them. The assembly should have an on and off switch with parts fastened tightly together and not interfering with each other.

Activity 2.1.6 Worn Gears

Students practice measuring backlash on a model transmission. Then students disassemble and reassemble a gearbox while adjusting the backlash.

Teacher Preparation
Each student group will need a model transmission from *Activity 2.1.1 Manual Transmission* and a used gearbox. Refer to the materials list for the example gearbox part numbers and vendors used for this activity. Students may use other gearboxes, but activity instructions may not match. In addition, you will need the recommended backlash for the gearbox when students reassemble them. Be prepared to provide students with customer information and a complaint for completing a work/repair order.

Student Performance
Students practice measuring backlash between gears on the model transmission. Then they measure and record a gearbox's backlash. Then they disassemble the gearbox while recording all parts, procedures, and measurements in their *Logbook*. After disassembly, they lubricate the bearings and reassemble the gearbox while adjusting the backlash. They complete the activity by individually completing a Work/Repair order for the gearbox.

Results and Evaluation
Students complete and submit a work/repair order for you to evaluate using the **Work/Repair Order Evaluation Rubric**.

Assessment

Lesson 2.1 Check for Understanding

Lesson 2.1 Check for Understanding is included for you to use as an assessment tool for this lesson. Use **Lesson 2.1 Check for Understanding Answer Key** for evaluation purposes.

Name____

CASE

Activity 2.1.1 Manual Transmission

Have you ridden in a car where the driver manually shifted gears? What happens every time the driver shifts? How can gear systems have multiple speeds? Agricultural machines, such as tractors, have gear systems called transmissions that also change speeds.

Compound gear systems have drive, idler, and driven gears. A technician use ratios to calculate gear speeds. Driven gear speeds in a transmission are directly related to the drive gear size and speed. For example, if the drive gear connected to the engine has 30 teeth and the driven gear has 60 teeth, the gear ratio is 1:2, as shown in the calculation below.

$$\frac{\text{Drive gear teeth}}{\text{Driven gear teeth}} = \frac{30}{60} = \text{Ratio of 1:2}$$

A gear reduction is another way of expressing the relationship between connected gears. A technician can use the reduction to find the speed of the driven gear. Find a reduction by dividing the driven gear teeth by the drive gear teeth, which is the inverse of the ratio calculation. For example, a gear system with a 30-tooth drive gear and 60-tooth driven gear has a reduction of 2.

$$\frac{\text{Driven gear teeth}}{\text{Drive gear teeth}} = \frac{60}{30} = \text{Reduction of 2}$$

With a 1:2 ratio, or reduction of two, the driven gear will rotate at half the speed of the drive gear. Review the example ratio below for calculating the gear speeds in a mechanical drive system.

• A drive gear on an engine has 30 teeth and connects to a driven gear with 150 teeth. • Calculate the reduction by dividing the driven gear by the drive gear. • The reduction is 5. • The driven gear is five times slower than the drive gear.	$\frac{\text{Driven gear teeth}}{\text{Drive gear teeth}} = \frac{150}{30}$ $\frac{150}{30} = 5$
• The known speed of the drive gear is 100 rpm. • Find the speed of the driven gear using the reduction of 5. • Divide the drive rpm by 5 to find the rpm of the driven gear.	$\frac{100\text{ rpm}}{5} = 20\text{ rpm}$
• The speed of the driven gear is 20 rpm.	**Driven gear rpm = 20 rpm**

Figure 1. Example Gear Reduction

As seen in Figure 2, compound systems reduce the speed of a drive train more than a two-gear system would allow. The system in Figure 2 has an idler gear in between the drive and driven gears. Figure 3 shows the calculations for the compound gear reduction of the drivetrain in Figure 2.

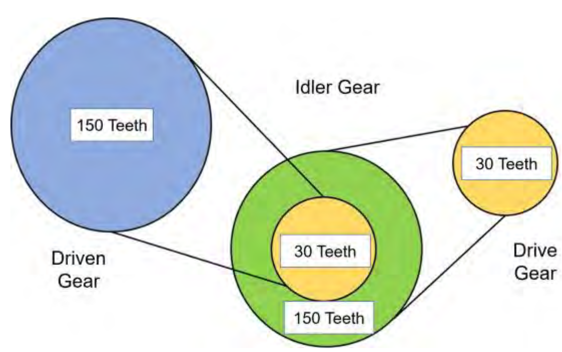


Figure 2. Compound System

• Calculate the drive and idler gear reduction by dividing the idler gear teeth by the drive gear teeth. • Calculate the idler and driven gear reduction by dividing the idler gear teeth by the drive gear teeth. • Find the compound gear reduction by multiplying each reduction. • The reduction is 25. • The driven gear is 25 times slower than the drive gear.	Compound reduction = $\frac{150}{30} \times \frac{150}{30}$ Compound reduction = 5 × 5 Compound reduction = 25 Reduction = 25
• The known speed of the drive gear is 100 rpm. • Find the speed of the driven gear using the reduction of 25.	$\frac{100 \text{ rpm}}{25} = 4 \text{ rpm}$
• The speed of the driven gear is 4 rpm.	**Driven gear rpm = 4 rpm**

Figure 3. Compound Gear Ratio

Drivetrains are an essential component of transferring energy. How are compound drivetrains used to change speeds in a transmission?

Materials

Per team of three students:

- Battery, 12V
- Breadboard pin wire, male to female, black
- Breadboard wire pin, male to female, red
- Flat bearing
- (2) Gear 12-tooth
- (2) Gears 36-tooth
- (2) Gears 60-tooth
- (3) Gears, 60-tooth, extra strength
- Hex wrench $^{3}/_{32}$″
- Hex wrench, $^{5}/_{64}$″
- Masking tape
- Motor clutch
- Motor, 2-wire motor, VEX 393
- (4) Nut, #8-32 keps
- Plastic storage containers
- (2) Screw, #6-32 x ½″
- (8) Screw, #8-32 x ¼″
- (11) Shaft collar
- (2) Shaft, 12″ square
- Shaft, 11mm
- Shaft, 4″ square
- (5) Spacers, 8mm
- (4) Standoffs, 3″
- (2) Steel angle 2x2x25
- (3) Steel rail, 2x1x25
- Wheel, 4″
- Wrench or nut driver, ¼″

Per student:

- Safety glasses
- Pen
- *VEX EDR Booster Kit* Guide
- *Agriscience Notebook*

Procedure

Work in a team of three to assemble a transmission and calculate the three optional speeds. Wear your safety glasses and tie back long hair.

Part One – Transmission Assembly

1. As a team, observe the example transmission assembled by your teacher and shown in Figure 4 with a top, front, and side view.

2. Gather the materials and organize them in plastic storage containers as instructed by your teacher. Then, individually read the remaining steps in Part 1.
    - Use *VEX EDR Booster Kit* guide to identify the materials marked with an asterisk(*).
    - Place large parts in the bottom storage area of the toolbox.
    - Organize small pieces you may lose in small, sealable plastic storage containers.

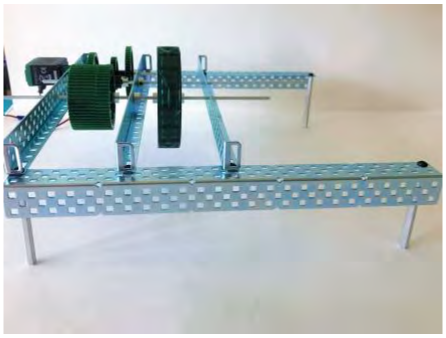
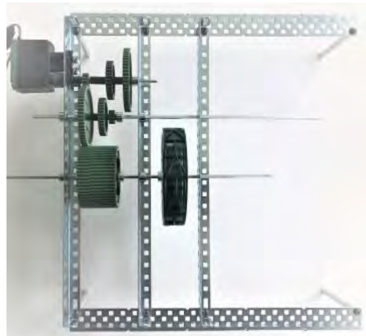
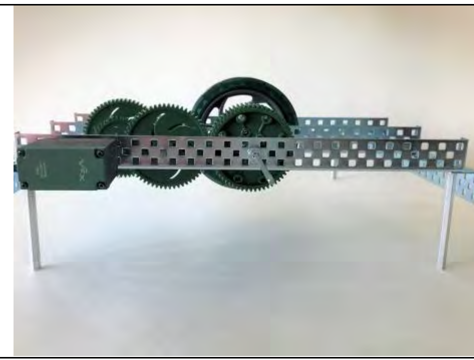
		
Front	**Top**	**Side**

Figure 4. Transmission Views

3. Use a $^{3}/_{32}$″ hex wrench and ¼″ wrench to assemble the following materials to make a C shaped frame setting on four standoffs, as shown in Figure 5.
    - (2) Steel angle 2x2x25
    - (1) Steel rail, 2x1x25
    - (4) Standoffs, 3″ standoffs
    - (4) Screws, #8-32 x ¼″

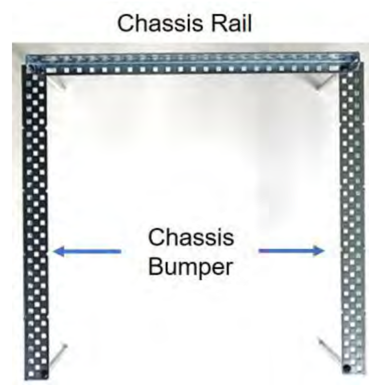


Figure 5. C Frame

4. Attach the motor, clutch, and 11mm shaft to the outside of the chassis rail and the flat bearing to the inside.
    - Line up the motor's drive with the 5th hole on the chassis rail, as seen in the Top view of Figure 4.
    - Use the $^{5}/_{64}$″ hex wrench to fasten two ½″ screws to the motor and chassis rail.
5. Assemble Axle 1 using the following parts on the 4″ shaft in the order listed from left to right. Leave approximately 5mm of the shaft extending from the side with the 8mm spacer. Use Figure 6 for reference.
    - 8mm spacer
    - 12-tooth gear
    - 8mm spacer
    - 8mm spacer
    - 36-tooth gear
    - 8mm spacer
    - 60-tooth gear
    - Shaft collar

Figure 6. Axle 1

6. Assemble Axle 2 using the following parts on a 12″ shaft in the order listed from left to right. Use Figure 7 for reference. Refer to this shaft as Axle 2.
    - Shaft collar
    - 60-tooth gear
    - 8mm spacer
    - 36-tooth gear
    - 12-tooth gear
    - Shaft collar

Figure 7. Axle 2

7. Place a square shaft insert into each 60-tooth high strength gear.
8. Assemble Axle 3 using the following parts on the second 12″ axle in the order listed from left to right. Use Figure 8 for reference. Refer to this shaft as Axle 3.
    - Shaft collar
    - 60-tooth high strength gear
    - 60-tooth high strength gear
    - 60-tooth high strength gear
    - Shaft collar

Figure 8. Axle 3

9. Place the shafts into the following rail holes. Use Figure 9 for reference.
    - Axle 1 – Hole 5, connected to the motor
    - Axle 2 – Hole 8
    - Axle 3 – Hole 13
10. Use two ¼″ screws and keps nuts to fasten a second rail to the frame to hold the opposite side of each shaft, as seen in Figure 10.
    - Refer to Step 9 for hole placement.
    - Tighten the rail on the 7th hole of each bumper chassis

Figure 9. Axle Placement

11. Place shaft collars on Axle 2 and Axle 3 to hold them in place, as seen circled in Figure 10.
    - Place the collars on the outside of the rails.
    - Four shaft collars are needed.
12. Slide the following parts onto Axle 3 in the following order.
    - Shaft collar
    - 4″ wheel
    - Shaft collar
13. Use two ¼″ screws and kep nuts to fasten the third rail to the frame to hold Axle 2 and Axle 3, as seen in Figure 11.
    - Refer to Step 9 for hole placement.
    - Tighten the rail on the 12th hole of each chassis bumper

Figure 10. Second Rail

14. Tighten all shaft collars except the two on the outsides of Axle 2.
    - Use a $^{5}/_{64}$″ hex wrench
    - Tightening the shaft collars will keep all gears, axles, and 8mm spacers in place
15. Slide Axle 2 back and forth and observe how the idler gears connect in the system.
16. Adjust Axle 2 so the 60-tooth gear of Axle 2 is in contact with drive and driven gears.
17. Tighten the shaft collars on the outsides of Axle 2 using a $^{5}/_{64}$″ hex wrench.
18. Answer the *Part One Analysis Questions* on the student data sheet.

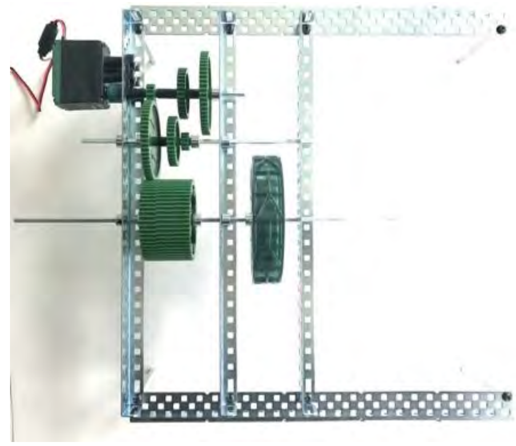


Figure 11. Completed Assembly

Part Two – Gear Speeds

1. Attach the black and red wire pin leads to the corresponding wires on the motor.
2. Place a piece of masking tape on the tread of the wheel.
3. In the 1st Gear Setting row of Table 1, record the number of teeth of the drive, idler, and driven gear currently driving the wheel.
4. Calculate the compound gear reduction for the *1st Gear Setting* and record it in Table 1.
5. Put on safety glasses and tie back long hair.
6. Connect the red and black wires to the battery.
7. Work with your partner to count the number of revolutions the wheel makes in 15 seconds.
    - Have your partner time you as you count the number of times the tape on the wheel rotates.
8. Record the wheel revolutions in Table 1.
9. Disconnect the wire leads from the battery to stop the system.
10. Multiply the number of revolutions during 15 seconds by 4 to find the rpm of the wheel.

    Number of revolutions x 4 = rpm

11. Record the rpm in Table 1.
12. Use the $^{5}/_{64}$″ hex wrench to adjust the idler gear, so the 36-tooth idler engages the drive gear, and the 60-tooth idler engages the driven gear.
13. Repeat Steps 3–12 for the *2nd Gear Setting*.
14. Use the $^{5}/_{64}$″ hex wrench to adjust the idler gear, so the 12-tooth idler engages the drive gear, and the 60-tooth idler engages the driven gear.
15. Repeat Steps 3–12 for the *3rd Gear Setting*.
16. Store the transmission and materials as instructed by your teacher. You will be using the transmission for future activities and projects.

Conclusion

1. How can compound gear systems be used to change speeds?

2. Why are transmissions essential components of mobile machines, such as a tractor?

Name____

Activity 2.1.1 Student Data

Table 1. ***Gear Observations***

Gear Settings	Drive Teeth	Idler Teeth	Driven Teeth	Gear Reduction	Wheel Revolutions per 15 seconds	Wheel rpm
1^{st} Gear Setting						
2^{nd} Gear Setting						
3^{rd} Gear Setting						

Part One Analysis Questions

Q1 What are the gear combinations that can drive the wheel?

Q2 Predict the speeds of each combination by ranking them from fastest to slowest.

Name____

CASE

Activity 2.1.2 Clutch Performance

Purpose

Have you ever driven or ridden a stick-shift vehicle? Stick shift vehicles have a clutch engaging and disengaging the transmission. Likewise, agriculture equipment has clutches engaging powertrains, power take-offs, and transmissions. In addition, a technician may find a series of clutches when following an equipment power source to the output. Which types of clutches do technicians find in equipment, and how do those clutches work?

Friction clutches, the most common type of, uses a pressure plate pressing against the engine's flywheel to transfer power to the transmission. The pressure plate consists of course materials binding to the flywheel driven by the engine. A manual or mechanically controlled lever applies pressure to the plate. The more pressure on the plate, the better the connection. If there is not enough pressure applied to the plate, the clutch will slip, and the pressure plate will wear. Operators sometimes say they are "riding the clutch" when not applying enough pressure on a clutch while driving. Riding a clutch causes the friction plate to wear prematurely.

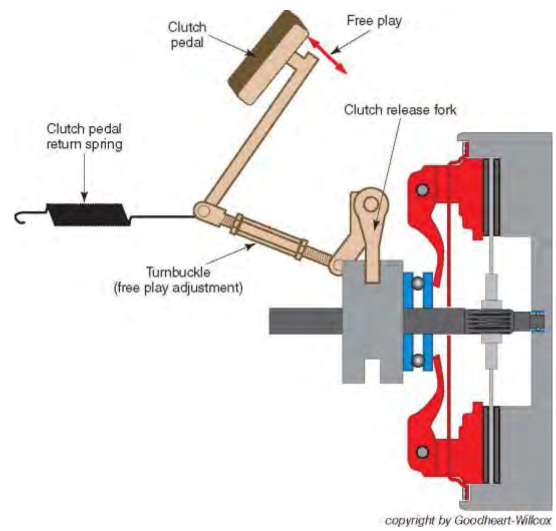


Photo from Goodheart-Wilcox, Heavy Equipment Power Trains and Systems, 2019

Figure 1. Friction Clutch

Besides tractors, slip clutches in equipment powertrains prevent damage when equipment engages an immovable object. For example, if a hay baler picks up a rock it cannot compact the hay, the entire powertrain may break. A clutch driving the powertrain will slip when the baler engages the rock, and the powertrain will immediately stop and prevent costly damage. Unlike friction clutches in tractors, which need to be engaged by the operator, friction clutches in equipment are always engaged until an object causes it to slip.

Power take-offs also have clutches. These clutches can be friction or electromagnetic. Once turned on, a switch sends an electrical current to the clutch, creating a magnetic force engaging the drive and driven sides. A technician adjusts a small air gap between the clutch plate on the drive side and an armature connected to the driven side. If a technician incorrectly sets the air gap, the clutch will not engage or potentially shorten the circuit and blow a fuse. Fuses prevent damage to an electrical circuit from a high current draw. Small implements use electromagnetic clutches to engage equipment such as lawnmower blades.

What causes friction and electromagnetic clutches to break, and how does a technician maintain them?

Materials

Per group of four students:

- Battery, 12V
- (3) Clutch disc
- (3) Dowel 6″ x 1″ diameter
- Electromagnetic clutch and manual
- Feeler gauge
- Fuse, 10 amp
- Hot glue gun
- Hot glue stick
- (3) Paper plates, 10″
- Permanent marker
- Plate, heavy, 12″
- (2) Sandpaper disc, 40-grit 6″
- Sandpaper disc 200 grit–6″
- Sandpaper disc, 120 grit – 6″
- Socket extension $^{3}/_{8}$″drive
- Socket wrench, $^{3}/_{8}$″ drive
- Socket, $^{9}/_{16}$″, $^{3}/_{8}$″ drive
- Switch, single-pole, single-throw
- Washers 1″
- (4) Wire with alligator clips

Per student:

- *Heavy Equipment Power Trains and Systems* text
- Safety glasses
- Pen
- *Agriscience Notebook*

Procedure

Make a model of a friction clutch and identify worn clutch discs. Then adjust the air gap in an electromagnetic clutch. Wear your safety glasses and tie back long hair.

Part One – Friction Clutch

1. Use a permanent marker to label a paper plate *Driven – High Friction* on the **inside** of the plate.
2. Stick a 40-grit plate to the center of the **outside** of the *Driven – High Friction* paper plate.
3. Repeat Steps 1–2 using a 120-grit and 200-grit sandpaper disc.
   - Label the 120-grit as *Driven – Medium Friction*
   - Label the 200-grit as *Driven – Low Friction*
4. Use a hot glue gun to attach a wooden dowel to the inside of the center of each plate.
5. Use a permanent marker to label the **inside** of the heavy plate *Drive.*
6. Stick a 40-grit plate to the center of the **inside** of the drive plate.
7. Place the *Driven – High Friction* plate on the drive plate to simulate a friction clutch on a tractor.
8. Sketch the model clutch on *Activity 2.1.2 Student Observations sheet*.
9. Use page 254 of the *Heavy Power Trains and Systems* text to label the following components of your clutch.
   - Flywheel
   - Clutch shaft
   - Pressure plate
   - Clutch disc
10. Hold on to the shaft to represent resistance to movement by the transmission.
11. Have your partner spin the flywheel.
12. Record your observations in the partially engaged clutch pedal column of Table 1 on the observation sheet.

13. Repeat Steps 10–12 with the medium and high friction plates.
14. Repeat Steps 10–13 with weight added to the driven plate.
15. Record your observations in the fully engaged clutch pedal column of Table 1.
16. Answer *Part One Analysis Questions* on the student observation sheet.

Part Two – Clutch Inspection

Your teacher will provide you with three clutch discs numbered one to three. Observe each disc and complete Table 2 on the observation sheet. Include evidence of damage, potential causes, and customer complaints. Then label each pad as new, used, or needing replacement.

Part Three – Clutch Adjustment

1. Locate the three windows in the clutch brake plate, one at each stud.
2. Use a permanent marker to label studs *1*, *2*, and *3*.
3. Sketch the clutch on the observations sheet and use the clutch manual to label the following components and the stud numbers.
    - Pulley (driven side)
    - Rotor (drive side)
    - Brake plate
    - Armature/brake plate contact surface
    - Window
4. Rotate the pully, so no rivets are in line with the three windows.
5. Measure the air gap by stud 1.
    - Insert a .012" feeler gauge through each window, carefully positioning the feeler gauge in the air gap between the rotor face and the armature. See Figure 2.
    - If the gap is greater than .012″, increase the size of the gauge until it snuggly fits.
    - If the gap is less than .012″, decrease the size of the gauge until it snuggly fits.

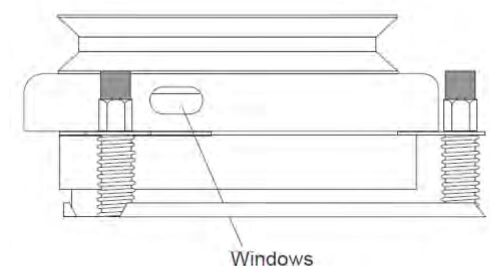
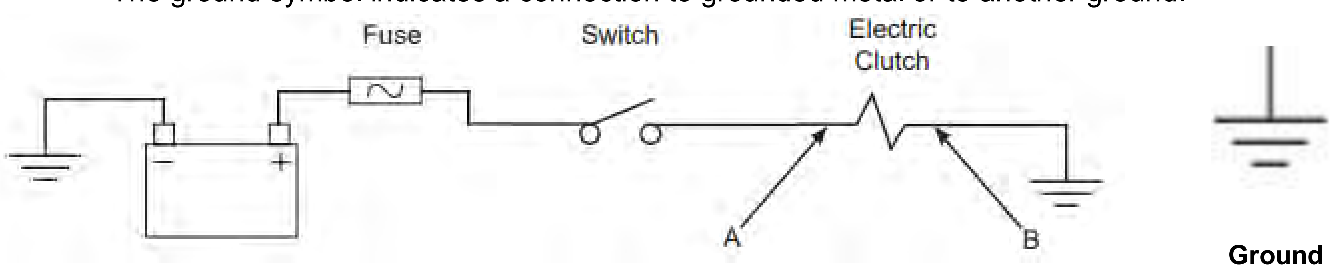


Figure 2. Window View of Air Gap

6. Record the original air gap by stud 1 on the observation sheet.
7. Repeat Steps 5–6 for the air gaps by stud *2* and *3* in Table 3.
8. Use the following materials to wire a circuit controlling an electromagnetic clutch. Use the schematic in Figure 3.
    - The ground symbol indicates a connection to grounded metal or to another ground.



Ground

Figure 3. Electromagnetic Clutch

9. Keep the switch in the off position.
10. Rotate the clutch when the switch is off and record its functionality on your observation sheet.
11. Move the switch to the on position.
12. Rotate the pully when the switch is on and record its functionality.
13. Move the switch to the off position.
14. Use a $^{9}/_{16}$″ socket and wrench to loosen the nuts until each is flush with the stud.
15. Measure the adjusted air gap by each stud and record it on the observation sheet.
16. Repeat Steps 8–12.
17. Adjust the air gap back to 0.012″.
18. Repeat Steps 8–12.
19. Answer *Part Three Analysis Questions* on the observation sheet.

Conclusion

1. How does a clutch work with a transmission?

2. What components in a clutch are more susceptible to wear and damage?

3. How is a friction clutch different from an electromagnetic clutch?

Name____

Activity 2.1.2 Student Observations

Part One – Friction Clutch

Model Clutch Sketch

Table 1. ***Clutch Observations***

Friction Plate	Partially Engaged Clutch	Fully Engaged Clutch
Low Friction		
Medium Friction		
High Friction		

Part One Analysis Questions

Q1 What happens if an operator does not apply enough pressure to the clutch pedal?

Q2 What will happen to the clutch disc if a technician misadjusts it, so it is always partially engaged?

Q3 What evidence did you see of the model clutch slipping?

Q4 Which clutch component do you believe a technician will need to replace most often? Why?

Part Two – Clutch Inspection

Table 2. ***Clutch Inspection***

Clutch #	Damage	Causes	Potential Complaints	Age
1				
2				
3				

Part Three – Clutch Adjustment

Electromagnetic Clutch Sketch

Table 3. ***Air Gap***

Stud Number	Original Air Gap	Adjusted Air Gap
1		
2		
3		

Table 4. ***Clutch Functionality***

Air Gap	Switch in Off Position	Switch in On Position
Original Air Gap		
Adjusted Air Gap		

Part Three Analysis Questions

Q5 How does the rotor engage the pulley?

Q6 Why is the air gap setting necessary on an electromagnetic clutch?

Q7 What would happen if the air gap setting was less than the recommended size?

Name____

Activity 2.1.3 Speed and Torque

Purpose

Bicyclists use gears on their bikes for speed and power. They may shift to smaller gears to acquire more speed when trying to pass another bicyclist. They may shift to larger gears to gain more power when going up a hill. How are speed and power measured in a multi-gear system?

In previous activities, you measured the rotational speed of gears and wheels in a system using revolutions per minute (rpm). Sometimes speed is measured linearly, such as feet per minute or miles per hour. The linear speed of a gear system driving a wheel depends on the wheel's diameter. As the diameter of the wheel increases, the greater distance it travels for every revolution. The distance a wheel travels for each revolution equals the wheel’s circumference. Find the wheel’s circumference by multiplying the diameter by *pi* (π), or approximately 3.14. Then, multiply the wheel’s circumference by the number of revolutions per minute to find the distance the wheel will travel during a set time. See example calculations in Figure 1 for a wheel with a diameter of 12 in. and a speed of 100 rpm.

Circumference	Speed – Inches per Minute	Speed – Miles per Hour
Circumference = D × π Circumference = 12in × π (3.14) Circumference = 37.70in The wheel travels 37.70in for every revolution	$\frac{\text{Distance}}{\text{Time}} = \frac{100\ \cancel{\text{revolutions}}}{\text{minute}} \times \frac{37.70\text{in}}{1\ \cancel{\text{revolution}}}$ $\frac{\text{Distance}}{\text{Time}} = \frac{3770\text{in}}{\text{minute}}$	$\frac{\text{Distance}}{\text{Time}} = \frac{3770\cancel{\text{in}}}{\text{minute}} \times \frac{1\text{ft}}{12\cancel{\text{in}}}$ $\frac{\text{Distance}}{\text{Time}} = \frac{314.16\text{ft}}{\text{minute}}$ $\frac{\text{Distance}}{\text{Time}} = \frac{314.16\cancel{\text{ft}}}{\cancel{\text{minute}}} \times \frac{1\text{ mile}}{5280\cancel{\text{ft}}} \times \frac{60\ \cancel{\text{minutes}}}{1\text{ hour}}$ $\frac{\text{Distance}}{\text{Time}} = \frac{3.57\text{ miles}}{\text{hour}}$ The wheel is traveling 3.57 miles/hour

Figure 1. Calculations

A wheel is a lever that revolves around an axis. The lever's length is the wheel's radius, as seen in Figure 2. The power of a wheel depends upon torque. Measure the torque of a wheel by multiplying the weight it can lift by the wheel's radius. For example, a wheel with a radius of 6 centimeters that can lift 10 Newtons has a torque of 60N-cm or 0.6N-m.

$$10\text{N} \times 6\text{cm} = 60\text{N} - \text{cm}$$

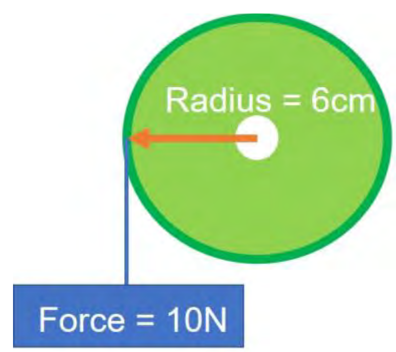


Figure 2. Wheel

Some gear systems have a clutch on the driveshaft to prevent the system from breaking if it cannot handle the torque. The clutch will slip if the force is too great, and the gears will not move. The clutch wears down each time it slips and will eventually break. Operators should shut down the system immediately if they observe the clutch slipping.

What is the relationship between a system's gear ratio, torque, and speed? What factors will cause a gear system to fail and a clutch to slip?

Materials

Per team of three students:

- Battery, 12V
- Calculator
- Cup, 9 oz
- Ruler
- String, 3′
- Switch, single-pole, single-throw
- Transmission model
- (40) Washers, 1″
- Wire with alligator clips, black
- (2) Wire with alligator clips, red

Per student:

- Safety glasses
- Pen
- *Agriscience Notebook*

Per class:

- (2) Electronic balance

Procedure

Work with your teammates to measure the speed and torque of a wheel driven by different gear systems. Record all data, answers to analysis questions, and calculations in your *Logbook*. Wear your safety glasses and tie back long hair.

Part One – Speed Calculations

1. Use a ruler to measure the diameter of the wheel in inches.
2. Calculate the circumference of the wheel and record it in Table 1 of *Activity 2.1.2 Student Observation*.
3. Use your rpm calculations from *Activity 2.1.1 Manual Transmission* to find the distance the wheel would travel in one minute for each of the three gear reductions.
4. Record the distance in Table 1.
5. Convert inches per minute to miles per hour for each of the three gear reductions. Record your calculations on the observations sheet and answers in Table 1.
6. Answer *Part One Analysis Questions*.

Part Two – Torque Calculations

1. Put on safety glasses and tie back long hair.
2. Attach a black and red wire lead to the motor’s pin wires.
3. Attach the other end of the red wire lead to a toggle switch.
4. Attach the other end of the black wire lead to the battery.
5. Attach one end of the second red wire to lead to the battery.
6. Attach one end of a three-foot string to the cup and the other end of the string to the wheel, as shown in Figure 3.
7. Hang the cup over the bracket and edge of the table.
8. Adjust the idler gear so the 60-tooth idler gear is engaged to both the drive and driven gears.
9. Attach the positive end of the battery to the second wire on the switch.
    - Be sure the switch is **OFF**.

10. Slowly turn the gears to wrap the string ¼ the way around and at the top of the wheel, as shown in Figure 3.
11. Add washers to the cup one at a time until the wheel turns or you run out of washers, whichever comes first.
12. Once the cup has fallen, or all washers have been added, have a teammate hold on to the system so it does not fall off the edge.
    - Turn on the motor by switching the toggle switch to the **ON** position.
    - Shut **OFF** the system after the cup raises approximately one foot or if the clutch slips.
    - **Caution**: Keep all hands and objects away from the moving gears and shafts.
13. Use an electronic balance to find the weight of the washers in the cup in pounds.

Figure 3. Wheel and String

14. Record the weight in Table 2 of the student observation sheet.
15. Calculate the torque (inch-pounds) placed on the system by multiplying the weight of the washers by the wheel's 2-inch radius. (inches x pounds = inch-pounds)
16. Record torque in Table 2.
17. Adjust the idler gear to engage 36-tooth and 60-tooth idler gears.
18. Repeat Steps 10–16.
19. Adjust the idler gear to engage the 12-tooth and 60-tooth idler gears.
20. Repeat Steps 10–16.
21. Answer *Part Two Analysis Questions*.
22. Store your system as instructed by your teacher.

Conclusion

1. Large tractors have engines with more power than some cars. Why is a tractor's speed slower than a car's?

2. Why are vehicles designed to change gears from low speed to high speed?

3. Why are speed and torque both considered when designing a drivetrain?

Name____

Activity 2.1.2 Student Observations

Part One – Speed Calculations

Table 1. ***Speed Measurements***

Idler Gear Setting	Wheel Circumference (in)	Wheel RPM	Distance in 1 minute	Speed (mph)
60 tooth				
36/60 tooth				
12/60 tooth				

Speed Calculations:

Part One Analysis Questions

Q1 How do gear reductions affect linear speed?

Q2 What would happen to the system's speed if the wheel were smaller? Why do you believe so?

Q3 How could you increase the system's speed without changing the gear reductions?

Part Two – Torque Calculations

Table 2. ***Torque Measurements***

Idler Gear Setting	Weight (lbs)	Wheel Radius (in)	Torque (in-lbs)
60 tooth		2 inches	
36/60 tooth		2 inches	
12/60 tooth		2 inches	

Part Two Analysis Questions

Q4 How does a compound gear design affect torque?

Q5 What is the relationship between speed and torque in a gear system?

Name____ CASE

Activity 2.1.4 Bearing Replacement

Purpose

All machines will have friction producing squeals, clunks, and generating heat at one time or another. If operators do not address these noises, the noises may become smoke and fire. Friction causes breakdowns and inefficiencies over the life of a machine. Agricultural equipment has specially designed components to reduce friction, dissipate heat, and reduce wear to prolong the life of the equipment. What are those components?

Most machines have lubricants, such as oil and grease, to separate moving surfaces. The moving services, called bearings and journals, have asperities, which are microscopic peaks and valleys in the metal that hold the lubricant. When an operator first operates equipment, asperities are much larger and wear down during an equipment's break-in period.

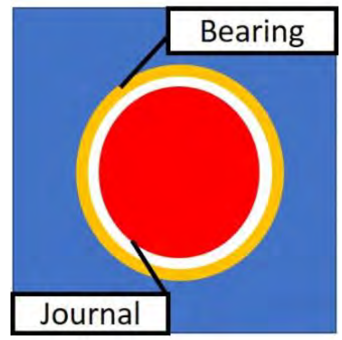


Figure 1. Stationary Bearing and Journal

The bearing is the external service holding a rotating component in place. The journal is the rotating component surrounded by the bearing. Stationary bearings, also called friction bearings, are composed of soft, non-ferrous metals and do not move. A sleeve or bushing is an example of a friction bearing seen in Figure 1. Antifriction bearings consist of rollers, balls, or needles, reducing the friction between components. Evidence of bearing damage includes nicks, pits, and cracks caused by a poor fit, excessive end play, misalignment, or contamination. Bearings are encased and sealed to prevent contaminants from causing damage.

The load placed on the bearing is another cause of failure. Radial and axial loads cause friction between the bearing and the journal. This friction can cause the bearing surface between the bearing and journal to be worn and out-of-round. Tapered bearings withstand the loads and do not become out-of-round as easily as ball bearings. Therefore, multiple measurements of the round bearing surface and journal are necessary to determine if they are out-of-round. A minimum of two measurements perpendicular (90°) to each other is required to determine if a part is out-of-round. A telescoping gauge represents the internal diameter of a bearing surface that a dial caliper cannot reach.

How is does the anatomy of bearings and bushings differ? As a technician, what is the procedure for measuring, identifying, and replacing a bearing?

Materials

Per pair of students:

- (3) Bearing
- Cleaning fluid
- Dial caliper, 6″/150mm
- Flathead screwdriver
- Shop towels
- Telescoping gauge

Per student:

- Safety glasses
- Nitrile gloves
- Pen
- *Agriscience Notebook*
- *Logbook*

Procedure

Identify the cause of bearing failure and find a replacement bearing to order for a customer.

Part One – Identification and wear

1. Put on safety glasses and gloves, and tie back long hair.
2. Acquire a set of bearings from your instructor.
3. Clean all bearings with a rag and cleaning solution.

Friction Bearing

1. Find the friction bearing to begin the identification process.
2. Sketch the bearing in your *Logbook*.
3. Inspect the bearing for an identifying number and record it in your *Logbook* if applicable.
    - Note the location of the identification number on your sketch.
4. Use a caliper and telescoping gauge to measure the bore, outer diameter, and width of the friction bearing and record it in your *Logbook*.
    - Make two measurements perpendicular to each other when measuring the diameters.
    - Note the measurements on your sketch.
5. Note in your *Logbook* if the friction bearing is out of round.
6. Use a dial caliper to measure the thickness of the bearing and record it in your *Logbook* on your sketch.
7. Note any nicks, cracks, or pits and record them on your sketch.

Ball Bearing

1. Find the ball bearing to begin the identification process.
2. Use a flathead screwdriver to remove the bearing face to see the interior components.
3. Sketch the bearing in your *Logbook* and label the following components
    - Outer race
    - Inner race
    - Bore
    - Balls
    - Cage
4. Inspect the bearing for an identifying number and record it in your *Logbook* if applicable.
    - Note the location of the identification number on your sketch.
5. Measure the outer diameter, bore diameter, and width of the ball bearing and record it in your *Logbook*.
    - Make two measurements perpendicular to each other when measuring the diameters.
    - Note the measurements on your sketch.
6. Note in your *Logbook* if the friction bearing is out of round.
7. Note any nicks, cracks, or pits and record them on your sketch.

Tapered Roller Bearing

1. Find the tapered roller bearing to begin the identification process.
2. Use a flathead screwdriver to remove the bearing face to see the interior components.
3. Sketch the bearing in your *Logbook* and label the following parts.
    - Cup
    - Cone
    - Rollers

- Bore
- Cage

4. Inspect the bearing for an identifying number and record it in your *Logbook* if applicable.
   - Note the location of the identification number on your sketch.
5. Measure the bore, outer diameter, and width of the friction bearing and record it in your *Logbook*.
   - Make two measurements perpendicular to each other when measuring the diameters.
   - Note the measurements on your sketch.
6. Note in your *Logbook* if the tapered bearing is out of round.
7. Note any nicks, cracks, or pits and record them on your sketch.

Part Two – Replacement

Use your measurements and internet research to find a replacement for each bearing you inspected. Write a pick list for the replacement bearings in your *Logbook*. Then, submit your *Logbook* for your teacher to assess.

Conclusion

1. How are friction and antifriction bearings different?

2. How does a tapered bearing reduce the forces of axial and radial loads?

3. How are bearings protected from outside contaminants?

4. What information does a technician need to replace a bearing?

Name____ CASE

Project 2.1.5 Machine Gears

Agricultural equipment consists of the same essential components you worked with in previous lessons. A mechanical system will have a drivetrain powered by a power take-off connected by a U joint. The drivetrain has components transferring power from one location to another. Synchronous drivetrains contain gears, sprockets, and chains transferring power with no slippage between the parts. Gears meshed together while a roller chain connects sprockets. A drive gear or sprocket attached to the drive shaft turns the driven gears or sprockets that work in a synchronous drive system.

A combine harvester is a complex machine with shafts facing multiple directions and moving at various speeds. The driven shafts operate a threshing system separating grain from a plant. Power from a single drive shaft from the engine is transferred to systems of different gears and drive components to thresh the grain.

What types of gears in sprockets do you find in equipment used in your local area?

Materials

Per team of three students:

- Battery, 12V
- Fabrication tools and materials
- Switch, single pole, single throw
- VEX supplies

Per student:

- *Agriscience Notebook*
- Computer with internet access
- *Employability Evaluation Rubric*
- *Heavy Equipment Power Trains and Systems* textbook
- *Logbook*
- Nitrile gloves
- Pen
- Safety glasses
- *Project 2.1.5 Evaluation Rubric*

Procedure

As a team of three, select a piece of agricultural equipment with a system of gears, chains, and sprockets from *Activity 1.1.1 Local Equipment*. Research the equipment's drive train components. Refer to the diagrams in Chapter 4 *Agricultural Equipment Identification* of the *Heavy Equipment Power Trains and Systems* textbook. Record the purpose of each component in your *Logbook*. Then identify the rotary and linear motions driving those components. Sketch the direction and speed of each movement in your *Logbook*. Record all research and sketches in your *Logbook*.

Work with your team to construct a mechanical system demonstrating the motions in the equipment and powered by your transmission. You will have access to the drive system components discussed during the *Drive Systems* presentation. The system should include a working model meeting the following criteria.

- A universal joint connecting the transmission to the driveshaft to power the model
- A minimum of four simulated motions
  - Three rotary motions
  - One linear motion
- Operated by a single-pole switch

Your teacher will inspect your assembly to ensure you can operate it safely, meeting the following criteria.

- Turned on and off with a single-pole switch
- Securely fastened components
- Has no interfering parts

Your teacher will use *Project 2.1.5 Evaluation Rubric* to assess the model, recorded research, and sketches. In addition, your teacher will use the *Employability Evaluation Rubric* to evaluate your work behavior during the project.

Conclusion

1. What is the purpose of using different gears and sprockets in a mechanical system?

2. What challenges do technicians face when assembling systems?

3. What factors affect the types of components used in a drivetrain?

Name____ CASE

Project 2.1.5 Evaluation Rubric

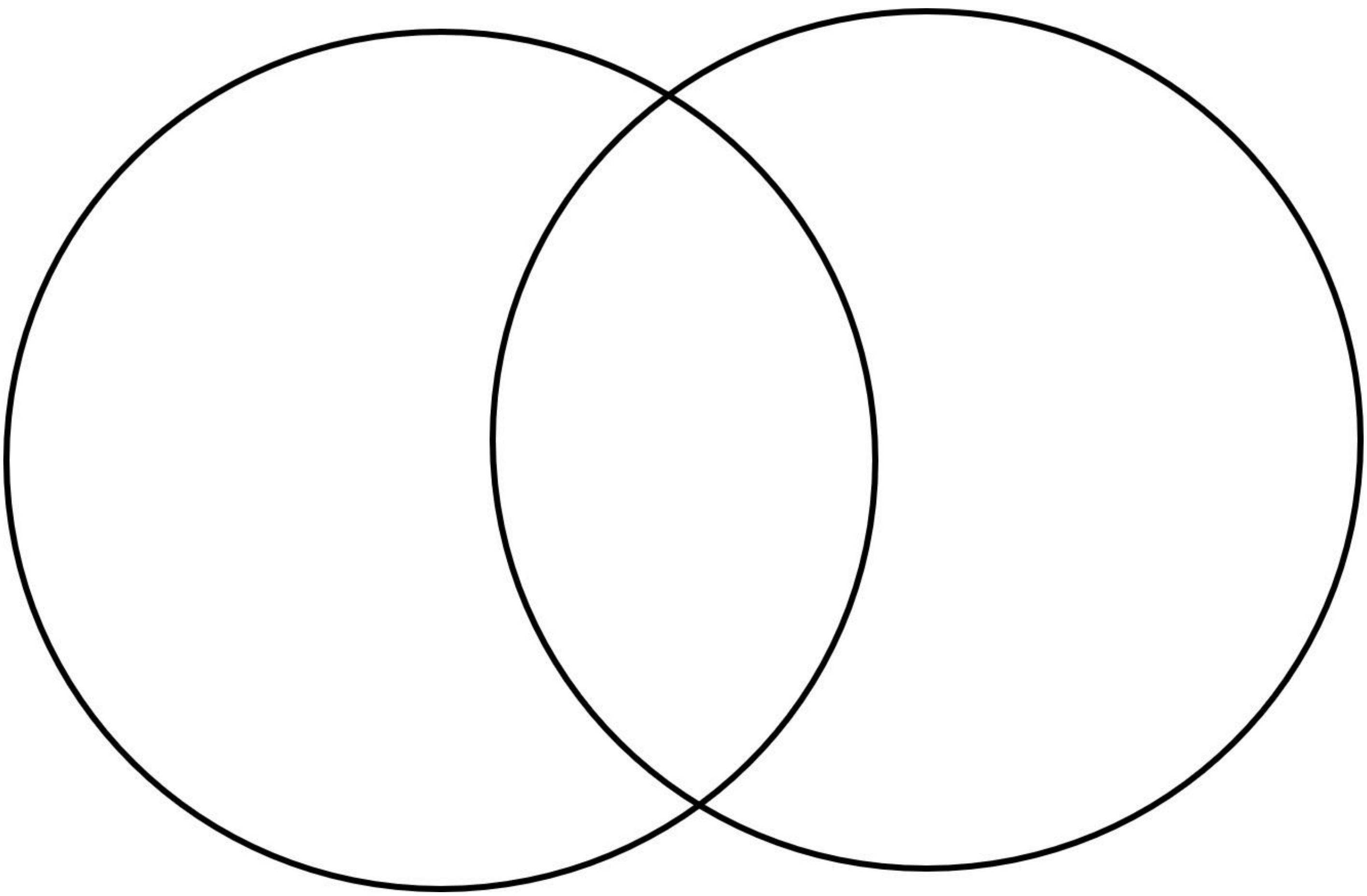
Areas with Room for Improvement	Criteria	Areas that Meet or Exceed Expectations
	Component Research Four components are described with the following information about each component. • Purpose • Speed • Direction	
	Driven Gears The model contains four driven gears, with each gear demonstrating a different speed, direction, or motion. At least one of the driven gears is driving a linear motion.	
	Sketch A machine sketch provides all information on the size, location, and placement of all gears, sprockets, and tracks needed for assembly. The sketch is neat and is easy to understand.	
	Gear ratios Four gear ratios are provided with mathematical calculations. All calculations are complete with the correct units and are easy to read.	
	Assembly and Operation The machine assembly meets all the following criteria after teacher inspection. • The machine is turned on and off with a touch sensor • All components are securely fastened • All components work without interfering with each other or breaking	

Name____

Lesson 2.1 Check for Understanding

1. How can a clutch prevent an equipment's drivetrain from becoming damaged?

2. Use a Ven diagram to explain the difference between a friction and electromagnetic clutch.



3. Which of the following is a characteristic of a friction bearing?
   a) A friction bearing has rollers that rotate around a journal.
   b) A friction bearing is composed of ferrous metal to prevent scarring and abrasions.
   c) A friction bearing does not move while the rotating part is in motion.
   d) A friction bearing is tapered to withstand an axial load.

4. Matching drivetrain component with the correct description

______ Sprocket	A. Reduces the rotary motion speed.
______ Worm gear	B. Changes the rotary motion by 90 degrees.
______ Cam gear	C. Converts rotary motion into linear motion.
______ Helical gear	D. Will not become out-of-round when placed under an axial load.
______ Tapered bearing	E. Transfers rotary motion while not changing the direction.
______ Bevel gear	F. Gear design is quieter than a spur gear.

5. What is the reduction in a drive system with a 24-tooth drive gear and 48-tooth driven gear? Show your work.

6. List three causes of bearing failure and an indication of each.

7. How can a technician determine if a drive train has a low or high backlash?

8. What is the relationship between torque and speed in a gear-driven mechanical system?

9. Rank the gear assemblies below from highest to lowest torque, with 1 highest. The gear furthest to the left in each assembly is the drive gear. The gear furthest to the right in each assembly is the driven gear.

Ranking:
Drive Gear = 36 teeth
Driven Gear = 36 teeth

Ranking:
Drive Gear = 12 teeth
Driven Gear = 60 teeth

Ranking:
Drive Gear = 12 teeth
Driven Gear = 36 teeth

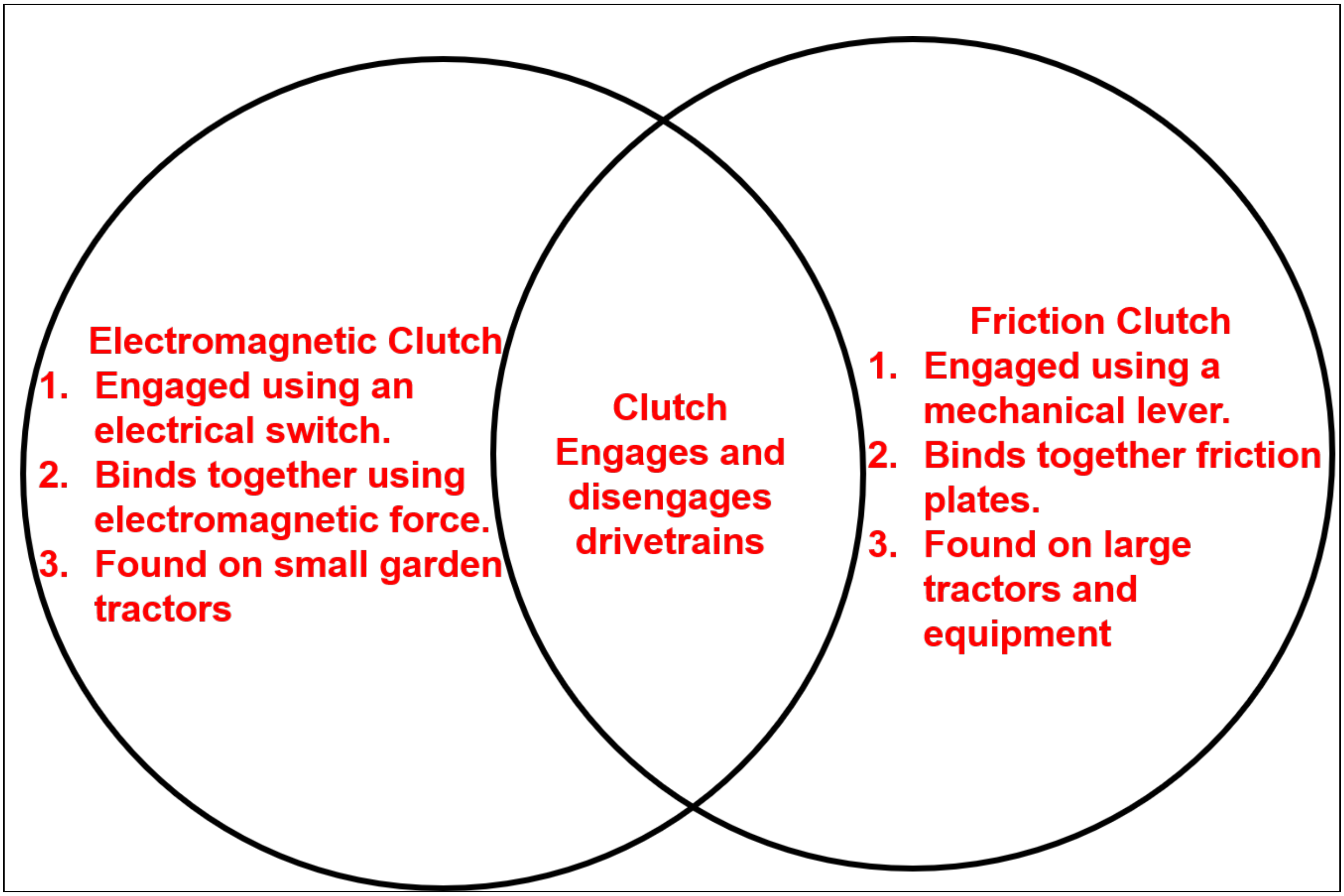
CASE

Lesson 2.1 Check for Understanding Answer Key

1. How can a clutch prevent an equipment's drivetrain from becoming damaged?

A friction clutch power an equipment drivetrain will slip if the drivetrain component comes in contact with an immovable object. If the clutch did not slip, a drivetrain component would break due to the applied forces and the inability of the drivetrain to move.

2. Use a Ven diagram to explain the difference between a friction and electromagnetic clutch.



3. Which of the following is a characteristic of a friction bearing?

   a) A friction bearing has rollers that rotate around a journal.
   b) A friction bearing is composed of ferrous metal to prevent scarring and abrasions.
   c) A friction bearing does not move while the rotating part is in motion.
   d) A friction bearing is tapered to withstand an axial load.

4. Matching drivetrain component with the correct description

E ____ Sprocket
A ____ Worm gear
C ____ Cam gear
F ____ Helical gear
D ____ Tapered bearing
B ____ Bevel gear

A. Reduces the rotary motion speed.
B. Changes the rotary motion by 90 degrees.
C Converts rotary motion into linear motion.
D. Will not become out-of-round when placed under an axial load.
E. Transfers rotary motion while not changing the direction.
F. Gear design is quieter than a spur gear.

5. What is the reduction in a drive system with a 24-tooth drive gear and 48-tooth driven gear? Show your work.

$$\textbf{Reduction} = \frac{\textbf{48 tooth}}{\textbf{24 tooth}}$$

Reduction = 2

6. List three causes of bearing failure and an indication of each.

Radial load – Bearing is unevenly worn and out-of-round
Contamination – Bearing was nicks, scratches, or cracks
Lack of lubrication – Bearing has signs of heat such as discoloration and scarring.

7. How can a technician determine if a drive train has a low or high backlash?

A gearbox with low backlash will have bound gears with little or no end play when a technician turns the connecting shaft. Gears with no backlash will bind and break.

A gearbox with high backlash will have loose gears with too much end play when a technician turns the connecting shaft. Gears with increased backlash will have signs of excess wear.

8. What is the relationship between torque and speed in a gear-driven mechanical system?

The speed and torque are inversely related. Therefore, as speed increases, torque decreases.

9. Rank the gear assemblies below from highest to lowest torque, with 1 highest. The gear furthest to the left in each assembly is the drive gear. The gear furthest to the right in each assembly is the driven gear.

Ranking: 3
Drive Gear = 36 teeth
Driven Gear = 36 teeth

Ranking: 1
Drive Gear = 12 teeth
Driven Gear = 60 teeth

Ranking: 2
Drive Gear = 12 teeth
Driven Gear = 36 teeth

Name____ CASE

Activity 2.1.6 Worn Gears

Purpose

Gears mesh together with exact spacing for them to work correctly. If the gears are connected tightly, they will bind and not move. If connected loosely, gears will have excessive wear, and a technician will need to replace them. How does a technician prevent gears from wearing?

Backlash is the play, or movement, between gears. Technicians feel backlash by moving one gear back and forth while holding the opposing gear in place. The free movement before the opposite gear starts moving is the backlash. Backlash is a critical measurement that allows the gears to mesh without binding and provide space for a lubricating oil film between the teeth. The lubricant prevents overheating and tooth damage to the gear.

Technicians measure backlash by placing a dial indicator's plunger at the edge of the gear's tooth. While viewing the dial indicator, they slightly rotate the gear back and forth while holding the opposing gear still and noting how far the dial moves to measure backlash. A gearbox needs correct backlash to transmit power in agricultural equipment. Gearboxes change the speed, torque, and direction of power flow. They transfer power to other powertrain components such as rotors, belts, augers, rollers, conveyors, reels, and shafts.

Gearboxes use a range of lubricants depending on the application. Always consult the manufacturer's service literature for specific lubricants. Technicians should inspect gearboxes for external leaks and maintain oil levels. When changing the gearbox oil, note the color of the oil and look for metallic material in the oil. Some gearbox drain plugs have a magnet; it is normal to have some debris attached to this plug. Inspect magnetic plug for large metal pieces to indicate possible gear or bearing damage.

If backlash is not within a manufacturer's specification, adjustment is required. Technicians use shims or quills to make backlash adjustments. The backlash will increase when the gears are moved apart and decrease when gears move towards each other. How will you inspect and adjust gears to prevent them from wearing?

Materials

Per group of four students:

- Ball peen hammer
- Brass drift punch
- Chisel
- Dial caliper 6″/150
- Dial indicator
- Gearbox
- Paint pen
- Seal installer
- Shop towels
- Slip joint pliers
- Socket set, $^{3}/_{8}$″ drive
- Socket wrench $^{3}/_{8}$″ drive
- Torque wrench, in-lb, $^{3}/_{8}$″ drive
- Transmission model

Per student:

- *Agriscience Notebook*
- *Logbook*
- Nitrile gloves
- Pen
- Safety glasses
- *Work/Repair Order Evaluation Rubric*
- *Work/Repair Order Template*

Procedure

Work in a group of four to inspect gear assemblies for wear and backlash. Wear your safety glasses.

Part One – Backlash Practice

Figure 1. Backlash Measurement

1. Acquire a transmission model and dial indicator.
2. Set up the dial indicator to measure the backlash between the driven and idler gear, as seen in Figure 1.
3. Hold the driven gear as you move the idler gear.
4. Observe the measurement change on the dial indicator and record the backlash in your *Logbook*.
5. Explain how you could increase or decrease the backlash between the gears.
6. Repeat Steps 2–4 to measure the backlash between the drive and idler gears.

Part Two – Power Train Inspection

Create a table in your *Logbook* entry for each step of disassembly and assembly. Include tasks, tools used, and measurement specifications. In addition, record the section, page, and figure number from the service manual related to each step taken when applicable.

1. Put on safety glasses and gloves, and tie back long hair.
2. Before disassembling the gearbox, check the current backlash setting by feel.
    - Hold the output shaft solid and turn the input shaft.
    - There should be some backlash in the gears.
3. Assemble dial indicator.
4. Set dial indicator base on the gearbox housing and plunger on the gear tooth
    - Make sure that the dial indicator has room to travel. Move the input shaft back and forth and measure the backlash.
5. Record measurements in your *Logbook*.
6. Mark the cover's orientation to the gearbox, using a paint pen for correct reassembly.
7. Remove fasteners with socket and socket wrench.
8. Organize fasteners and note size and length for proper reassembly in your *Logbook*. Remove the gearbox cover.
9. Sketch the internal components of the gearbox in your *Logbook* and label the input shaft, output shaft, bearings, and shims.
10. Remove the input shaft from the housing by hand.
11. Remove bearings, seals, and shims from the input shaft.
12. Remove the output shaft from the housing.
13. Remove bearings, seals, and shims from the output shaft.
14. Clean the housing, shaft, and bearings using a parts washer and/or brake cleaner.
15. Dry parts with disposable rags.
16. Dispose of rags in a flame-resistant container.

17. Identify the gear type and bearing type used in this gearbox and record them in your *Logbook*.
18. Inspect bearing rollers, inner cone, and bearing cup for damage, chips, or flaking.
19. Record the damage and cause of damage, and record a pick list in your *Logbook*.

Part Three – Work/Repair Order

1. Reassemble the gearbox in reverse order.
    - Use your disassembly notes in your *Logbook* to help you.
2. Record your assembly procedure in your *Logbook*.
3. Measure the backlash as you did during Part One.
4. Record measurement in your *Logbook*.
5. Look up the correct backlash range in the user manual or get the measurement from your teacher.
6. If the backlash is not in the correct range, add or remove shims until the backlash is confirmed.
7. Use your *Logbook* notes to individually complete a *Work/Repair Order* and submit it to your teacher to be evaluated using the *Work/Repair Order Evaluation Rubric*.
    - Your teacher will provide you with the customer information.

Conclusion

1. Why do gears need to have backlash?

2. How does a technician determine if gears are incorrectly set?

3. What will happen to a powertrain if the gear backlash is too low?

Lesson 2.2 Final Drives

Preface

A variety of factors affect the power of a mobile machine. Final drive systems adjust a machine’s torque and speed before powering a drive wheel. A machine’s ballasting and tire selection impact the efficiency of power transfer.

Differentials and planetary gears are two systems used to optimize speed and torque on a final drive. Differentials allow two wheels on the same axle to turn at different speeds while maintaining torque. Planetary gears use a compact design to distribute the total load to multiple gears to decrease wear and needed space. Once the drive system's power is optimized, the system transfers the power to the wheels or track.

All rotating wheels and tracks have bearings to increase their efficiency. Technicians use precision tools to measure, replace, and install drive train components with bearings. The endplay, which is the perpendicular movement of a rotating wheel, can be reduced by torquing the nut holding a wheel on a spindle. Torquing the nut compacts the bearings and increases the force needed to rotate, called the preload. Endplay and preload settings are essential for an efficient drive train transferring power to the tires.

Tires transfer the power from the machine to the ground. Proper tire selection is an essential skill for technicians. Tires use compressed air to support the equipment. Improper tire maintenance and selection decrease a machine's efficiency and can increase wheel slippage. Wheel slippage can cause a tractor to tip backward, severely injuring or killing the operator. Technicians add weights called ballasts to the tractor to increase traction, efficiency, and weight distribution. Ballasts are added to the tractor’s front, wheels, or the three-point hitch

Students begin the lesson by constructing a model differential system. Next, they use a simulator to control a planetary drive. Then students identify and select tires for agricultural equipment. Finally, students calculate the wheel slippage of a model tractor and add ballasting to optimize efficiency.

Concepts	**Performance Objectives**
Students will know and understand	*Students will learn concepts by doing*
1. Differentials allow implements to maintain equal torque at different speeds.	• Assemble a model of a differential system. (Activity 2.2.1)
2. Planetary gears affect the torque, speed, and direction of a machine.	• Simulate planetary gear settings and observe the input and output speeds. (Activity 2.2.2)
3. Technicians use precision measurement tools to set preload and endplay in a powertrain system.	• Disassemble and adjust tapered bearings on a wheel hub. (Activity 2.2.3)
4. Tire and tracks provide traction in agricultural equipment when proper ground contact is applied.	• Identify and select tires for a tractor. (Activity 2.2.4) • Determine ballast requirements for specific equipment applications. (Activity 2.2.5)
5. Technicians use precision tools to complete a failure analysis and determine the root cause of an equipment failure.	• Troubleshoot and complete a work/repair order for a broken drive train. (Project 2.2.6)

National AFNR Common Career Technical Core Standards Alignment

Career Ready Practices
2. Apply appropriate academic and technical skills.
• CRP.02.02: Use strategic thinking to connect and apply technical concepts to solve problems in the workplace and community.

Power, Structural and Technical (AG-PST)
1. Apply physical science principles and engineering applications related to mechanical equipment, structures, and biological systems to solve problems and improve performance in AFNR power, structural, and technical systems.
• AG-PST 1.3: Investigate solutions to AFNR power, structural, and technical systems.
2. Operate and maintain mechanical equipment related to AFNR power, structural, and technical systems.
• AG-PST 2.1: Maintain machinery and equipment by performing scheduled service routines.
• AG-PST 2.2: Perform service routines to maintain power units and equipment.
• AG-PST 2.3: Operate machinery and equipment while observing all safety precautions.
3. Service and repair mechanical equipment and power systems used in AFNR power, structural and technical systems.
• AG-PST 3.2: Service and repair power transmission systems following manufacturer's guidelines.

Next Generation Science Standards Alignment

Crosscutting Concepts	
Systems and System Models	A system is an organized group of related objects or components; models can be used for understanding and predicting the behavior of systems.
	• Systems can be designed to do specific tasks. • When investigating or describing a system, the boundaries and initial conditions of the system need to be defined and their inputs and outputs analyzed and described using models. • Models (e.g., physical, mathematical, computer models) can be used to simulate systems and interactions—including energy, matter, and information flows—within and between systems at different scales. • Models can be used to predict the behavior of a system, but these predictions have limited precision and reliability due to the assumptions and approximations inherent in models.

Common Core State Standards for High School Mathematics

Modeling standards are indicated by the star symbol (*) throughout other conceptual categories.

CCSS: Conceptual Category – Number and Quantity	
Quantities	*Reason quantitatively and use units to solve problems.

Common Core State Standards for English Language Arts

CCSS: English Language Arts Standards » Science & Technical Subjects » Grade 11-12	
Key Ideas and Details	• **RST.11-12.3 –** Follow precisely a complex multistep procedure when carrying out experiments, taking measurements, or performing technical tasks; analyze the specific results based on explanations in the text.
Craft and Structure	• **RST.11-12.4 –** Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to grades 11-12 texts and topics.
Integration of Knowledge and Ideas	• **RST.11-12.9 –** Synthesize information from a range of sources (e.g., texts, experiments, simulations) into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible.
Range of Reading and Level of Text Complexity	• **RST.11-12.10 –** By the end of grade 12, read and comprehend science/technical texts in the grades 11-CCR text complexity band independently and proficiently.

CCSS: English Language Arts Standards » Writing » Grade 11-12	
Range of Writing	• **WHST.11-12.10 –** Write routinely over extended time frames (time for reflection and revision) and shorter time frames (a single sitting or a day or two) for a range of discipline-specific tasks, purposes, and audiences.

Essential Questions

1. What are the advantages of a differential system?
2. Where are differentials found on equipment?
3. What are the advantages of planetary gears?
4. How can a planetary system be used to increase speed or torque?
5. Why are preload and endplay important?
6. How are preload and endplay adjusted on a final drive?
7. How are tires measured?
8. What factors does a technician consider when selecting a tire?
9. How does a technician measure wheel slippage?
10. What is the purpose of ballasting?

Key Terms

Abrasive wear	**Adhesive wear**	**Ballast**
Ballasting	**Bead**	**Bias-ply**
Corrosion	**Department of Transportation (DOT) tire code**	**Differential**
Differential carrier	**Direct drive**	**Failure analysis**
Fracture	**Load index**	**Overdrive mode**
Pinion gear	**Planetary carrier**	**Planetary gear set**
Plies	**Ply rating**	**Preload**
Radial-ply	**Ring gear**	**Side gear**
Sidewall	**Spalling**	**Speed rating**
Spider gear	**Sun gear**	**Tread**
Torque multiplying	**Wheel ballast**	**Wheel slip**

Day-to-Day Plans
Time: 12 days

*Refer to the Teacher Resources section for specific information on teaching this lesson, in particular **Lesson 2.2 Teacher Notes**, **Lesson 2.2 Glossary**, **Lesson 2.2 Materials**, and other support documents.*

Day 1:

- Present **Concepts**, **Performance Objectives**, **Essential Questions**, and **Key Terms** to provide a lesson overview.
- Provide students with a copy of **Activity 2.2.1 A Differential Approach**.
- Assign students to read pages 547–551 of *Heavy Equipment Power Trains and Systems*.

Day 2:

- Review pages 547–551 of *Heavy Equipment Power Trains and Systems* with students.
- Students work in teams of three to complete *Activity 2.2.1 A Differential Approach*.

- Assign students to read pages 283–288 of *Heavy Equipment Power Trains and Systems*.

Day 3:

- Review pages 283–288 of *Heavy Equipment Power Trains and Systems* with students.
- Provide students with a copy of **Activity 2.2.2 Planetary Power**.
- Students work individually to complete *Activity 2.2.2 Planetary Power*.

Day 4 – 5:

- Provide students with a copy of **Activity 2.2.3 Taper Bearing**.
- Students work in pairs to complete *Activity 2.1.3 Taper Bearing*.
- Assign students to read pages 755–761 of *Heavy Equipment Power Trains and Systems*.

Day 6:

- Review pages 755–761 of *Heavy Equipment Power Trains and Systems* with students.
- Provide students with a copy of **Activity 2.2.4 Find a Tire**.
- Students work with a partner to complete *Activity 2.2.4 Find a Tire.*

Day 7:

- Provide students with a copy of **Activity 2.2.5 Optimizing Performance**.
- Students work in groups of four to complete Part One of *Activity 2.2.5 Optimizing Performance.*

Day 8:

- Students work in groups of four to complete *Activity 2.2.5 Optimizing Performance*
- Assign students to read pages 591–597 of *Heavy Equipment Power Trains and Systems*.

Day 9 – 11:

- Review pages 591–597 of *Heavy Equipment Power Trains and Systems* with students.
- Provide students with a copy of **Project 2.2.6 Drive Train Repair**, **Work/Repair Order Template**, **Work/Repair Order Evaluation Rubric**, and **Group Presentation Evaluation Rubric**.
- Students work in pairs to complete *Activity 2.1.6 Drive Train Repair*.
- Use the *Work/Repair Order Evaluation Rubric* and *Group Presentation Evaluation Rubric* to assess student work.

Day 12:

- Distribute **Lesson 2.2 Check for Understanding**.
- Students will complete *Lesson 2.2 Check for Understanding* and submit it for evaluation.
- Use **Lesson 2.2 Check for Understanding Key** to evaluate student assessments.

Instructional Resources

Student Support Documents

Lesson 2.2 Glossary

Activity 2.2.1 A Differential Approach

Activity 2.2.2 Planetary Power

Activity 2.2.3 Tapered Bearing

Activity 2.2.4 Find a Tire

Activity 2.2.5 Optimizing Performance

Project 2.2.6 Drive Train Repair

Teacher Resources

Lesson 2.2 Final Drives PDF

Project 2.6 Complaint Cards

Lesson 2.2 Teacher Notes

Lesson 2.2 Materials

Lesson 2.2 Check for Understanding

Answer Keys and Assessment Rubrics

Lesson 2.2 Check for Understanding Answer Key

Work/Repair Order Evaluation Rubric

Group Presentation Evaluation Rubric

Student Templates

Work/Repair Order Template

Reference Sources

Dell, Timothy W. (2019). *Heavy equipment power trains and system, 1st edition.* Tinely Park, IL: The Goodheart-Willcox Company, Inc.

FFA Connections

This lesson provides conceptual and procedural knowledge related to the following FFA awards, activities, and educational resources.

- Agricultural Proficiency
  - **Agricultural Mechanics Repair and Maintenance –Placement**
  - **Agricultural Mechanics Repair and Maintenance –Entrepreneurship**
- Agriscience Fair
  - **Power, Structural and Technical Systems**
- Career Development Events
  - **Agricultural Technology & Mechanical Systems**
- Educational Resources
  - **SAE Idea Cards-Power, Structural and Technical Systems**
  - **Power, Structural and Technical System Careers**
  - **Power, Structural and Technical Systems Career Focus Area Resources**
  - Agricultural Mechanics (**Word)** (**PDF**)
  - Keegan Humm-SAE-Placement-Implement Dealership Lesson Plan (**Word**) (**PDF**)
  - Power, Structural and Technical Careers **(Word)**

Skills and knowledge from this lesson support the development and implementation of service-learning projects that address final drives.

- **Service-Learning and Living to Serve Grants**
  - Service-learning projects focused on addressing local issues related to tires, torque and safety.
  - Project ideas include hosting a used tire recycling drive and fixing tires on agriculture equipment to enhance safety.
  - Living to Serve Grants provide funding to FFA chapters to support service-learning and community service projects.

For more information, visit the **National FFA Organization** website.

SAE for All

Immersion SAE

Students interested in this lesson's topics should explore the following related Immersion SAEs. An immersion SAE is optional and replaces the agricultural literacy component of the Foundational SAE.

- Placement/Internship
    - **Implement Dealership Placement SAE | Keegan Humm**
    - **Agricultural Mechanics SAE | Jeremiah Hager**

For more information on the guiding principles for implementing SAE programs, visit the **SAE for All: Evolving Essentials** site.

Critical Thinking and Application Extensions

Explanation

1. Students will explain how torque and speed are affected by changing the tire size on a machine.

Application

2. Students will measure wear and air pressure in a tire and determine the replacement costs.

CASE

Lesson 2.2 Teacher Notes

Lesson 2.2 Final Drives

In preparation for teaching this lesson, review Concepts, Performance Objectives, Essential Questions, and Key Terms. Also, review all activity, project, and problem directions, expectations, and work students will complete.

Students construct a differential and collect speed data from a virtual planetary system. Next, students adjust the preload and endplay on a wheel hub. Then they select tires and calculate the wheel slippage for equipment. Finally, they complete a failure analysis for a broken drive train component.

Reading Discussion

Heavy Equipment Power Trains and Systems, Pages 547–551

Use the questions below to facilitate a class discussion on Day 2 pertaining to differentials. Encourage student participation and assess student understanding of materials based on discussion.

- What are the parts of a differential?
- How does a differential work?
- How can you adjust a differential?

Heavy Equipment Power Trains and Systems, Pages 283–288

Use the questions below to facilitate a class discussion on Day 3 pertaining to planetary gears. Encourage student participation and assess student understanding of materials based on discussion.

- What are the components of a planetary system?
- What are the advantages of a planetary system?
- How are overdrive and direct drive different?

Heavy Equipment Power Trains and Systems, Pages 755–761

Use the questions below to facilitate a class discussion on Day 6 pertaining to tire selection. Encourage student participation and assess student understanding of materials based on discussion.

- How do you identify a tire?
- What are the main components of a tire?
- What factors should a technician consider when selecting a tire?

Heavy Equipment Power Trains and Systems, Pages 591–597

Use the questions below to facilitate a class discussion on Day 2 pertaining to failure analysis in a power train. Encourage student participation and assess student understanding of materials based on discussion.

- What is failure analysis?
- What types of wear does a technician find in a power train?
- What causes a component to corrode?

Activities, Projects, and Problems

Activity 2.2.1 A Differential Approach

Students work in teams of three to assemble and attach a differential to the constructed powertrain from *Activity 2.1.1 Manual Transmission*.

Teacher Preparation

Students use the 12V battery from the EETC electrical board to power the power train. Purchase additional 12V batteries for powering all systems or have teams share the batteries.

Student Performance

Students start the activity by observing how a wheel and axle system work without a differential. Then students assemble a differential and identify each component. Next, students attach the differential to a powertrain and wheels. Finally, students power the system and observe how the differential operates to complete the activity.

Results and Evaluation

Students should have a working differential connected to the powertrain upon completing the activity. Use the example responses to the analysis questions to assess student understanding.

Table 1. ***Analysis Questions and Potential Responses***

Q1	How do the speeds of each wheel differ?	*Each wheel is going at the same speed.*
Q2	Why is a differential not needed for the axle and wheel to turn the corner?	*The internal wheel slips as it goes around a corner.*
Q3	How do the speeds of each wheel differ?	*The speed of the outside wheel increases while the inside wheel speed decreases.*
Q4	What is controlling the speed of each wheel?	*The axles connected to the differential control the speed of each wheel. Because the axles are not directly connected, they can operate at different speeds.*
Q5	How are backlash and endplay affecting the differential's performance?	*The gears in the differential will bind and not turn if there is no backlash or endplay.*
Q6	What adjustments can you make to change the backlash and endplay?	*I can change the backlash and endplay by adjusting the distance between each gear and squaring the frame.*

Activity 2.2.2 Planetary Power

Students work individually to observe how a planetary gear works.

Teacher Preparation

Students need access to a device with internet access to view the **Planetary Gear Simulator**.

Student Performance

Students observe the effect of changing the speed and state of planetary gear components while answering analysis questions.

Results and Evaluation

Students learn how the state of each component impacts the drive output's direction, speed, and torque. Tables 2–4 contain answers to the transmission settings. Use example responses in Table 5 to assess student understanding.

Table 2. ***Carrier Held Key***

	Gear Speeds (rpm)					
Sun Gear Speed	**12**	**8**	**4**	**0**	**-4**	**-8**
Carrier Speed	0	0	0	0	0	0
Ring Gear Speed	-6	-4	-2	0	2	4

Table 3. ***Carrier Output Key***

Gear Speeds (rpm)						
Sun Gear Speed	0	0	0	2	4	6
Carrier Output Speed	**1.3**	**2.6**	**4.0**	**0.66**	**1.3**	**2**
Ring Gear Speed	2	4	6	0	0	0

Table 4. ***Carrier Input Key***

Gear Speeds (rpm)						
Sun Gear Speed	0	0	0	**6**	**12**	**18**
Carrier Input Speed	2	4	6	2	4	6
Ring Gear Speed	**3**	**6**	**9**	0	0	0

Table 5. ***Analysis Questions and Potential Responses***

Q1	What is the sun gear speed dependent upon?	*The sun gear speed is dependent upon the ring gear and carrier speeds.*
Q2	Is the system in direct drive or overdrive? Why?	*Direct drive. Two components are moving simultaneously, and the planetaries are not moving.*
Q3	When would a held carrier be used in a machine?	*To reverse the direction of the machine.*
Q4	Which component is the drive input and drive output when a fast speed is needed?	*Drive input – Ring Gear* *Drive output – Sun Gear*
Q5	Which component is the drive input and drive output when a slow speed is needed?	*Drive input – Sun Gear* *Drive output – Ring Gear*
Q6	What is the carrier speed dependent upon?	*The carrier speed is dependent upon the ring and sun gear speeds.*
Q7	When would a carrier be used as the output?	*To increase the torque of the machine*
Q8	Which component is the drive input and drive output when a high torque fast speed is needed?	*Drive input – Ring Gear* *Drive output – Carrier*
Q9	Which component is the drive input and drive output when a slow speed is needed?	*Drive input – Sun Gear* *Drive output – Carrier*
Q10	When would a carrier be used as the input?	*To increase the machine's speed.*
Q11	Which component is the drive input and drive output when a slow overdrive speed is needed?	*Drive input – Carrer* *Drive output – Ring Gear*
Q12	Which component is the drive input and drive output when a fast overdrive is needed?	*Drive input – Carrier* *Drive output – Sun Gear*

Activity 2.2.3 Taper Bearing

Students disassemble and reassemble a wheel hub while adjusting for endplay and preload.

Teacher Preparation

Students need a new **wheel hub**, part# 128008 from Northern Tool. Students may use other wheel hubs, but activity instructions may not match. Have additional cotter pins and bearing seals available as replacement parts. Review how to use a dial indicator. If needed, review with your students before starting the activity.

Student Performance

Students measure and record a wheel hub's endplay. Then they disassemble the wheel while recording all parts, procedures, and measurements in their *Logbook*. After disassembly, they lubricate the bearings and reassemble the hub while adjusting the endplay and preload.

Results and Evaluation

Review student *Logbooks* for correct procedures and measurements. Then check the endplay and preload of the wheel hub to ensure the students have adjusted it correctly.

Activity 2.2.4 Find a Tire

Students work in pairs to read tire labels and select a tire for a tractor.

Teacher Preparation

The class will need two pieces of equipment with tire sidewalls to read. Assign half the class to each piece of equipment. Note which tire students should read if there are multiple sizes on the equipment.

Student Performance

Students read tire information on the data plate and on the sidewalls of tires on two pieces of equipment. They record the tire information on the student data sheet. To complete the activity, students read a scenario and select two tire options for a tractor operator.

Results and Evaluation

Review the students' data sheets for accurate recordings and reasonable recommendations for tire selection. The answers will vary depending upon the two tires the student selects.

Activity 2.2.5 Optimizing Performance

Students calculate wheel slippage for a model tractor. Then they ballast the tractor to optimize wheel slippage.

Teacher Preparation

Have a bag of bulk pea gravel for students to add to their containers. Attach an eye hook to each plastic container, as shown in Figure 1.

Figure 1. Container and Eyehook

Student Performance

Students measure the wheel slippage of a tractor with and without a load. Then they ballast the tractor to adjust the wheel slippage and increase the tractor's efficiency.

Results and Evaluation

Use example student observations and example answers to analysis questions in Table 6. to assess student understanding. Student observations will cause answers to vary.

Table 6. Observations and *Analysis Question Responses*

Part One		
Tractor type		*Two-wheel tractor because the two rear wheels are the only drive wheels.*
Maximum wheel slippage		*The maximum wheel slippage for a two-wheel drive tractor is 15%.*
Rear-wheel revolutions with haybale		*Example answer: 5 Revolutions*
Rear-wheel revolutions without haybale		*Example answer: 4 Revolutions*
Wheel slippage calculations		*Example answer: (5-4)/5 = 20%*
Q1	Is the wheel slippage appropriate for the type of drive system?	*No, the slippage is too high.*
Q2	What happened to the RC tractor while pulling extra weight?	*The slippage increased, and the tractor's front end lifted off the ground.*
Part Two		
Rear-wheel revolutions with 1kg		*Example answer: 5.5 Revolutions*
Wheel slippage calculations		*Example answer: (5.5-4)/5/5 = 27%*
Tractor sketch with ballasts		*Sketches will vary.*
Ballast wheel revolutions with 1kg		*Example answer: 4.25 Revolutions*
Wheel slippage calculations		*Example answer: (4.25-4)/5/5 = 5%*

Project 2.2.6 Wheel Repair

Students complete a failure analysis for a power train component for a customer and practice their communication skills by presenting their diagnosis to the class.

Teacher Preparation

Print a copy of **Project 2.2.6 Complaint Cards** and cut out each card. Acquire and prepare failed power train components from local dealers or suppliers for each complaint card. The cause of each failure and problem do not need to be the same. Students will need tools used during related activities and projects. Table 7 has example components, materials, and related activities. Develop your own complaint cards if needed to fit available supplies. The project materials list does not have the tools listed. Part of the project is for students to identify the correct tools.

Table 7. ***Power Train Information***

Complaint Card	Failed Component	Materials and Tools	Related Activity
#1	Electromagnetic clutch with a large air gap.	• Battery, 12V • Feeler gauge • Fuse, 10 amp • Socket extension $^{3}/_{8}$″drive • Socket wrench, $^{3}/_{8}$″ drive • Socket, $^{3}/_{8}$″ drive $^{9}/_{16}$″ socket • Switch, Single-pole/single-throw • (4) Wires with alligator clips	*Activity 2.1.2 Clutch Performance*
#2	Electromagnetic clutch with no air gap.		
#3	Wheel hub with seized bearing	• Ball-peen hammer • Brass drift punch • Chisel • Dial calipers • Dial indicator • Hub user manual • Seal/bearing driver • Slip joint pliers • Socket 1”, ½″ drive Socket wrench, ½″ drive • Pry bar • Tapered punch • Torque wrench • Torque wrench, 5–80 ft-lbs, ½″ drive • Wheel hub/spindle • (2) Woodblocks, 6”-2x4 • Workbench with vise	*Activity 2.2.3 Tapered Bearing*
#4	Wheel hub with worn bearing		
$5	Two sprockets with loose chain	• Dial caliper • Dial indicator	*Activity 1.1.4 Combining Chains and Belts*
#6	Two misaligned sprockets with a tight chain		
#7	Two pulleys with a loose belt	• Dial caliper • Dial indicator	
#8	Two pulleys with a tight belt		
#9	Misaligned shaft and worn bearings	• Dial caliper • Dial indicator	*Activity 2.1.4 Bearing Replacement*
#10	Worn partially deflated tire on a wheel.	• Air pressure gauge	*Activity 2.2.4 Find a Tire*

Student Performance
Students work in pairs to tear down and examine a broken wheel hub. Then they complete a pick list and work/repair order for the owner of the wheel hub. Students complete the project by presenting how they will repair it to the class

Results and Evaluation
Use the **Work/Repair Order Evaluation Rubric** and **Group Presentation Rubric** to assess student work.

Assessment

Lesson 2.2 Check for Understanding

Lesson 2.2 Check for Understanding is included for you to use as an assessment tool for this lesson. Use **Lesson 2.2 Check for Understanding Answer Key** for evaluation purposes.

Name____ CASE

Activity 2.2.1 A Differential Approach

Purpose

An operator takes a tight turn with a front-wheel-drive tractor. The tractor's front-end hops, and the inside tire slips and tears up the ground. The operator calls a technician and explains the situation. The technician tells the operator that the differential is not working correctly. What is a differential, and what does it have to do with a vehicle's turning ability?

A differential is a gearing system allowing two wheels on the same axle to turn at different speeds while maintaining the same torque. A tractor's inside wheel travels a shorter distance than the outside wheel when turning a corner, as shown in Figure 1. Because of the shorter distance, the inside wheel needs to travel slower, or the outside wheel faster. Besides varying speeds, differentials also allow different sized wheels or wheels under varied resistance to work together on the same axle.

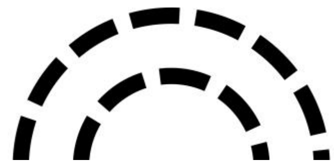


Figure 1. Turning Tracks

A differential consists of a case, ring gear, spider gears, and side gears. A ring gear is a driven gear connected to the differential case. The ring gear turns the differential case, which turns the spider gears. The spider gears drive the side gears driving the axles and wheels. Some differentials can lock, so both wheels must spin simultaneously to increase torque in high load situations. Newer differentials have control systems allowing them to engage at certain turning angles. The operator's situation discussed earlier is an example of a differential not engaging when needed.

How will you explain the importance and operation of a differential to your customers as a technician?

Materials

Per team of three students:

- Assembled transmission
- Battery, 12V
- (3) Bevel gears
- Differential case
- Gear, 84 tooth gear
- Hex wrench, $^{5}/_{64}$″
- (2) Shaft, 4″ square
- (3) Shaft collars
- Shaft, 12″ square
- Switch, single-pole, single-throw
- (2) Wheels
- (2) Wire with alligator clips, black
- Wire with alligator clips, red

- **Per student:**
  - Safety glasses
  - Pen
  - *Agriscience Notebook*
  - *Logbook*

Procedure

Work in a team to assemble and observe a differential system. Individually record all sketches and answers to analysis questions in your *Logbook*. Wear your safety glasses and tie back long hair.

1. Place two wheels on a single 12″ axle, as seen in Figure 2.
2. Simulate the wheels turning a corner and observe the speed of each wheel.
3. Answer the analysis questions in your *Logbook*.

   Q1 How do the speeds of each wheel differ?
   Q2 Why is a differential not needed for the axle and wheel to turn the corner?
4. Remove the axle from the wheels.
5. Obtain a differential case and add three bevel gears and two axles, as shown in Figure 3.
6. Sketch the differential in your *Logbook*.
7. Label the following on your sketch
   - Ring gear
   - Spider gear
   - Spider gear axle
   - Side gears
8. Drive axles Attach a wheel to both drive axles on the differential.
9. Turn the differential to simulate the wheels turning a corner and observe the speed of each wheel.
10. Answer the analysis questions in your *Logbook*.

    Q3 How do the speeds of each wheel differ?
    Q4 What is controlling the speed of each wheel?
11. Obtain an assembled transmission from *Activity 2.1.1 Manual Transmission*.
12. Add an 84 tooth gear to the drive axle, as seen in Figure 4.
13. Install your differential to the manual transmission, so the 84 tooth gear is driving the ring gear, as shown in Figure 5.
    - Before installing, you may need to disassemble the differential system and adjust the transmission rails.
    - Use retaining collars to hold the differential in place between the rails.
14. Use the schematic in Figure 6 to wire the battery, switch, and electric motor.
15. Adjust the manual transmission to the lowest drive speed.
16. Turn on the motor and observe your differential system.
    - Use your hand to stop the left wheel and record how the differential reacts in your *Logbook*.
    - Record your observations when you stop the right wheel.

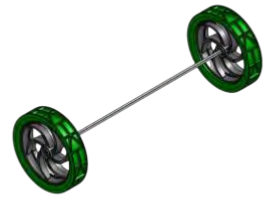


Figure 2. Axle

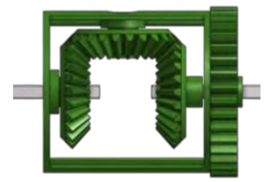


Figure 3. Differential

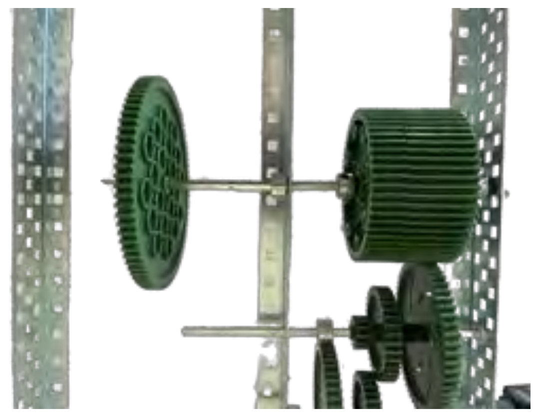


Figure 4. 84 Tooth Drive

Figure 5. Differential Installation

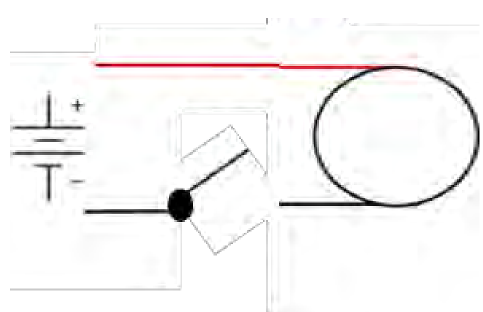


Figure 6. Electrical Schematic

17. Shut off the motor.
18. Answer the analysis questions in your *Logbook*.
    Q5 How are backlash and endplay affecting the differential's performance?
    Q6 What adjustments can you make to change the backlash and endplay?
19. Make adjustments to your differential to improve its performance.
20. Turn on the motor and record how your changes affected the differential system.
21. Shut off the motor and disconnect the battery.
22. Store materials as instructed by your teacher.

Conclusion

1. Why are differentials an essential component of a drive system?

2. What are the advantages and disadvantages of a differential system?

3. What are some possible causes for a differential failure?

Name____ CASE

Activity 2.2.2 Planetary Power

Purpose

How could you redesign the gear set constructed during *Activity 2.1.1 Manual Transmission* to take up less space? Planetary gears have a compact design and are in almost all equipment. Many tractors have compact planetary gears transferring power from the differential to the wheels. The total load on a planetary gear is distributed to multiple components, reducing wear and tear. In addition, planetary gears provide an operator with more speed and torque options for optimal machine performance.

Planetary gears contain a sun gear, planetary gears, ring gear, and a carrier working together to power equipment. Multiple planetary gears surround and rotate around the sun gear. A large internal tooth gear called a ring gear holds the planetary gears in place. The planetary carrier attaches to the planetary gear. The sun gear, ring gear, and carrier can all be the driving or driven members of a planetary system. The driving member is the power input, and the driven member is the output. The planetary gear system controls a machine's torque, speed, and direction. The torque, speed, and direction depend on which member is driving, driven, or held.

Figure 1. Planetary Gear

Operators can set a planetary system in reverse, torque multiplication, direct drive, or overdrive. Torque multiplication occurs at slow speeds, while overdrive is a high-speed setting. Direct drive occurs when two components move at the same speed in the same direction.

How does the state of each planetary component impact a machine's speed and direction?

Materials

Per student:

- Device with internet access
- *Agriscience Notebook*

Procedure

Simulate planetary gear operation in a tractor and observe how the speed changes. Complete all tables and answer analysis questions on the *Activity 2.2.2 Student Data* sheet.

Part One – Held Carrier

1. Launch the **Planetary Gear Simulator** (http://www.thecatalystis.com/gears/).
    - Gear teeth should be set at the following for the entire activity.
        - o Sun teeth – 36
        - o Planet teeth – 18
        - o Ring teeth – 72

2. Sketch the planetary system in your *Logbook* and label the following parts.
    - Sun gear
    - Planet gear
    - Ring gear
    - Carrier
3. Solve for **Sun Gear**.
4. Set the sun, ring, and carrier speed to zero.
5. Try to increase the sun speed without increasing the carrier or ring speeds.
    - The sun speed should be fixed.
6. Set the carrier and ring speed to 2 rpm.
7. Set the sun, ring, and carrier speed to zero.
8. Change the *Ring Speed* to -6 rpm.
9. Record the sun speed in Table 1 on *Activity 2.2.2 Data Sheet*.
10. Repeat Steps 8–9 by changing the gear speeds to the settings shown in Table 1.
11. Answer the *Part One Analysis Questions*.

Part Two – Carrier Output

1. Solve for **Planets and Carrier**.
2. Set the sun, ring, and carrier speed to zero.
3. Try to increase the carrier speed without increasing the sun or ring speeds.
    - The planets and carrier speed should be fixed.
4. Change the *Ring Speed* to 2 rpm.
5. Record the carrier speed in Table 2 on *Activity 2.2.2 Data Sheet*.
6. Repeat Steps 4–5 by changing the gear speeds to the settings shown in Table 2.
7. Answer the *Part Two Analysis Questions*.

Part Three – Carrier Input

1. Solve for **Ring Gear**.
2. Set the sun, ring, and carrier speed to zero.
3. Try to increase the ring gear speed without increasing the sun or carrier speeds.
    - The ring gear speed should be fixed.
4. Change the *Carrier Speed* to 2 rpm.
5. Record the *Ring Speed* in Table 3 on the data sheet.
6. Repeat Steps 4–5 by changing the gear speeds to the settings shown in Table 3.
    - You will need to solve for Sun Gear for some of the settings.
7. Answer the *Part Two Analysis Questions*.

Conclusion

1. Which component is held in place for a machine to drive in reverse?

2. What are the advantages of a planetary gear system?

3. The operator complains of noise coming from the planetary gear set. However, they do not hear noise when the gear set is in direct drive. What is the potential cause?

Name____

Activity 2.2.2 Student Data

Table 1. ***Carrier Held***

Gear Speeds (rpm)						
Sun Gear Speed						
Carrier Speed	0	0	0	0	0	0
Ring Gear Speed	-6	-4	-2	0	2	4

Part One Analysis Questions

Q1 What is the sun gear speed dependent upon?

Q2 Is the system in direct drive or overdrive? Why?

Q3 When would a held carrier be used in a machine?

Q4 Which component is the drive input and drive output when a fast speed is needed?

Q5 Which component is the drive input and drive output when a slow speed is needed?

Table 2. ***Carrier Output***

Gear Speeds (rpm)						
Sun Gear Speed	0	0	0	2	4	6
Carrier Output Speed						
Ring Gear Speed	2	4	6	0	0	0

Part Two Analysis Questions

Q6 What is the carrier gear speed dependent upon?

Q7 When would a carrier be used as the output?

Q8 Which component is the drive input and drive output when a high torque fast speed is needed?

Q9 Which component is the drive input and drive output when a slow speed is needed?

Table 3. ***Carrier Input***

Gear Speeds (rpm)						
Sun Gear Speed	0	0	0			
Carrier Input Speed	2	4	6	2	4	6
Ring Gear Speed				0	0	0

Part Three Analysis Questions

Q10 When would a carrier be used as the input?

Q11 Which component is the drive input and drive output when a slow overdrive speed is needed?

Q12 Which component is the drive input and drive output when a fast overdrive is needed?

Name____

Activity 2.2.3 Tapered Bearing

Purpose

An operator recently replaced the tires on his wagon. As he tows the wagon, one wheel starts to wobble, and smoke starts billowing from another. He immediately stops the tractor and calls a service technician. The technician tells him he has too much endplay in one wheel and placed too much preload on another. What does the operator need to do to set the endplay and preload on components with bearings?

Tapper roller bearings require preload or endplay setup depending on location and load. Endplay is the distance a shaft, hub, or gear can move after installing the bearings. Preload is the static force applied to the bearings after being adjusted for zero endplay. Proper preload and endplay settings result in bearings with long service life. A wheel with too much endplay will vibrate and wobble, causing the bearing assembly to wear. A technician reduces the endplay by tightening the nut on a wheel hub, as seen in Figure 1. After reducing endplay to zero, the nut compresses the bearings, increasing the preload.

How will you measure and adjust the endplay and preload on a wheel hub?

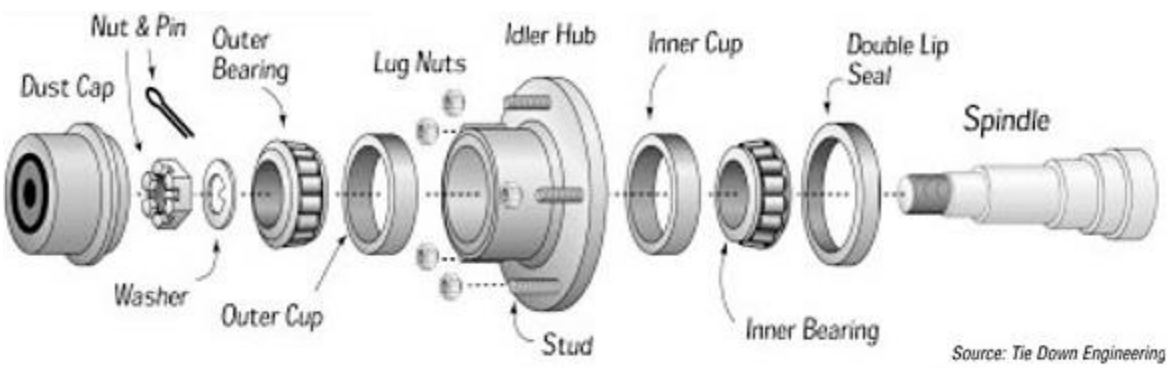


Figure 1. Wheel Hub Anatomy

Materials

Per group of four students:

- Ball-peen hammer
- Brass drift punch
- Chisel
- Cotter pin, replacement
- Dial caliper 6″/150mm
- Dial indicator
- Grease gun
- **Hub User Manual**
- Pry bar
- Seal/bearing driver
- Seal, replacement
- Slip joint pliers
- Socket 38mm, ½″ drive
  Socket wrench, ½″ drive
  Tapered punch
- Torque wrench, 5–80 ft-lbs, ½″ drive
- Wheel hub/spindle
- (2) Woodblocks, 6″-2x4
- Workbench with vise

Per student:

- Ear plugs
- Safety glasses
- Nitrile gloves
- Pen
- *Logbook*
- *Agriscience Notebook*

Per class:

- Brake cleaner
- Flame resistant container
- Lithium grease
- Shop towels

Procedure

Disassemble a wheel, identify components, and adjust for endplay and preload. Create a table in your *Logbook* entry for each step of disassembly and assembly. Include tasks, tools used, and measurement specifications. Refer to Figure 1 or **Hub User Manual** (https://www.dexteraxle.com/user_area/content_media/raw/059-831-00_HubDrumBearingInstructionSheet.pdf) to identify the components. Record the section, page, and figure number from the Hub User Manual related to each step as you disassemble the wheel when applicable.

Part One – Hub Disassembly

1. Put on safety glasses, gloves, ear protection, and tie back long hair.
2. Secure the wheel hub shaft assembly in a vise. Place the assembly shaft in the vise leaving enough clearance to allow the hub to rotate, as seen in Figure 2.
3. Rock the wheel hub side-to-side and top-to-bottom.
4. Record your observations in your *Logbook*.
5. Use a ball-peen hammer and chisel to remove the dust cap from the bearing assembly on the wheel hub.
6. Assemble the dial indicator.
7. Set the dial indicator base on the wheel mounting surface and pin on the end of the shaft.
    - Refer to Figure 2.
    - Make sure that the dial indicator has room to travel.
8. Pull idler hub in and out to check bearing endplay.
    - Use a pry bar if available.
9. Record the endplay in your *Logbook*.
10. Use slip joint pliers to bend the cotter pin and remove it from the shaft.
11. Remove the castle nut and washer using the correct drive socket and socket wrench.
12. Pull the idler hub off the shaft.
    - The idler hub, bearing, and seals will come off as one unit.
    - Be careful to support the bearings on both sides of the hub to prevent them from falling on the floor.
13. Place the hub on a clean workbench and remove the bearings.
    - Support the hub with woodblocks on both sides using wood blocks to keep the shaft seal end of the hub off the flat surface.
14. Record and sketch the direction of the bearing and seal and record it in your *Logbook*.
    - You will use this information for the reassembly process.
15. Use the brass drift punch and hammer to strike on the bearing's inner cone towards the seal end of the hub to remove the inner bearing and seal.
    - The brass drift punch will transmit the force of the hammer, but it is a softer material that will not damage the bearing cone.
16. Use a punch and hammer to remove the outer and inner cups from the hub.
    - Place the punch on the cup's inside.
    - Drive the bearing cup out away from the center of the hub.

Figure 2. Hub and Dial Indicator Placement

- Firmly strike the bearing cup on one side and then strike the cup on the opposite side.
- Repeat until you drive the cup out evenly.

17. Use a parts washer and/or shop towels and brake cleaner to clean the hub and bearings.
18. Dispose of rags in a flame-resistant container.
19. Inspect the bearing rollers, inner cone, and cups for damage, chips, or flaking.
20. Record findings in your *Logbook.*
21. Measure the following parts using a dial caliper. Record measurements in your *Logbook*.
    - Outer bearing and inner bearing
        - Inside diameter and width
    - Outer cup and inner cup
        - Outside diameter and width
    - Bearing cup outside diameter and cup width.
    - Seal
        - Inside diameter, outside diameter, and width.
    - Spindle diameters where each of the following fit
        - Outer cup
        - Inner cup
        - Seal

Part Two – Hub Assembly

1. Install bearing cups in the hub using the bearing driver and hammer.
    - Drive the bearing cups inward with the taper of the cup facing out so they are evenly and fully seated against the hub.
    - The tone of the tapping should change, indicating that the race has bottomed out.
2. Apply multi-purpose lithium grease to both inside bearing cups and cones.
    - Fill the space around each roller with grease. Start with a small amount of grease in your palm and press the bearing into the grease.
    - Grease the bearing cup surface.
3. Place inner bearing into the hub with the taper of the cone directed to the cup.
4. Use the seal driver and hammer to install the seal.
    - Refer to your *Logbook* for correct orientation.
5. Place outer bearing in the hub.
6. Install the hub and bearing assembly on the spindle with the seal end of the hub facing down.
7. Use the socket and torque wrench to tighten the nut on the hub to 50 ft-lbs of preload.
    - Spin hub and make sure that bearings roll smoothly.
    - Use the torque-wrench to recheck and confirm the torque to ensure the bearings are correctly installed and fully seated.
    - Loosen the nut with ratchet and socket and tighten the nut by hand.
8. Assemble the dial indicator. Set dial indicator base on the wheel mounting surface and pin on the end of the shaft. Make sure that the dial indicator has room to travel. Pull bearing hub in and out to check bearing endplay.
9. Record the endplay in your *Logbook*.
10. Adjust the retaining nut to set the bearing endplay to .010″.
    - Loosen the nut to increase the endplay and tighten the nut to decrease the endplay.

11. Install the cotter pin once you have set the endplay.
12. Bend the cotter pin so it stays in place.
13. Finish assembling by installing the dust cap on the hub with the hammer.
14. Use a grease gun to lubricate the hub.

Conclusion

1. What is the relationship between endplay and preload?

2. Besides a wheel hub, what other components have endplay and preload settings?

3. What measurement tools does a technician need for setting the endplay and preload?

Name____ CASE

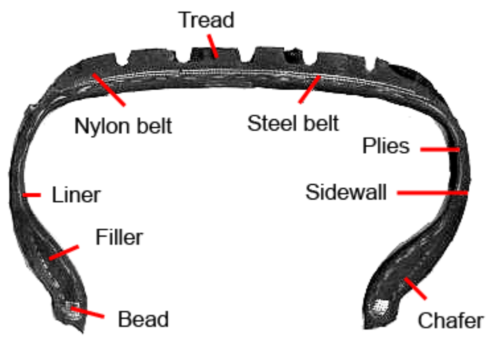
Activity 2.2.4 Find a Tire

Purpose

Agricultural equipment requires tires or tracts to move across a field. Tires are pneumatic, needing compressed air to inflate the tire and support the equipment.

A tire consists of plies, beads, sidewall, and tread supporting heavy equipment. Figure 1 shows a cross-section of a tire and its components.

- Plies are layers of rubber embedded with cords that provide strength to the tire. Bias-ply tires include cords made from fabric, such as nylon. Radial-ply has steel embedded within each ply. Radial tires contain an R in the number code on the tire wall, while bias tires contain a B or X.
- Tires include a ply rating indicating the number of layers. For example, a 4-ply tire has four-ply layers within the tire.
- Each ply wraps around a bead package comprised of both steel and rubber. The bead provides a firm base for the tire to seal to the metal rim.



Source: Bridgestone

Figure 1. Tire Cross-Section

- A sidewall is a flexible rubber exterior that covers the side of the tire. The sidewall works to flex when equipment is under a load, protect the plies from abrasions, and resist cracking.
- A tire's tread is the outer surface of the tire that comes in contact with the ground. Engineers design a tire tread to withstand wear and provide traction.

Tire replacement is the second-largest operating expense for operators. Therefore, technicians should know the tire size, load index, speed rating, and manufacturing date when selecting a tire. A tire's sidewall contains the printed information, as shown in Figure 2. Tire information can also be found on a data plate on the frame of the equipment.

- Tire size includes the width, aspect ratio, construction type, and rim size. The aspect ratio is a percentage of the height equal to the sidewall height. For example, an 18/70R38 tire is 18″ wide, has a 12.6″ sidewall (70% of 18″ = 12.6″), is a radial-ply, and fits a 38″ diameter rim. Tire manufacturers also use metric measurements to describe a tire. A 400/80R24 tire is 400mm wide and fits a 24″ rim.

Figure 2. Sidewall Information

- Each tire has a load index and speed rating affecting the carrying capacity and maximum speed for the tire at a given PSI.
- The last two numbers on a Department of Transportation (DOT) Code signify the manufacturing year.

Can you help a customer source the correct tire for a tractor? What information will you need?

Materials

Per class:

- (2) Equipment with tires

Per pair of students:

- Device with internet access

Per student:

- Pen
- *Agriscience Notebook*

Procedure

Work with a partner to read a tire label and identify the correct tire size. Next, recommend a tire to a hypothetical customer.

Part One – Setting Up

Find the tire information on two pieces of equipment. Note that some equipment may be missing a data plate and some tires may not have all information.

1. Go to the equipment assigned by your teacher.
2. Locate the tire size on the data plate and record it in Table 1 of *Activity 2.2.4 Student Data*.
3. Sketch the tread pattern in Table 1.
4. Record the tire width, sidewall height, and rim diameter in Table 1.
5. Determine if the tire is radial-ply or bias-ply and record under *Ply Type* in Table 1.
6. Locate the load index, speed rating, and recommended inflation. Record in Table 1.
7. Locate the DOT code and record the last two numbers in Table 1.
   - The DOT number will vary by manufacture if made before the year 2000.
8. Note if the tire uses metric or imperial measurements in Table 1.
9. Repeat Steps 2–7 with a tire on a second piece of equipment.

Part Two – Tire Selection

You are a technician at a dealership coordinating with Firestone for tire sales. A client has a tractor needing the rear tires replaced. First, read the *Customer Concern* and identify the pertinent information needed to replace the tire.

Customer Concern
The customer drives a tractor with old and worn tractor tires that need replacement. The farmer uses the tractor for row crop production, requiring a narrower and taller tire. The tire width is 15.5″, and the rim is 38″ in diameter.

Then, use **Agricultural Tires** (https://commercial.firestone.com/en-us/agriculture/tires) to find the tires available through your supplier. Next, record your top two recommend tires with pertinent information in Table 2. Finally, record an explanation for the tire that you would recommend.

Conclusion

1. What information would a technician find on the sidewall of a tire?

2. What factors does a technician consider when selecting a tire?

Name____

Activity 2.2.4 Student Data

Table 1. ***Tire Size***

Tire Information	Tire #1	Tire #2
Tire size		
Sketch		
Width		
Sidewall height		
Rim diameter		
Ply Type		
Load index		
Speed rating		
Inflation recommendation		
DOT Code		
Metric/Imperial		

Table 2. ***Tire Recommendations***

Pertinent Information	Tire #1	Tire #2
Tire size		
Model		
Article number		
Ply rating		
Ply type		
Max load and inflation		
Product features		
Recommended tire and explanation		

Name____

CASE

Activity 2.2.5 Optimizing Performance

Purpose

Have you been stuck in the snow? In northern states, many car owners will carry extra weight in their trucks during winter to increase traction in winter conditions. The tractor tires may slip on loose ground and never gain traction without this extra weight. Tire and tracks provide traction in agricultural equipment when proper weight is applied.

Wheel slips result in 60–70% of an engine's horsepower pulling an implement. Wheel slips occur when the wheels turn faster than the tractor's speed. Agricultural equipment reaches peak efficiency with a small degree of wheel slip. Wheel slip depends upon the type of tractor and ground conditions. Table 1 summarizes the types of tractors and their desired wheel slip.

Table 1. ***Desired Amount of Wheel Slip***

Type of Tractor	Acceptable Wheel Slip
Two-wheel drive	10–15%
Four-wheel drive	8–12%
Rubber track tractor	2–4%
Source: *Goodheart-Wilcox Publisher*	

Technicians calculate wheel slippage by comparing tire revolutions under a load to revolutions without a load, as shown in Figure 1.

$$\%\text{ wheel slip} = \frac{\text{Revolutions with load} - \text{Revolutions without a load}}{\text{Revolutions with load}} \times 100$$

Figure 1. Wheel Slip Calculations

Wheel slips increase as the tractor's load increases. Sometimes the wheel slip is so great that a tractor can tip backward, severely injuring or killing the operator. When wheel slip is more than desired, the operator must ballast the tractor. Ballasting is adding weight to the tractor to increase traction, efficiency, and weight distribution. Ballasts come in the form of metal weights added to the tractor's front, wheels, or the three-point hitch. In addition, some producers add liquid ballast inside the wheels to add weight at a lower cost. Figure 2 shows a tractor using suitcase ballasts on a tractor's front. Figure 3 shows a tractor with ballasts on the rear wheels.

Figure 2. Ballast Weights

Figure 3. Wheel Ballasts

How does ballasting increase safety? How can a technician measure a tractor's wheel slip?

Materials

Per group of four students:

- Masking tape
- Pea gravel, 1kg
- Permanent marker
- Plastic container with eye hook
- RC Tractor
- Tape measure, 25′
- Transmitter
- Washers, 1″

Per student:

- Pen
- *Agriscience Notebook*

Per class:

- Electronic balance

Procedure

Use an RC tractor to observe how ballasting influences wheel slippage and safe operation.

Part One – Wheel Slippage

Simulate the slippage in a tractor by driving an RC tractor with and without a simulated hay bale.

Hay Bale

1. Obtain and inspect an RC tractor and transmitter from your teacher.
2. Record the type of tractor and the maximum wheel slippage on *Activity 2.2.5 Student Observations* sheet.
3. Remove all the weights from the tractor.
4. Place two strips of masking tape 5 ft apart on the floor or table. The tape will serve as your starting and finish lines for the test.
5. Prepare the tractor for driving, as shown in Figure 4.
    - Mark a rear wheel with masking tape and a marker.
    - Place the mark at the beginning of the start line.

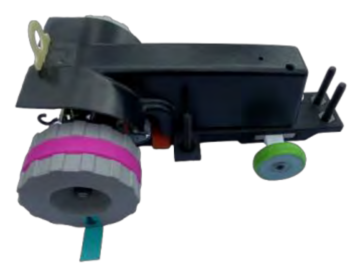


Figure 4. RC Tractor Preparation

6. Prepare the sled to model the weight of a hay bale pulled by the tractor, as shown in Figure 5.
    - Fill the plastic container with 500g of pea gravel.
    - Connect the eye hook to the back of the tractor.
7. Turn on the tractor.
    - Turn on the switch on the back of the tractor.
    - Turn on the transmitter. Do not touch any controls until the RC tractor has made a series of beeping sounds.

Figure 5. Hay Bale Model

8. Drive the tractor forward and count the number of rear-wheel revolutions. Stop when the RC tractor passes the second line.
9. Record the number of rear-wheel revolutions with the haybale on Table 2.
10. Answer *Part One Analysis Questions*.

No Hay Bale

11. Return the RC tractor so the tire mark is at the starting line, as shown in Figure 4.
12. Remove the weight from the RC tractor.

13. Drive the tractor forward and count the number of rear-wheel revolutions. Stop when the RC tractor passes the second line.
14. Record the number of rear-wheel revolutions without the haybale on the Table 2.
15. Use the formula below to calculate the wheel slippage on the observation sheet. Show your work.

$$\frac{\text{revolutions with hay bale} - \text{revolutions without a hay bale}}{\text{revolutions with hay bale}} \times 100 = \%\ \text{wheel slip}$$

Part Two – Ballasting

1. Increase the mass of the simulated hay bale to 1kg (1,000g).
2. Set up the RC tractor and attach it to the simulated hay bale at the starting line.
3. Drive the RC tractor forward.
4. Record the rear wheel revolutions with 1kg of weight and calculate the wheel slippage in Table 3.
5. Ballast the RC tractor by adding washers to the bolts on the chassis. Modify the placement of the ballasts until the RC tractor operates safely.
6. Sketch the tractor showing the location and number of ballasts.
7. Return the RC tractor so the tire mark is at the starting line.
8. Drive the tractor forward and count the number of rear-wheel revolutions. Stop when the RC tractor passes the second line.
9. Record the rear wheel revolutions with 1kg of weight and calculate the wheel slippage in Table 3.
10. Calculate the wheel slippage with the 1kg bale and the ballasting. Record in Table 3.

Conclusion

1. How does ballasting improve safety?

2. How does ballasting improve traction?

Name____

Activity 2.2.5 Student Observations

Table 2. ***Part One Observations***

Tractor type	
Maximum wheel slippage	
Rear-wheel revolutions with haybale	
Rear-wheel revolutions without haybale	
Wheel slippage calculations	

Part One Analysis Questions

Q1 Is the wheel slippage appropriate for the type of drive system? Why or why not?

Q2 What happened to the RC tractor while pulling extra weight?

Table 3. ***Part Two Observations***

Rear-wheel revolutions with 1kg	
Wheel slippage calculations	
Tractor sketch with ballasts	
Ballast wheel revolutions with 1kg	
Wheel slippage calculations	

Name____

CASE

Project 2.2.6 Drive Train Repair

Purpose

A technician's primary job is servicing machines and equipment for customers. They use a unique combination of communication and technical skills to fix mechanical problems. Communication skills are essential for the technician working with a customer to diagnose a mechanical failure. How does a technician work with an equipment owner to diagnose a mechanical failure?

A service technician fixes machines and equipment through troubleshooting and failure analysis. You have had experience using diagnostic tools to troubleshoot electrical and mechanical failure. Failure analysis is the process of determining why a machine failed and identifying the root cause. The root cause may be a faulty part or subpar assembly, making it the company's responsibility. Other times, the customer may be at fault due to poor maintenance or improper use. Whoever is at fault will eventually need to pay for the repairs or replacement of the equipment.

Power train failure can result from a wide range of root causes. Therefore, a service technician searches for clues to determine the cause of the failure. First, they must understand the relationships between bearings, lubrication, endplay, and preload. Next, technicians use clues to determine what initially caused the failure.

Physical clues include wear, spalling, distortion, fractures, and corrosion. Adhesive wear occurs when friction between two components causes them to fuse. Abrasive wear is caused by foreign material. Technicians find spalling between mated surfaces that are not aligned correctly. When a component is under stress, it may twist or bend, becoming distorted before breaking into multiple pieces called a fracture. Finally, many components will chemically react with the environment causing corrosion. After using the clues to determine the root cause, the technician must communicate their findings to the customer.

Communications are an essential part of the service process. The technician needs to listen to the customer's concerns and keep an open mind. Even if the customer may be at fault, the technician must show understanding and work with the customer to feel satisfied with the service. A technician should explain to the customer what happened, why it happened, and how to prevent it in the future.
For example, if the owner caused a wheel failure by not checking the endplay, a technician should explain how to prevent the problem in the future. The explanation could include the importance of lubrication and maintenance, an example maintenance plan, and recommended types of lubrication, along with providing a pick list and repair order.

Sharing information with the customer and fixing the problem will increase customer satisfaction and decrease future mechanical failures. How will you ensure customer satisfaction?

Materials

Per pair students:

- *Customer Complaint Card*
- Failed component
- Mechanical and precision tools

Per student:

- Safety glasses
- Nitrile gloves
- Pen
- *Agriscience Notebook*
- *Group Presentation Rubric*
- *Logbook*
- *Work/Repair Order Evaluation Rubric*
- *Work/Repair Order Template*

Procedure

A customer has come into the shop with a failed component. Your teacher will provide you with the components, along with the customer information and complaint. Use your knowledge from previous activities to identify the cause and correct the problem. Wear your safety glasses and gloves while working with the components. Record observations, measurements, and procedures in your *Logbook*. Make a pick list for any parts that need replacement and complete a work/repair order. Once you have repaired the component, complete a *Work/Repair Order* and develop a service plan with a recommendation for the owner.

Present your service plan to the class as you would a customer who may need to pay for the repairs. Your teacher will assess the *Work/Repair Order* and presentation with the *Work/Repair Order Evaluation Rubric* and *Group Presentation Rubric*.

Conclusion

1. How can you use precision tools to explain why a part failed for a customer?

2. How did you determine the cause of the customer complaint?

CASE

Project 2.2.6 Complaint Cards

Complaint Card #1

Otto Gray brought in this electromagnetic clutch on February 10th. He removed the clutch when replacing the belt. The clutch did not engage after he reinstalled it.

Complaint Card #2

Robert Holdingford brought in this electromagnetic clutch on February 20th. Unfortunately, the fuse in the electrical circuit blows each time the clutch is engaged.

Complaint Card #3

Sam Tipton brought in this wheel on March 18th. The wheel squeaks and becomes hot when rolling down the road.

Complaint Card #4

Van Golden brought in this wheel on March 12th. The wheel wobbles and shakes when rolling down the road.

Complaint Card #5

Grace Watkins brought in this power train on April 16th. The chain falls off the sprocket when the power train is engaged.

Complaint Card #6

Troy Sturgis brought in this power train on November 16th. The chain broke when the power train was engaged.

Complaint Card #7

Geoff Moore brought in this power train on April 16th. The belt falls off the pulley when the power train is engaged.

Complaint Card #8

Nate Thompson brought in this power train on November 16th. The belt squeals when the power train is engaged, and the pulleys seem to be wearing.

Complaint Card #9

Olivia McCormick has a powertrain with an axle that shakes, causing the sprocket to become misaligned.

Complaint Card #10

Oliver Cotts brought in this tire that has worn faster than the other three tires he purchased. The tires are two months old and still under warranty.

Name____

CASE

Lesson 2.2 Check for Understanding

1. What is the purpose of a differential system in a tractor?

2. Match the planetary gear components seen in Figure 1. Use some letters more than once.

	Ring gear
	Planetary gear
	Sun gear
	Planetary carrier
	Drive output for high speed and torque multiplication
	Drive input for overdrive
	Drive input for slow speed and torque multiplication
	Held in place for reverse
	Held in place for highest speed
	Held in place for the lowest speed
	Drive input for the lowest speed
	Drive output for highest speed

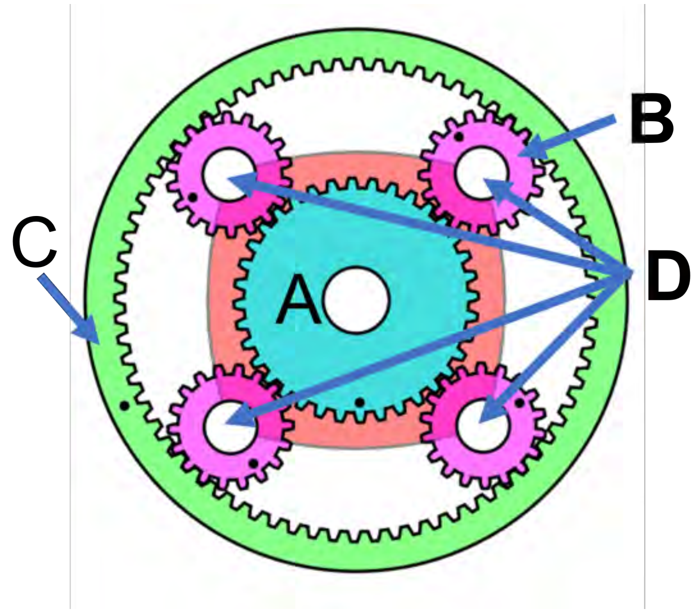


Figure 1. Planetary Gear

3. What are three advantages of a planetary gear system?

4. Explain how a technician uses precision tools to set the end play and preload on a wheel and why end play and preload are important.

5. What information does a technician need when selecting a tractor tire?
   a) Ballast weight, tire diameter, rim diameter, tire width, travel speed
   b) Ballast weight, tire diameter, rim weight, tire width, travel speed
   c) Tractor weight, tire diameter, rim diameter, tire width, travel speed
   d) Tractor weight, tire diameter, rim weight, tire width, travel speed

6. Complete the table below for the following tire: 620/70R46

Table 1. ***Tire Specifications***

Description	Specification
Tire width	
Sidewall height	
Ply Type	
Rim Diameter	

7. Why does a technician ballast a tractor?

8. A technician has collected the following wheel slip data for a two-wheel-drive tractor. Calculate the wheel slippage.

Table 2. ***Wheel Slip Data***

Description	Measurement
Revolutions with load	10 revolutions
Revolutions without load	8 revolutions

9. Is the wheel slippage calculated acceptable? If not, how can a technician improve the tractor's efficiency?

10. Identify the wear for each of the following failed components. Then explain a cause and correction for each.

Failed Component	Wear	Cause	Correction

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Lesson 2.2 Check for Understanding Answer Key

1. What is the purpose of a differential system in a tractor?

Differential systems allow two wheels on the same powertrain to move at different speeds without reducing a system's torque.

2. Match the planetary gear components seen in Figure 1. Use some letters more than once.

C	Ring gear
B	Planetary gear
A	Sun gear
D	Planetary carrier
D	Drive output for high speed and torque multiplication
D	Drive input for overdrive
C	Drive input for slow speed and torque multiplication
D	Held in place for reverse
C	Held in place for highest speed
C	Held in place for the lowest speed
A	Drive input for the lowest speed
A	Drive output for highest speed

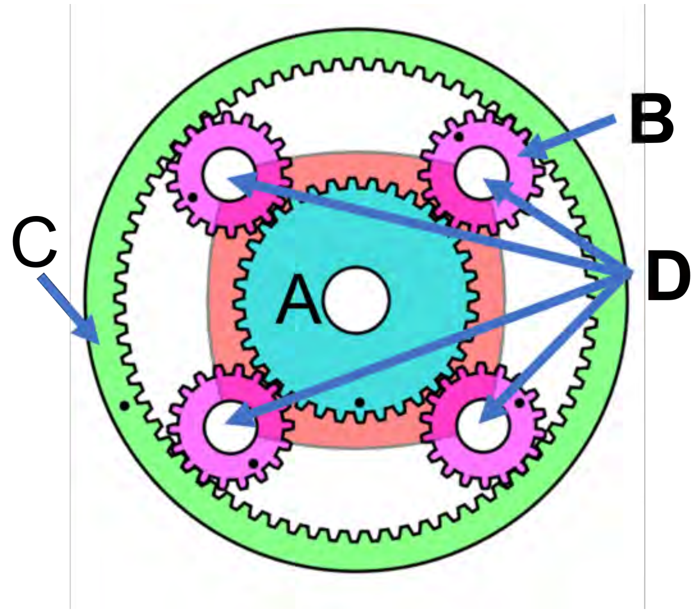

Figure 1. Planetary Gear

3. What are three advantages of a planetary gear system?

Provide a variety of speeds and torques.
Compact design
Load offset by multiple pinion gears

4. Explain how a technician uses precision tools to set the end play and preload on a wheel and why end play and preload are important.

A technician uses a dial indicator to measure the end play and a torque wrench to measure the preload placed on the wheel. A wheel with too much endplay will vibrate and cause the bearing to fail. A wheel with too much preload will compact the bearing, increasing the friction.

5. What information does a technician need when selecting a tractor tire?

a) Ballast weight, tire diameter, rim diameter, tire width, travel speed
b) Ballast weight, tire diameter, rim weight, tire width, travel speed
c) Tractor weight, tire diameter, rim diameter, tire width, travel speed
d) Tractor weight, tire diameter, rim weight, tire width, travel speed

6. Complete the table below for the following tire: 620/70R46

Table 1. ***Tire Specifications***

Description	Specification
Tire width	**620mm**
Sidewall height	**70% x 620mm = 434mm**
Ply Type	**Radial**
Rim Diameter	**46 inches**

7. Why does a technician ballast a tractor?

Decrease wheel slippage
Increase tire traction
Increase work efficiency

8. A technician has collected the following wheel slip data for a two-wheel-drive tractor. Calculate the wheel slippage.

Table 2. ***Wheel Slip Data***

Description	Measurement
Revolutions with load	10 revolutions
Revolutions without load	8 revolutions

$$\frac{10-8}{10} \times 100 = 20\% \text{ wheel slip}$$

9. Is the wheel slippage calculated acceptable? If not, how can a technician improve the tractor's efficiency?

The wheel slippage is over the 10-15% threshold for a two-wheel-drive tractor. Therefore, a technician should add weight to the rear wheels to increase traction.

10. Identify the wear for each of the following failed components. Then explain a cause and correction for each.

Failed Component	Wear	Cause	Correction
	Corrosion	**Water chemically reacted with the component**	**Use a lubricant or seal that prevents water intrusion**
	Adhesive wear	**Friction between parts built up heat causing the parts to weld together**	**Install the heat-treated components.**
	Abrasive wear	**Foreign particles caused the components to wear.**	**Add clean lubrication to the components.**

*****Example causes and corrections – others may also be correct.**

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Curriculum for Agricultural Science Education

Agricultural Equipment Maintenance and Technology

Bearings

Unit 2 – Lesson 2.1 Drive Train Components

Bearings

- Support rotating shafts and gears
- Reduces friction
- Friction causes
  - Drag
  - Heat
  - Wear

Antifriction Bearings

- Two steel rings
  - Inner race
  - Outer race
- Balls, rollers, or needles that roll between these races.
- Separator evenly spacing the rolling element around the inner race.

Maxx-Studio/Shutterstock

Bearings

There are three types of loads exerted on bearings.

- Radial
- Thrust
- Angular

Bearings are chosen based upon the type of load.

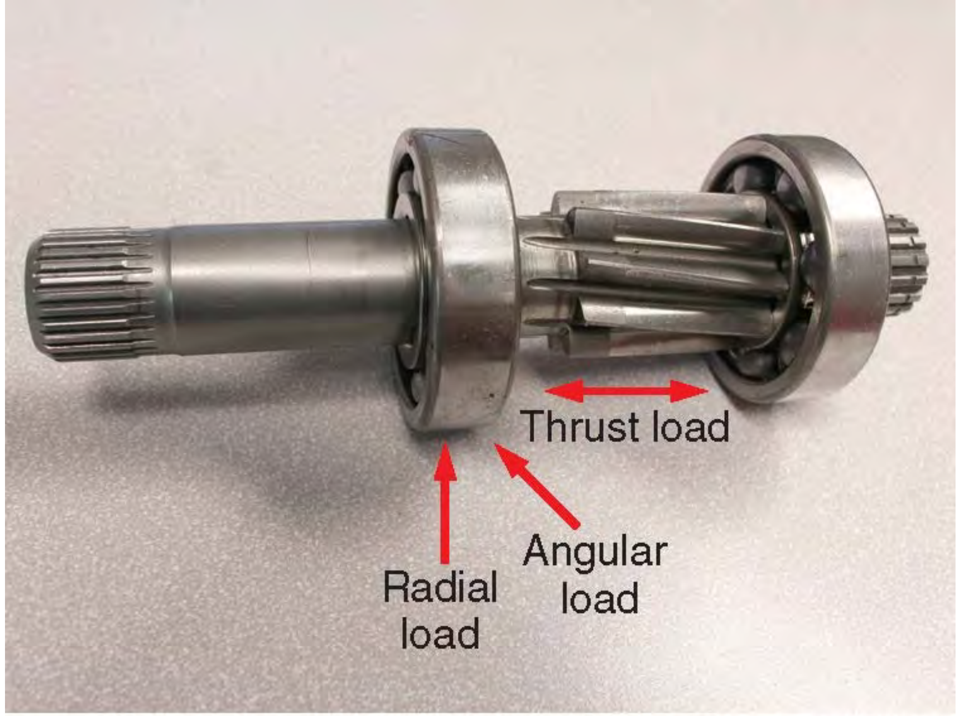


Photo from Goodheart-Wilcox, Heavy Equipment Power Trains and Systems, 2019

Ball Bearings

- Support radial and thrust loads
- High speeds
- Do not support heavy loads.
- Shaft must be aligned properly, or bearings will bind and wear out

Roller Bearings

Roller bearings

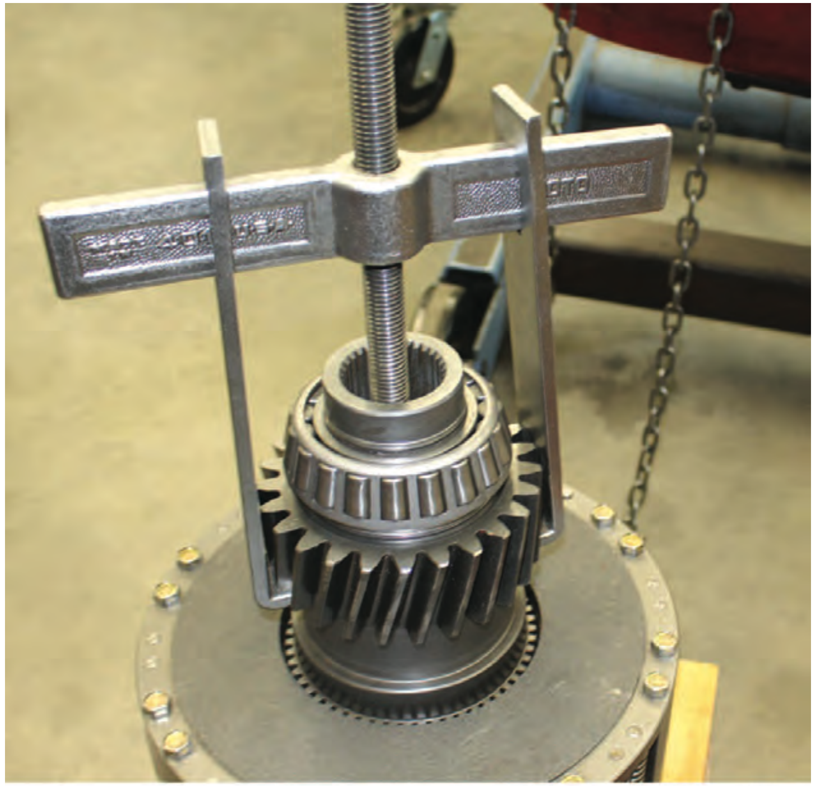
- Straight roller bearing
- Tapered roller bearing
- Needle roller bearing
- Spherical roller bearing
- Thrust bearing

Photos from Goodheart-Wilcox, Heavy Equipment Power Trains and Systems, 2019

Removal

Multiple types of tools are used for removing bearings:

- Presses
- Drivers
- Slide Hammers
- Mechanical Pullers



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Cleaning and Inspecting

Cleaning and inspecting

- Clean with solvent and allow to sit and dry
- Inspect reused bearing for damage
  - Check for nicks, pits, cracks, and wear.

Installation

- Use a driver or press that fits the bearing's race.
- Do not use a hammer to drive a bearing race as it can damage the race.
- Only apply pressure to press-fit bearing races, and never bearing cages.
- Refer to service literature for special instructions such as applying heat.

Presentation Review

- Mark or highlight three key points
- List two ideas or concepts related to previous knowledge.
- List questions you have about this topic.
- Keep notes organized and available for use throughout the course.

References

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Curriculum for Agricultural Science Education

Agricultural Equipment Maintenance and Technology

Clutches

Unit 2 – Lesson 2.1 Drive Train Components

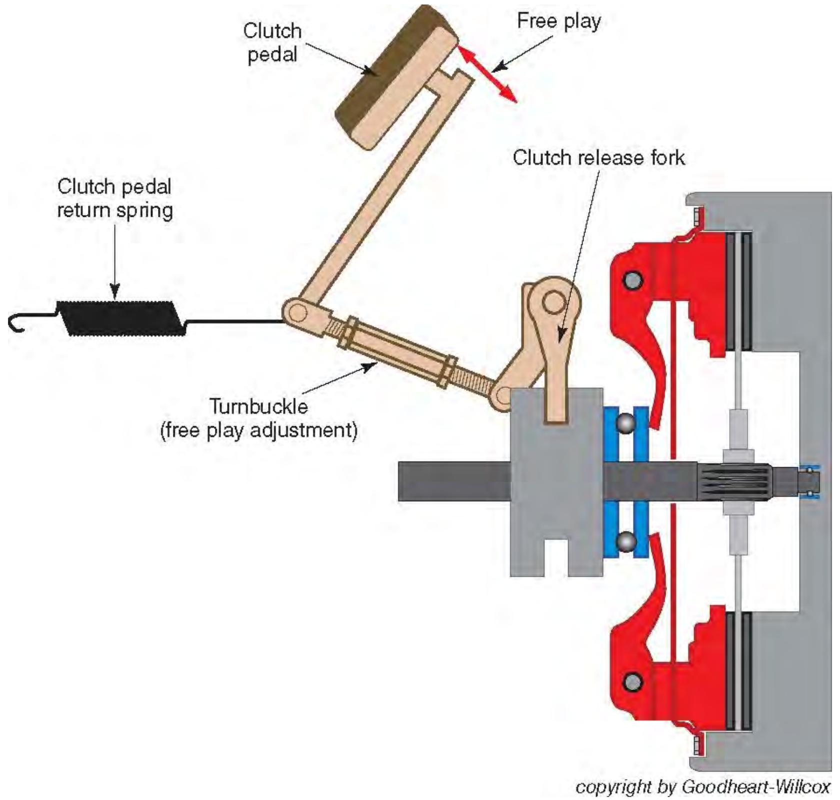
Clutches

Cutches engage and disengage power.

- Traction clutches—connect and disconnect power to the transmission.
- PTO clutches—connect and disconnect power to the PTO shaft.
- Bands or brakes—bring a rotating shaft/drum to a stop or hold it stationary.

Single-Disc Traction Clutch

- Flywheel is bolted to crankshaft
- Clutch assembly is bolted to the flywheel
- Disc is splined to the transmission input shaft
- Clutch pedal is actuated to apply pressure to the release bearing and remove pressure from the clutch disc



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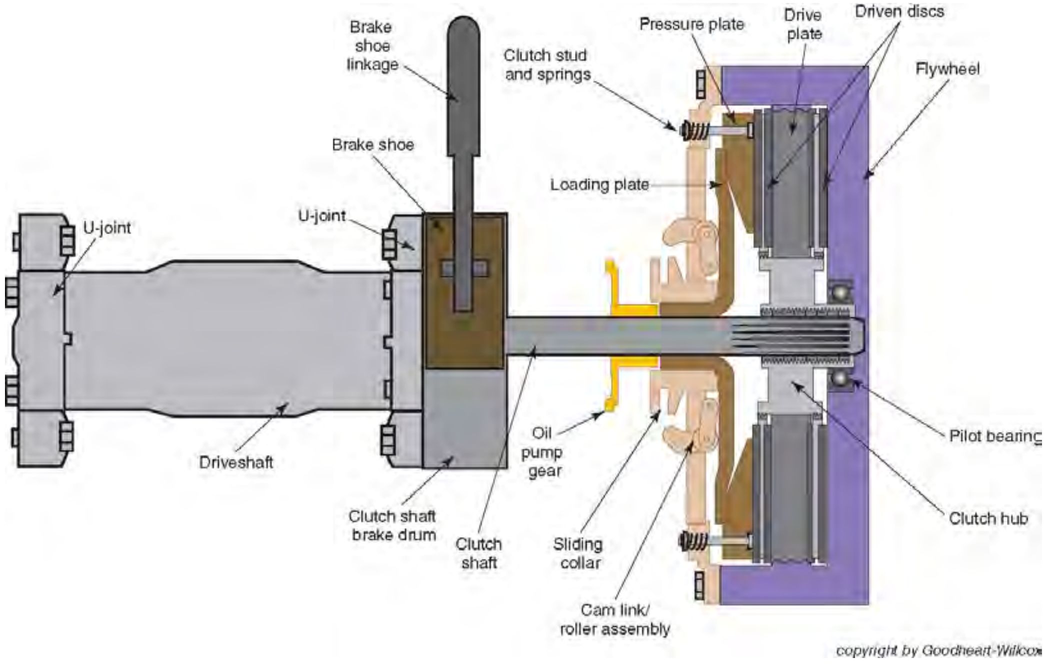
Dual-Disc Traction Clutch

- Flywheel surrounds clutch assembly
- Two driven discs splined to clutch hub
- Two discs allow for a higher amount torque to be transmitted through the clutch



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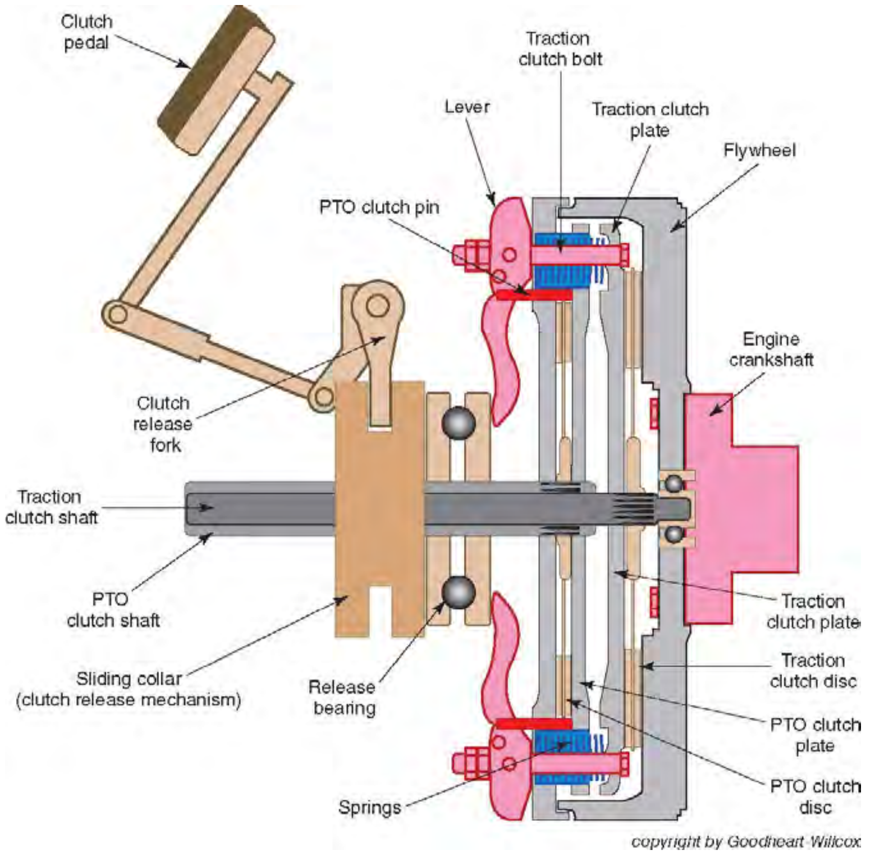
PTO and Traction Clutch Assemblies

- One clutch pedal controls both PTO and traction clutches
- Half-pressed pedal disengages traction clutch
- Fully pressed pedal disengages both
- The advantage of this clutch is that the PTO can be engaged without the tractor moving



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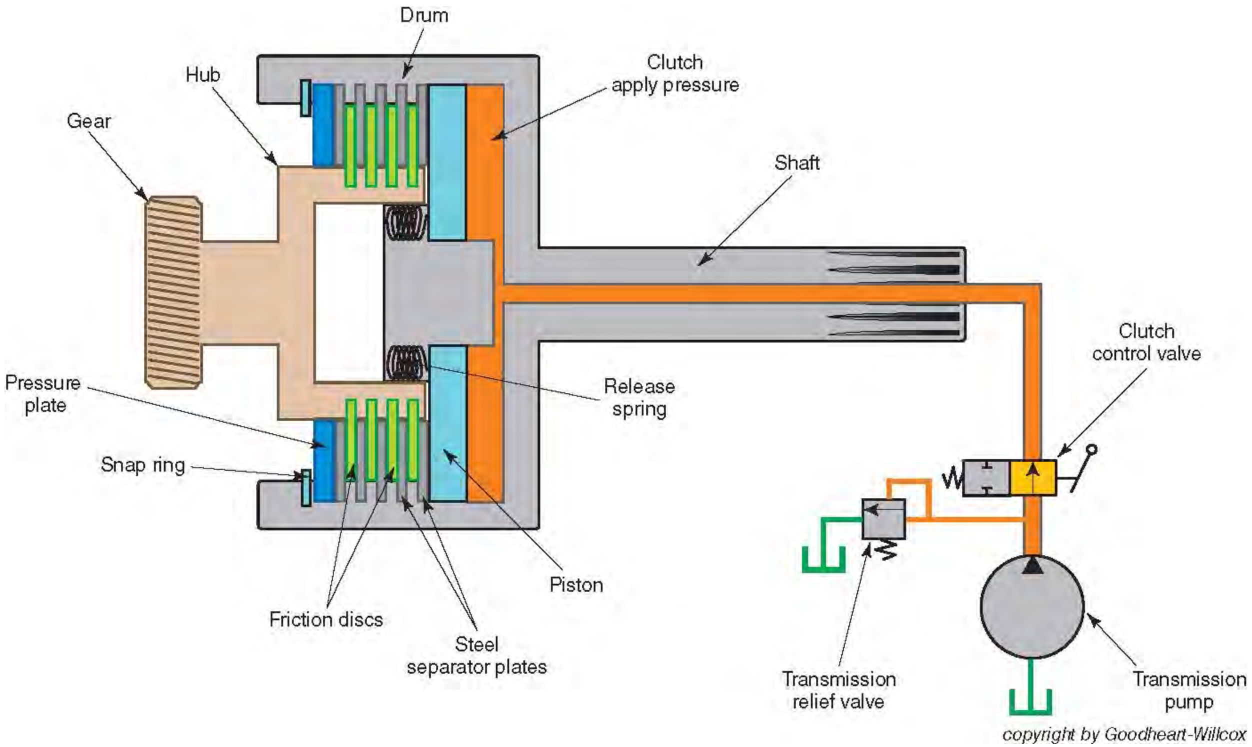
Multiple-Disc Clutches

- Friction discs alternate between steel separator plates
- Friction disc are spined to the hub
- Separator plates are spined to the drum



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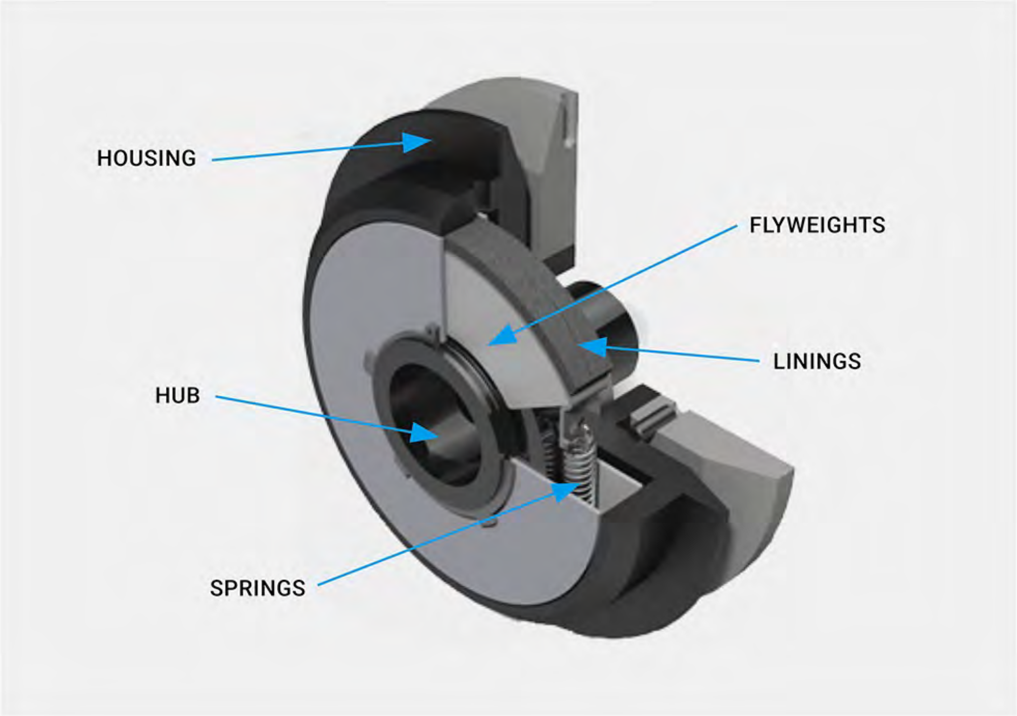
Slip Clutch

- Designed to slip when it encounters an excessive load
- Spring tension keeps clutch engaged in normal state
- Must be intentionally slipped (burnished) each season

Photo from Goodheart-Wilcox, Heavy Equipment Power Trains and Systems, 2019

Centrifugal Clutch

- Use flyweight assembly to engage clutch at set speed
- Commonly found on chain saws and all-terrain vehicles (ATV).



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References

- Dell, Timothy W. (2019). *Heavy equipment power trains and system, 1st edition.* Tinely Park, IL: The Goodheart-Willcox Company, Inc.

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Curriculum for Agricultural Science Education

Agricultural Equipment Maintenance and Technology

Gears

Unit 2 – Lesson 2.1 Drive Train Components

Gears

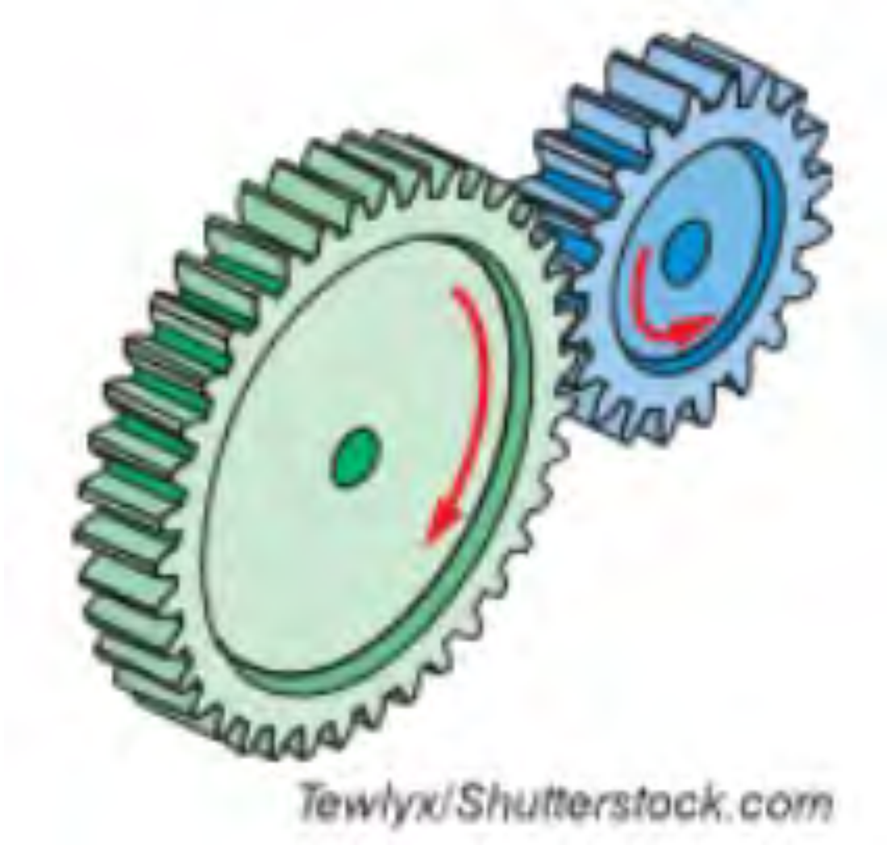
Propel Machines

Power transmissions

- rotors, belts, augers, rollers, conveyors, reels, and shafts.
- Mulitple types
- designed to match the power transmission purpose.

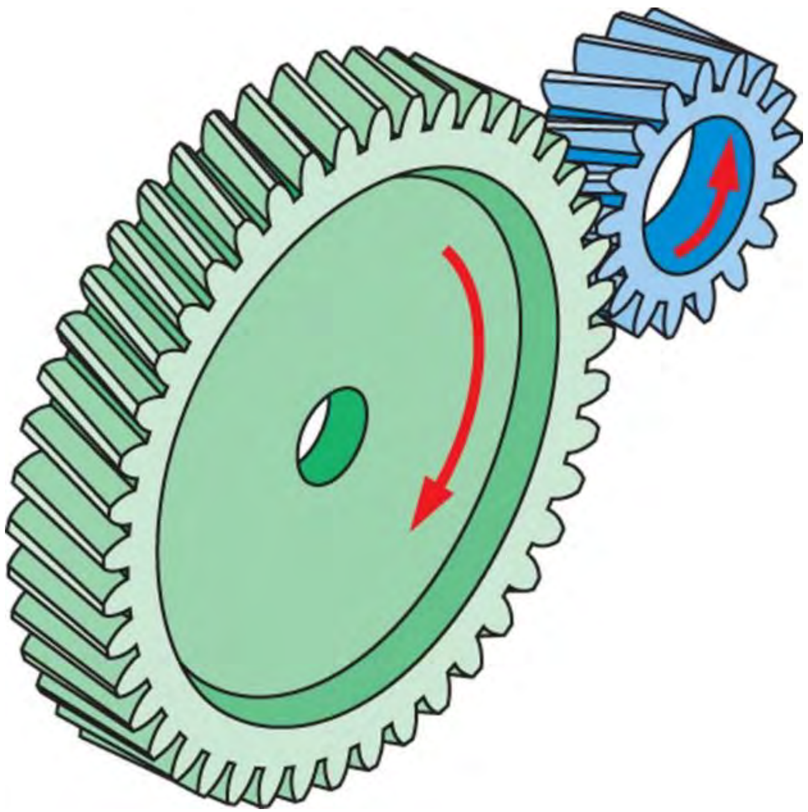
Spur Gear

- Straight cut teeth
- Least expensive to machine
- Don’t produce end trust
- Noisy
- Distribute power one tooth at a time.



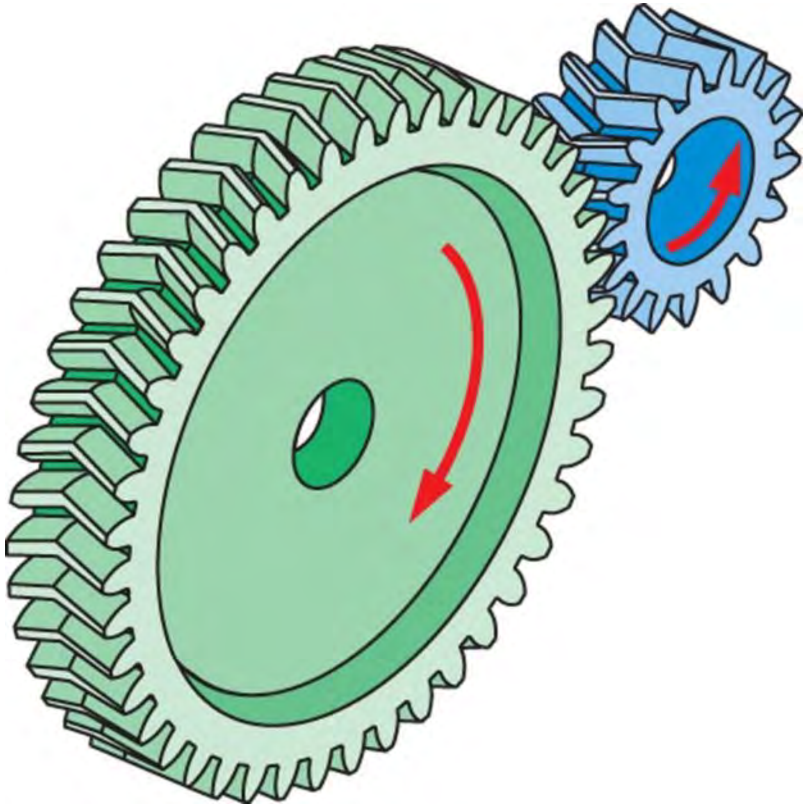
Helical Gears

- Teeth cut at angle
- Quieter operation
- Distribute power on more than one tooth at a time.
- Angled teeth create side thrust.



Herringbone Gear

- Chevron tooth pattern or V
- Quite operation
- No side thrust
- High speed operation
- Expensive to manufacture



Bevel Gears

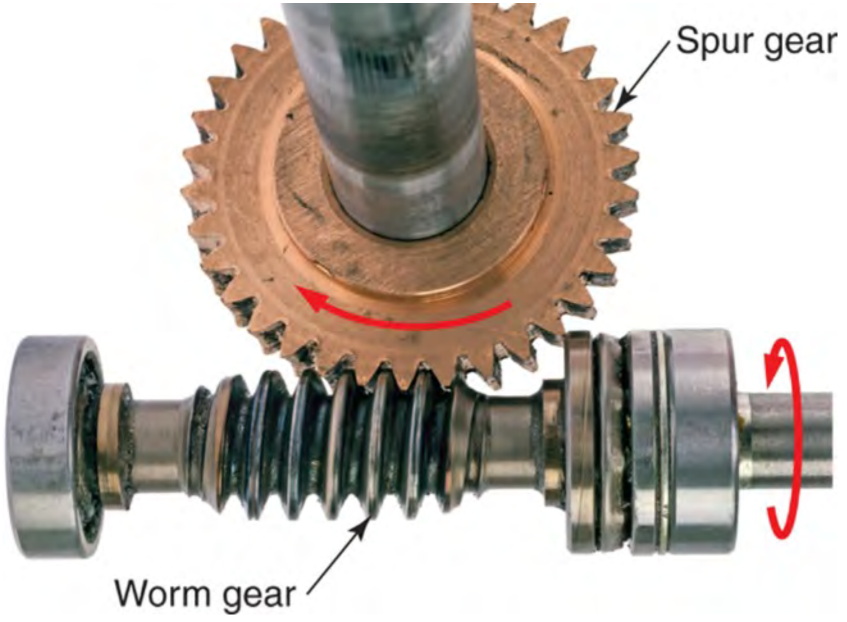
- Provide a change in the direction of power flow.
  - Straight Bevel
    - Unloading augers
    - PTO gearbox
  - Spiral Bevel
    - Reduce noise and have a higher strength
  - Hypoid
    - Pinion gear is positioned below the center axis of the ring gear
    - Automotive differential

Rack-and-Pinion Gear

- Change's rotary motion into linear
- Pinion gear rotates, rack moves linearly
- Trapdoor openers on the bottom hoppers on grain semitrailers.
- Rack and Pinion steering.

Worm Gear

- Provides a change in direction of power flow
- Used for high-speed input and low speed output.
- Uses such as actuating the concaves on a combine.



Cam Gear

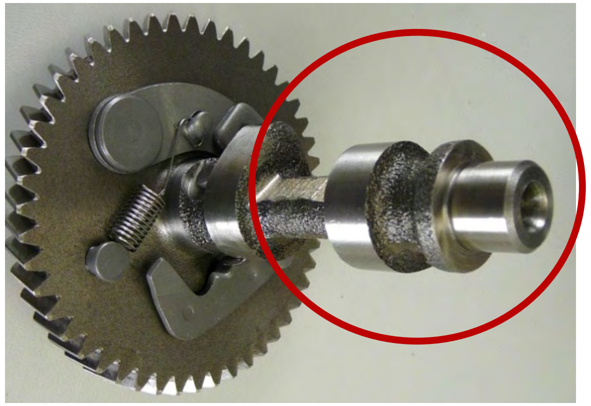
Change rotary motion to linear motion

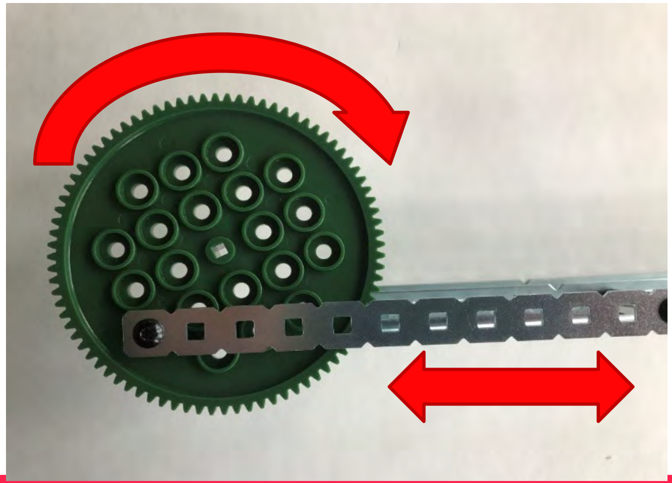
Small engine cams

- Rotating objects

Face cam

- Lever attached to face of rotating component such as a gear or sprocket





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- Gillespie, J.R., & Flanders, F.B. (2015). *Modern livestock and poultry production (9th ed.).* Clifton Park, NY: Delmar.
- Herren, R. V., & Donahue, R. L. (2000). *Delmar's agriscience dictionary with searchable CD-ROM*. Albany, NY: Delmar.

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SECTION CONTENTS

Brake System

Drive System

PTO

Mower Deck

BRAKE SYSTEM

Brake Linkage Adjustment

This adjustment is used to prevent the brake from dragging when the brake pedal is released. Brake engagement is not adjustable and should not require service for the life of the brake assembly. If the brake does not hold when engaged, replace the brake pad assembly.

The brake is fully disengaged when the pedal is released and the brake arm (B, Figure 1) points straight up. Use the nut (A) to adjust the brake rod so the brake is not dragging when the brake is disengaged.

1. Turn off the engine and remove the key from the ignition. DO NOT engage the parking brake.
2. Remove the back bumper to gain access to the brake rod adjustment nut (A).
3. Angle the brake assembly arm (B) so that it is standing straight up. Hold in place.
4. With the brake assembly arm straight up and the brake pedal at rest, turn the brake rod adjustment nut (A) until the spacer (C) contacts the brake pivot arm (D). Do not over-tighten. Over-tightening will cause the brake to drag.

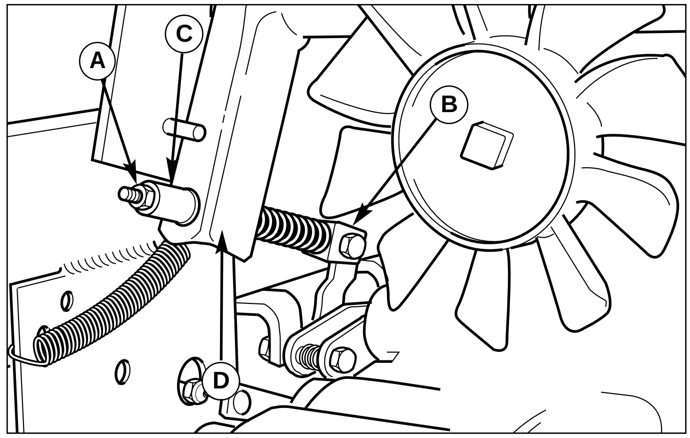

Figure 1. Brake Linkage Adjustment
A. Brake Rod Adjustment Nut
B. Brake Assembly Arm
C. Spacer
D. Brake Pivot Arm

Brake Switch Adjustment

NOTE: Normally, the break pedal switch does not require any adjustment. In the event that debris damages or bends the brake switch components, this adjustment procedure should be followed. The normal angle of the tab is about 45 degrees, and setting the tab to that point would be a good starting point.

1. Park the tractor on a level surface.
2. Place blocks in front of and behind the front wheels.
3. Turn the ignition key switch to the OFF position, remove the key, DO NOT set the parking brake, and turn the PTO switch off (PTO switch pulled up).
4. Disconnect the negative (-) battery cable (see Section 7, ELECTRICAL SYSTEM SERVICE).
5. Remove the mower deck and any other accessories (see Section 6, COMMON SERVICE PROCEDURES).
6. Disconnect spark plug wires or glow plug wires to prevent the possibility of accidental starting while the PTO is being adjusted.
7. Angle the brake assembly arm so that is standing straight up. Hold in place.

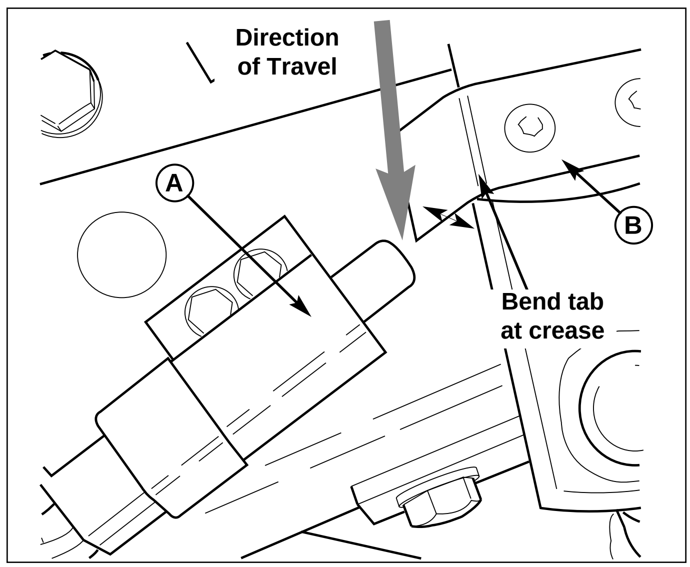

Figure 2. Brake Switch Adjustment
A. Brake Switch **B. Tab**

8. With the brake assembly arm straight up and the brake pedal at rest, the tab (B, Figure 2) on the brake pedal arm should not be in contact with the brake switch (A).
9. As the brake pedal is depressed, the tab (B) should come into contact with the switch (A) at 1/4 the total travel distance of the brake pedal.
10. Bend the tab (B) accordingly to engage the switch (A) at the proper position.

DRIVE SYSTEM

Cruise Control Lever Tension Adjustment

If the cruise control lever will not hold ground speed, perform the following adjustment.

1. Locate the cruise control tension bolt (A, Figure 3).
2. Tighten the bolt until desired tension is achieved.

   DO NOT OVER-TIGHTEN. The brake pedal must be able to return the cruise control lever to neutral.

Differential Lock Cable Adjustment

1. Locate the adjustment nuts (A, Figure 4) on the forward cable shroud located under the left foot rest.
2. Loosen the adjustment nuts so that the cable is slack and the foot pedal rod (B) drops down.
3. Tighten the cable until the foot pedal just touches the upstop (C). There MUST be some slack in the cable.

IMPORTANT NOTE

DO NOT ADJUST THE CABLE SO TIGHT AS TO REMOVE ALL CABLE SLACK. This will partially engage the differential lock and damage the transmission.

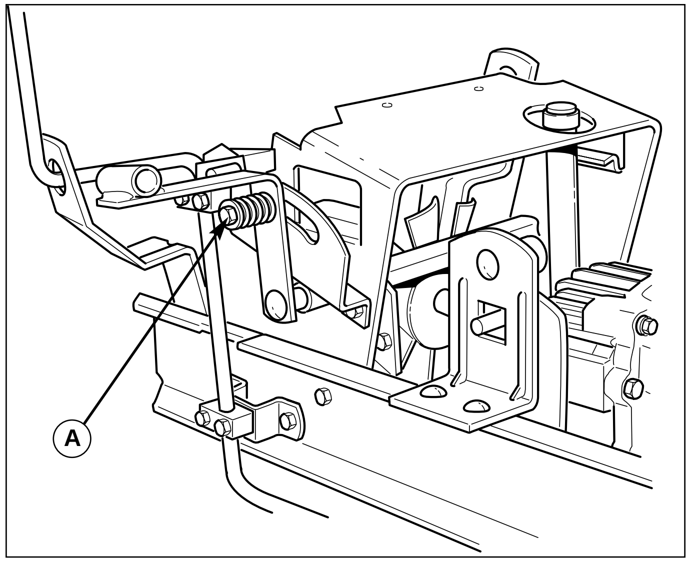

Figure 3. Cruise Control Lever Adjustment
A. Tension Bolt

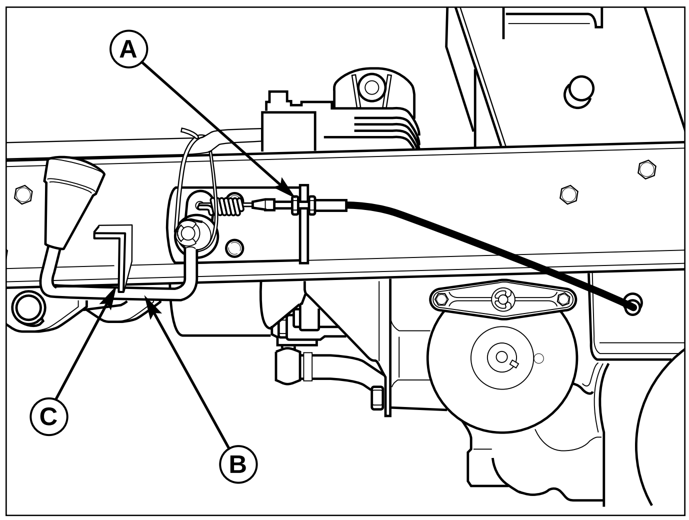

Figure 4. Differential Lock Cable Adjustment
A. Adjustment Nuts
B. Foot Pedal Rod
C. Upstop

Neutral Adjustment

If the tractor creeps forward or backward with the ground speed control pedal at rest (neutral) and the cruise control lever set in neutral, perform the following neutral adjustment.

NOTE: The neutral adjustment bracket (C, Figure 5) can be accessed from under the right side of the seat deck.

1. Block the front tires.
2. Elevate the rear end of the tractor with a jack and jackstands or overhead hoist so that both rear wheels DO NOT contact the ground.
3. Disengage the cruise control and depress the brake pedal. Start the engine.
4. Release the brake pedal and depress the forward and reverse ground speed pedals.

   Both the forward and reverse pedals should return to neutral when released and the wheels should not turn.

   If the unit creeps, proceed to step 7.
5. Check that the neutral spring (B) is contacting both sides of the neutral gate spacer (A) and neutral pin (E). If not, loosen the carriage bolt securing the neutral gate spacer (A).
6. Slide the spacer up and down until the neutral spring (B) is contacting both sides of the neutral pin (E) and neutral gate spacer (A). The spring must touch all four contact points (see Figure 2).
7. Loosen the neutral bracket bolts (D).
8. Slide the neutral bracket (C) back and forth until neutral is found.

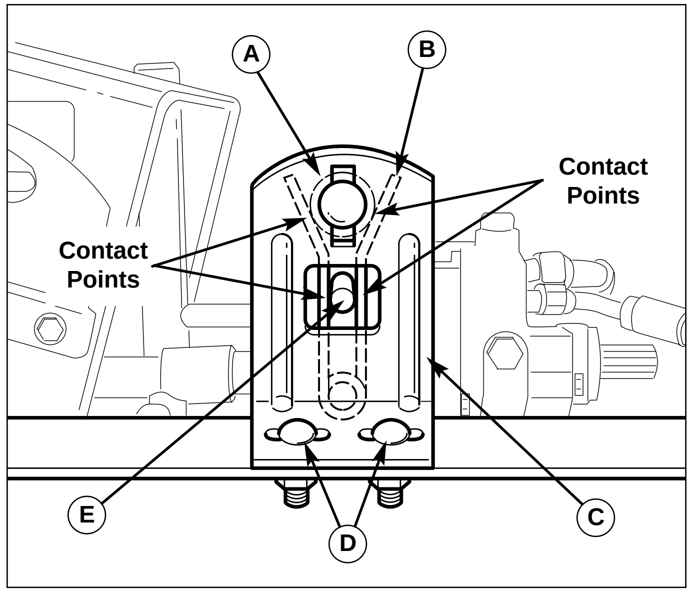

Figure 5. Neutral Adjust

A. Neutral Gate Spacer
B. Neutral Spring
C. Neutral Bracket
D. Neutral Bracket Bolts
E. Neutral Pin

9. Tighten the neutral bracket bolts (D) securing the neutral bracket (C).
10. Test the pedals. Depress and release the forward pedal and then the reverse pedal.

    Both pedals should return to neutral when released and the wheels should not turn.

    If the tractor still creeps, repeat steps 7-10. If repeating steps 7-10 does not solve the problem the neutral gate spacer (A) will need to be adjusted; proceed to step 5.
11. Tighten the neutral gate spacer (A) carriage bolt.
12. Recheck neutral by repeating steps 4-12.

To avoid damaging belts, do not pry belts over pulleys.

WARNING

The muffler and surrounding areas can be extremely hot. Allow the engine to cool before performing this procedure.

WARNING

To avoid serious injury, perform adjustments only with engine stopped, key removed, tractor on level ground, and spark plug wires disconnected.

PTO Clutch Adjustment

Check the PTO clutch adjustment after the initial 50 hour break-in period and then after every 250 hours of operation. Also perform the following procedure if the clutch is slipping or will not engage.

1. Park the tractor on a level surface.
2. Turn the ignition key switch to the OFF position, remove the key, set the parking brake, and turn the PTO switch off (PTO switch pulled up).
3. Disconnect the negative (-) battery cable (see Section 7, ELECTRICAL SYSTEM SERVICE). Disconnect spark plug wires to prevent the possibility of accidental starting while the PTO is being adjusted.
4. See Figure 6. Note the position of the three adjustment slots (A) in the side of the brake plate and the adjustment nuts (B). Insert a .012" feeler gauge through each slot, positioning the gauge between the rotor face and the armature face as shown in Figure 7.

NOTE: The air gap must be NO LESS THAN .012" and NO MORE THAN .015". An air gap of less than .012" will not allow the brake to fully disengage. An air gap greater than .015" may cause the clutch to slip.

5. Alternately tighten the adjustment nuts (B, Figure 6) until the rotor face and armature face just contact the gauge. Check the slots for an equal amount of tension when the gauge is inserted and removed, and make any necessary adjustments by tightening or loosening the adjustment nuts.

NOTE: Adjustment at one location will change adjustment at the two other slots. Make sure all three locations have proper adjustment.

NOTE: The actual air gap between the rotor and armature may vary even after performing the adjustment procedure. This is due to dimensional variations of component parts, and is an acceptable condition.

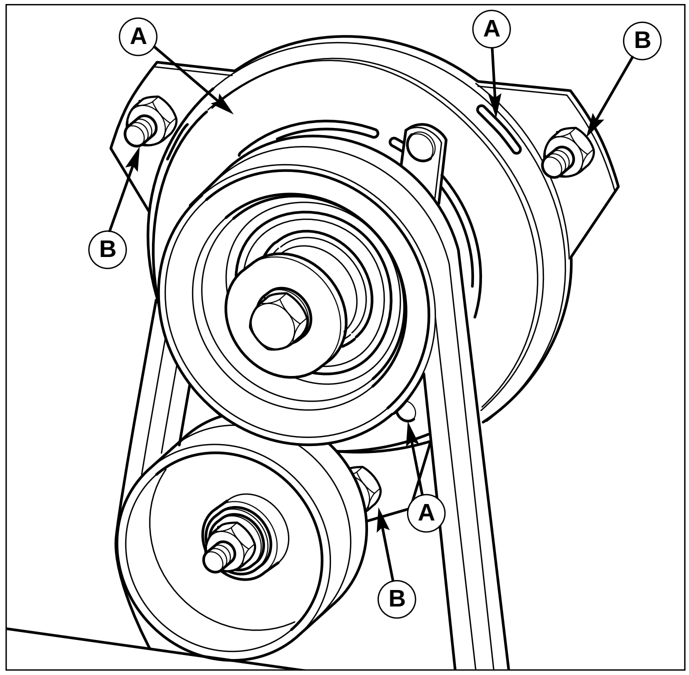

Figure 6. Front PTO Adjustment
A. Slots B. Nuts

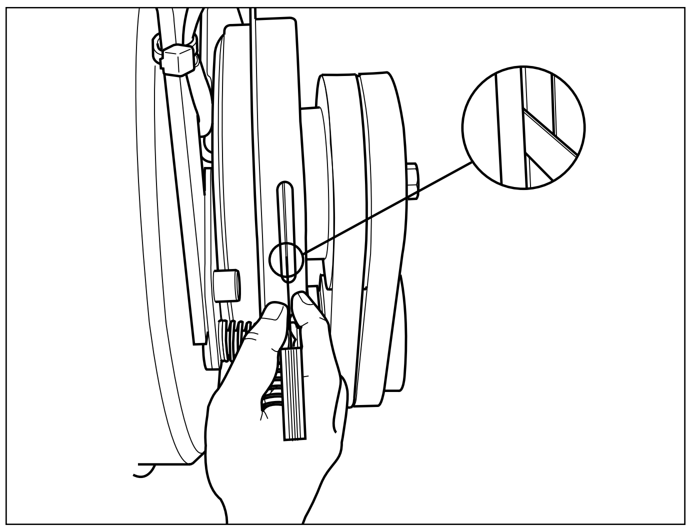

Figure 7. Check Air Gap

6. Reconnect the negative (-) battery cable (see Section 7, ELECTRICAL SYSTEM SERVICE).
7. With tractor in neutral, PTO disengaged, and operator in seat, start the tractor engine.
8. Engage the front PTO and wait several seconds. Disengage the front PTO and check the amount of time it takes for the mower drive belt to stop. If mower drive shaft does not stop within five seconds, repeat the adjustment procedure. If the shaft still does not stop within five seconds, replace the clutch.

MOWER DECK

⚠ WARNING

Before checking mower, shut off PTO clutch and engine. Allow all moving parts to stop. Remove ignition key.

Leveling

If the cut is uneven, the mower may need leveling. Unequal or improper tire pressure may also cause an uneven cut. Tire pressure should be as follows:

- Front: 12-15 psi
- Rear: 6-8 psi

SIDE TO SIDE LEVELING

1. With the mower installed, place the tractor on a smooth, level surface such as a concrete floor. Turn the front wheels straight forward.
2. Place the cutting height adjust in high-cut position.
3. Set the parking brake, turn off the ignition, and remove the key.
4. Check for bent blades and replace if necessary.
5. Arrange the mower blades so that they are pointing from side-to-side.
6. Measure the distance between the outside tips of each blade and the ground. If there is more than 1/8" (3 mm) difference between the measurements on each side, proceed to step 7. If the difference is 1/8" (3 mm) or less, proceed to Front to Back Leveling.
7. See Figure 8. Loosen the outside nut (A) then turn the eccentric nut (B) to raise or lower the left side of the deck. Repeat on the right side of the deck. When the mower deck is level, hold the eccentric nut while tightening the outside nut.

FRONT TO BACK LEVELING

1. Arrange the blades so they face front-to-back.
2. Measure the distance from the ground to the front and rear tips of each blade. The measurement should be equal for both blades. Front tips should be equal to rear tips or within 1/8" higher. If not, proceed to step 3.
3. Loosen the two rear jam nuts (A, Figure 9) on both both arm assemblies. Adjust the jam nuts on both arms until the mower deck is level or the front is 1/4” higher.

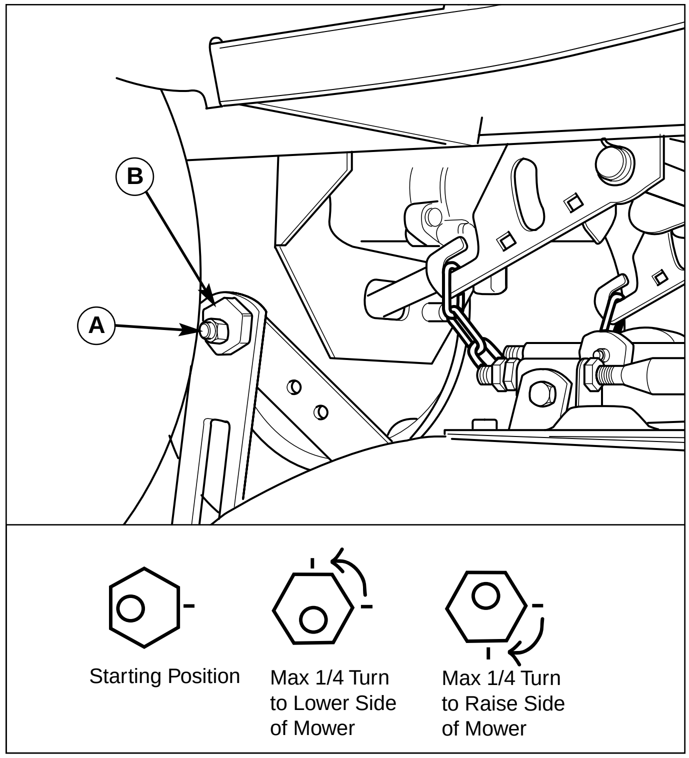

Figure 8. Side-to-Side Adjustment
A. Outside Nut **B. Eccentric Nut**

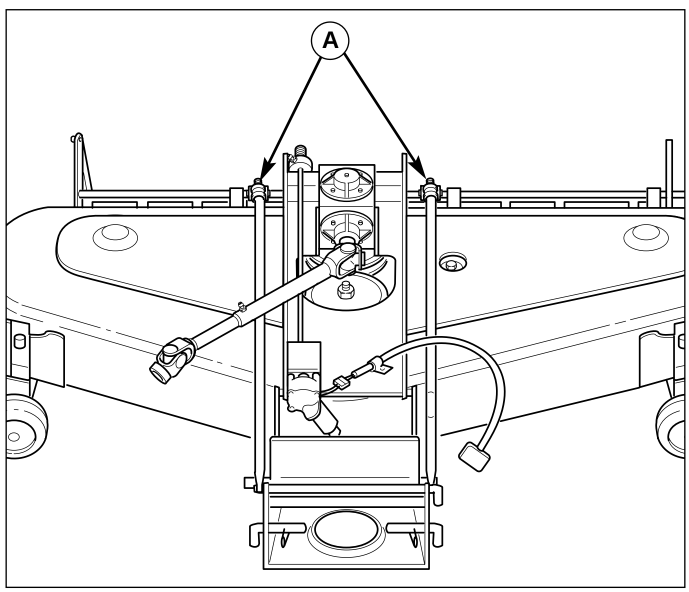

Figure 9. Front to Back Leveling
A. Jam Nuts

Pulley Stop Adjustment (48" Mower Only)

The pulley stop (A, Figure 10) prevents the idler pulley from contacting the idler arm tension spring (B) when the deck is engaged.

1. Remove the mower deck. See Mower Deck Removal & Installation, in Section 18.
2. Remove the left side cover.
3. Loosen the idler pulley bolt and orient the pulley stop (A) as shown in Figure 10.

Gauge Wheel Adjustment (54" Mower Only)

The mower gauge wheels can be placed in two positions depending on the height of cut. When using higher cutting heights, set the wheels in the lower position. When using lower cutting heights, set the wheels in the upper position. To adjust:

1. Remove the hairpin clip (A, B, Figure 11).
2. For upper position, install the pin (A) through the spindle above the bracket (C). For the lower position, push down on the top of the spindle, and install the hairpin clip (B) below the top of the bracket (C).

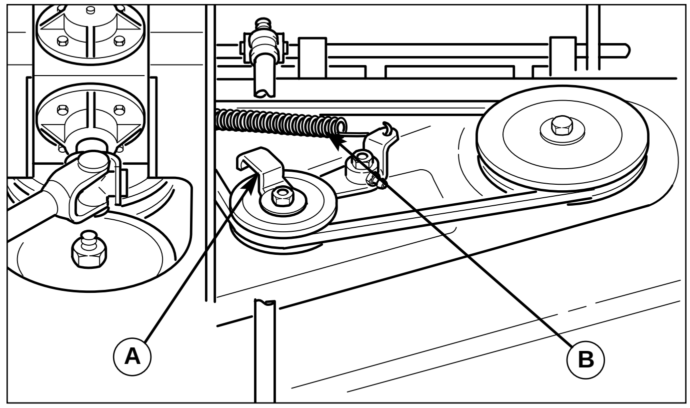

Figure 10. Pulley Stop Position
A. Pulley Stop
B. Idler Arm Tension Spring

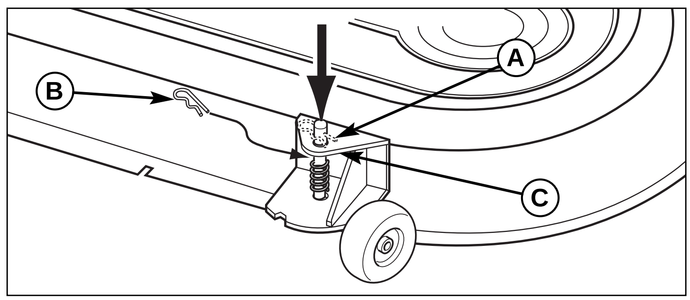

Figure 11. Gauge Wheel Adjustment
A. Hairpin Clip (Upper Position)
B. Hairpin Clip (Lower Position)
C. Gauge Wheel Bracket

Roller Bracket Adjustment (60" Mower Only)

The anti-scalping rollers (A, Figure 12) can be adjusted for different cutting heights by positioning roller brackets on the mower baffle (B).

1. Remove bolts, lockwashers, and nuts securing roller bracket to baffle.
2. If you typically cut using the lower half of the mower cutting height range, the roller brackets should be positioned in the upper set of holes.
3. Use the lower set of holes if mowing is usually done in the upper half of the cutting height range, or if scalping occurs at lower cutting heights due to uneven terrain.

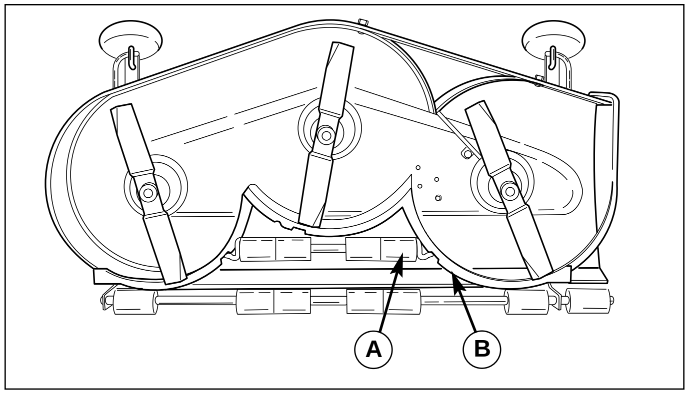

Figure 12. Anti-Scalping Rollers
A. Rollers
B. Mower Baffle

Idler Pulley Adjustment (60" Mower Only)

If the mower deck belt has stretched over time, the outermost idler pulley (A, Figure 13) can be moved to the outer hole in the mower deck to take up the belt slack.

If the mower belt is being replaced, move the pulley back to the inside hole.

To adjust:

1. Remove the drive belt.
2. Remove the idler pulley (A, Figure 13) hardware.
3. Move the idler pulley to the outer hole and retighten the hardware.
4. Reinstall the drive belt.

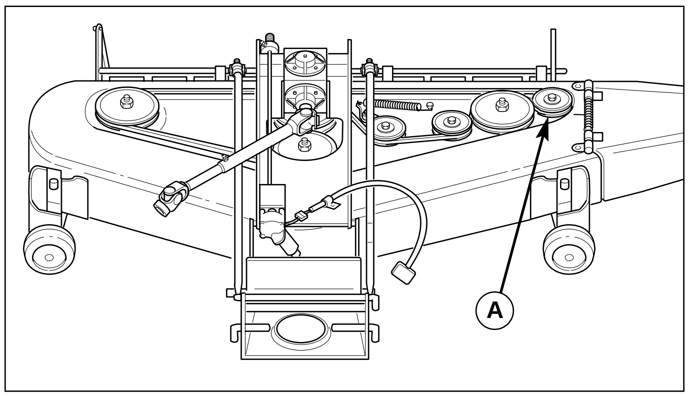

Figure 13. Idler Pulley Adjustment – 60" Decks Only
A. Adjustable Idler Pulley

CASE

Lesson 3.1 Precision Systems

Preface

A combination of mechanical and global positioning systems optimizes farm production. Using site-specific applications, global positioning systems installed on equipment can monitor agricultural yield and increase agricultural efficiencies. Automated systems with GPS technology precisely monitor and apply agricultural inputs such as seed, fertilizer, water, and herbicide.

Guidance systems on tractors and field equipment ensure farmers treat a field without excessive overlaps or skips. Overlaps are areas of the field receiving too much of an application, and skips are areas not receiving enough. Similar types of guidance systems on combines and other equipment use sensors to collect data that farmers can use to make production decisions.

Before a producer can operate a complex guidance system, they must check the controller settings to ensure the equipment is fully operable. Controller settings include GPS signals, software updates, sensor connections, field boundaries, and implement information. Once settings are in place, the operator can use the field equipment.

Operators ask technicians to diagnose precision system problems they face in the field. Technicians use their knowledge of sensors, programmable logic controllers (PLCs), and electrical circuits to identify the cause of precision system failures. PLCs are the control hubs for precision systems receiving sensor information and sending control signals to outputs such as lights, alarms, and motors.

Students will familiarize themselves with precision system hardware and software throughout this lesson. First, they learn how to calibrate equipment to avoid wasting valuable inputs and how guidance systems follow those calibration settings. Then they identify the precision agricultural components in a combine and adjust the precision system settings for a virtual tractor. Next, students calculate the cost savings of using a precision agricultural system. Finally, students use a global positioning sensor to activate a model irrigation and guidance system to complete the lesson.

Concepts	**Performance Objectives**
Students will know and understand	*Students will learn concepts by doing*
1. Equipment calibration increases the efficiency of outputs and limits overlaps and skips in a field.	• Calibrate a hand sprayer and fertilizer spreader. (Activity 3.1.1)
2. Precision systems require a wireless connection with satellites to find a geographic location.	• Locate satellites and determine signal quality for a global positioning system. (Activity 3.1.2)
3. Controller systems in precision agriculture include guidance systems, yield monitors, sensors, and automated outputs.	• Draw a flow chart explaining the relationship between precision agricultural components found on a combine. (Project 3.1.3) • Operate a simulated tractor and guidance system. (Activity 3.1.4)
4. Precision agriculture increases production efficiencies that reduce application costs while improving yields.	• Calculate the potential savings for using an autosteer tractor and a piece of tillage equipment. (Activity.3.1.5)
5. Agricultural producers use sensors and automated controls to increase production efficiencies.	• Set up a control system for activating an irrigator. (Activity 3.1.6)

	• Construct a control system modeling a tractor's autosteer system. (Project 3.1.7)

National AFNR Common Career Technical Core Standards Alignment

Career Ready Practices
2. Apply appropriate academic and technical skills.
• CRP.02.01: Use strategic thinking to connect and apply academic learning, knowledge, and skills to solve problems in the workplace and community.
• CRP.02.02: Use strategic thinking to connect and apply technical concepts to solve problems in the workplace and community.
4. Communicate clearly, effectively and with reason.
• CRP.04.01: Speak using strategies that ensure clarity, logic, purpose and professionalism in formal and informal settings.
• CRP.04.02: Produce clear, reasoned and coherent written and visual communication in formal and informal settings.
• CRP.04.03: Model active listening strategies when interacting with others in formal and informal settings.
6. Demonstrate creativity and innovation.
• CRP.06.01: Synthesize information, knowledge, and experience to generate original ideas and challenge assumptions in the workplace and community.
• CRP.06.02: Assess a variety of workplace and community situations to identify ways to add value and improve the efficiency of processes and procedures.
• CRP.06.03: Create and execute a plan of action to act upon new ideas and introduce innovations to workplace and community organizations.
8. Utilize critical thinking to make sense of problems and persevere in solving them.
• CRP.08.01: Apply reason and logic to evaluate workplace and community situations from multiple perspectives.
• CRP.08.02: Investigate, prioritize, and select solutions to solve problems in the workplace and community.
• CRP.08.03: Establish plans to solve workplace and community problems and execute them with resiliency.
11. Use technology to enhance productivity.
• CRP.11.01: Research, select and use new technologies, tools, and applications to maximize productivity in the workplace and community.
12. Work productively in teams while using cultural/global competence.
• CRP.12.01: Contribute to team-oriented projects and builds consensus to accomplish results using cultural global competence in the workplace and community.
• CRP.12.02: Create and implement strategies to engage team members to work toward team and organizational goals in a variety of workplace and community situations (e.g., meetings, presentations, etc.).
Agriculture, Food, and Natural Resources Career Cluster
Agribusiness Systems Career Pathway (AG-BIZ)
4. Develop a business plan for an AFNR enterprise or business unit.
• AG-BIZ 4.3: Develop an operation and/or production plan to provide required levels of product or service.
Power, Structural and Technical (AG-PST)
1. Apply physical science principles and engineering applications related to mechanical equipment, structures, and biological systems to solve problems and improve performance in AFNR power, structural, and technical systems.
• AG-PST 1.2: Use hand and power tools commonly required in power, structural, and technical systems
• AG-PST 1.3: Investigate solutions to AFNR power, structural, and technical systems.
• AG-PST 1.4: Design or modify equipment, structures, or biological systems to improve performance of an AFNR enterprise or business unit.
2. Operate and maintain mechanical equipment related to AFNR power, structural, and technical systems.
• AG-PST 2.3: Operate machinery and equipment while observing all safety precautions.
3. Service and repair mechanical equipment and power systems used in AFNR power, structural and technical systems.

• AG-PST 3.6: Service electrical systems by troubleshooting from schematics.
5. Use control, monitoring, geospatial and other technologies in AFNR power, structural and technical systems.
• AG-PST 5.1: Execute procedures and techniques for monitoring and controlling electrical systems using basic principles of electricity.
• AG-PST 5.2 Design control systems by referencing electrical drawings.
• AG-PST 5.3 Use geospatial technologies in AFNR applications.

Next Generation Science Standards Alignment

Crosscutting Concepts	
Patterns	Observed patterns in nature guide organization and classification and prompt questions about relationships and causes underlying them.
	• Patterns of performance of designed systems can be analyzed and interpreted to reengineer and improve the system.
Systems and System Models	A system is an organized group of related objects or components; models can be used for understanding and predicting the behavior of systems.
	• Systems can be designed to do specific tasks.

Common Core State Standards for High School Mathematics

Modeling standards are indicated by the star symbol (*) throughout other conceptual categories.

CCSS: Conceptual Category – Number and Quantity	
Quantities	*Reason quantitatively and use units to solve problems.

CCSS: Conceptual Category – Algebra	
Seeing Structure in Expressions	*Interpret the structure of expressions. *Write expressions in equivalent forms to solve problems.

CCSS: Conceptual Category – Geometry	
Modeling with Geometry	*Apply geometric concepts in modeling situations.

Common Core State Standards for English Language Arts

CCSS: English Language Arts Standards » Science & Technical Subjects » Grade 11-12	
Key Ideas and Details	• **RST.11-12.3 –** Follow precisely a complex multistep procedure when carrying out experiments, taking measurements, or performing technical tasks; analyze the specific results based on explanations in the text.
Craft and Structure	• **RST.11-12.4 –** Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to grades 11-12 texts and topics.
Integration of Knowledge and Ideas	• **RST.11-12.9 –** Synthesize information from a range of sources (e.g., texts, experiments, simulations) into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible.
Range of Reading and Level of Text Complexity	• **RST.11-12.10 –** By the end of grade 12, read and comprehend science/technical texts in the grades 11-CCR text complexity band independently and proficiently.

CCSS: English Language Arts Standards » Writing » Grade 11-12	
Research to Build and Present Knowledge	• **WHST.11-12.7 –** Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation.
Range of Writing	• **WHST.11-12.10 –** Write routinely over extended time frames (time for reflection and revision) and shorter time frames (a single sitting or a day or two) for a range of discipline-specific tasks, purposes, and audiences.

Essential Questions

1. Why do technicians calibrate equipment?

2. How does equipment calibration reduce input costs?
3. How do GPS receivers work?
4. What causes poor satellite signals?
5. How does a guidance system work on a mobile machine?
6. What information does a precision agricultural system collect during crop production?
7. What are the advantages of producers using a precision agriculture system?
8. How does an operator set up a guidance system?
9. What types of electrical circuits does a precision agriculture system use?
10. How does a programmable logic controller work?
11. Why are sensors an essential component of precision agriculture systems?

Key Terms

Altitude	**Antenna**	**Baud rate**
Breadboard	**Calibration**	**Compound logic**
Continuous data	**Coordinate**	**Contour**
Channel	**Degree**	**Differential correction (DGPS)**
Differential receiver	**Dilution of precision (DOP)**	**Elevator mount unit (EMU)**
Equator	**Ephemeris**	**Ephemeris errors**
Force sensor	**Geographic information system (GIS)**	**Global positioning receiver**
Global positioning system (GPS)	**GPS console**	**Guidance system**
Horizontal dilution of precision (HDOP)	**Inputs**	**Latitude**
Light-emitting diode (LED)	**Lightbar**	**Light sensor**
Load sensor	**Longitude**	**Minute**
Moisture sensor	**Monitor**	**Multipath**
Offset	**Outputs**	**Overlap**
Position dilution of precision (PDOP)	**Precision agriculture**	**Prime meridian**
Proximity sensor	**Programmable logic controller (PLC)**	**Resistor**
Skip	**Satellite constellation**	**Second**
Threshold logic	**Trilateration**	**Vertical dilution of precision (VDOP)**

Day-to-Day Plans
Time: 15 days

*Refer to the Teacher Resources section for specific information on teaching this lesson, in particular **Lesson 3.1 Teacher Notes**, **Lesson 3.1 Glossary**, **Lesson 3.1 Materials**, and other support documents.*

Day 1 – 2:

- Present **Concepts**, **Performance Objectives**, **Essential Questions**, and **Key Terms** to provide a lesson overview.
- Provide students with a copy of **Activity 3.1.1 Calibration**.
- Students work in pairs to complete *Activity 3.1.1 Calibration*.

Day 3 – 4:

- Provide students **Presentation Notes** pages to be used throughout the presentation to record notes and reflections. Students add these pages to their *Agriscience Notebook*.
- Present PowerPoint® **Precision Systems**.
- Students take notes using the *Presentation Notes* pages provided by the teacher.
- Provide students with a copy of **Activity 3.1.2 Surrounding Satellites**.
- Students will complete *Activity 3.1.2 Surrounding Satellites*.

Day 5 – 6:

- Provide students *Presentation Notes* pages to be used throughout the presentation to record notes and reflections. Students add these pages to their *Agriscience Notebook*.
- Present PowerPoint® **Precision Parts**.
- Students take notes using the *Presentation Notes* pages provided by the teacher.
- Provide students with a copy of **Project 3.1.3 Precisely Put Together** and **Project 3.1.3 Evaluation Rubric**.
- Students work individually to complete *Project 3.1.3 Precisely Put Together*.
- Assess student work with *Project 3.1.3 Evaluation Rubric*.

Day 7:

- Provide students with a copy of **Activity 3.1.4 Guided Operation**.
- Students work individually to complete *Activity 3.1.4 Guided Operation*.

Day 8 – 9:

- Provide students with a copy of **Project 3.1.5 Cost Savings** and **Project 3.1.5 Evaluation Rubric**.
- Students work individually to complete *Project 3.1.5 Cost Savings*.
- Assess student work with *Project 3.1.5 Evaluation Rubric*.

Day 10:

- Provide students *Presentation Notes* pages to be used throughout the presentation to record notes and reflections. Students add these pages to their *Agriscience Notebook*.
- Present PowerPoint® **Controlling with Precision**.
- Students view the **Breadboard Video**.

Day 11 – 12:

- Provide students with a copy of **Activity 3.1.6 Global Irrigation**.
- Assess student work in pairs to complete *Activity 3.1.6 Global Irrigation*.

Day 13 – 14:

- Provide students with a copy of **Project 3.1.7 Guiding Light** and **Project 3.1.7 Evaluation Rubric**.
- Students work in pairs on *Project 3.1.7 Guiding Light*.

Day 15:

- Students work in pairs to complete *Project 3.1.7 Guiding Light*.
- Assess student work with *Project 3.1.7 Evaluation Rubric*.
- Distribute **Lesson 3.1 Check for Understanding**.
- Students will complete *Lesson 3.1 Check for Understanding* and submit it for evaluation.
- Use **Lesson 3.1 Check for Understanding Key** to evaluate student assessments.

Instructional Resources

PowerPoint® Presentations

Precision Systems

Precision Parts

Controlling with Precision

Student Support Documents

Lesson 3.1 Glossary

Presentation Notes

Activity 3.1.1 Calibration

Activity 3.1.2 Surrounding Satellites

Project 3.1.3 Precisely Put Together

Activity 3.1.4 Guided Operation

Project 3.1.5 Cost Savings

Activity 3.1.6 Global Irrigation

Project 3.1.7 Guiding Light

Teacher Resources

Lesson 3.1 Precision Systems PDF

Lesson 3.1 Teacher Notes

Project 3.1.3 Presenter Checklist

Lesson 3.1 Materials

Lesson 3.1 Check for Understanding

Answer Keys and Assessment Rubrics

Lesson 3.1 Check for Understanding Answer Key

Project 3.1.3 Evaluation Rubric

Project 3.1.5 Evaluation Rubric

Project 3.1.7 Guiding Light

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Ess, Dan. (2003). Precision Farming Guide for Agriculturalists. Madison, WI: Deere and Company

John Deere. (2021). Display and commandarm simulator. Retrieved from **https://www.deere.com/en/parts-and-service/manuals-and-training/simulators/display-and-command-arm-simulator/**

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Science Buddies. (2021). *How to use a breadboard.* Retrieved from https://www.sciencebuddies.org/science-fair-projects/references/how-to-use-a-breadboard?from=YouTube

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FFA Connections

This lesson provides conceptual and procedural knowledge required for participation in the following FFA activities:

- Agricultural Proficiency
  - **Agricultural Mechanics Repair and Maintenance –Placement**
  - **Agricultural Mechanics Repair and Maintenance –Entrepreneurship**
- Agriscience Fair
  - **Power, Structural and Technical Systems**
- Career Development Events
  - **Agricultural Technology & Mechanical Systems**
- Educational Resources
  - **SAE Idea Cards-Power, Structural and Technical Systems**
  - **Power, Structural and Technical System Careers**
  - **Power, Structural and Technical Systems Career Focus Area Resources**
  - Agricultural Mechanics (**Word)** (**PDF**)
  - Keegan Humm-SAE-Placement-Implement Dealership Lesson Plan (**Word**) (**PDF**)
  - Power, Structural and Technical Careers **(Word)**

Skills and knowledge from this lesson support the development and implementation of service-learning projects that address precision systems

- **Service-Learning and Living to Serve Grants**
  - Service-learning projects focused on precision agricultural equipment, irrigation and waste reduction.
  - Project ideas include installing an irrigation system to a local community garden or using GPS to map farms for first responders.
  - Living to Serve Grants provide funding to FFA chapters to support service-learning and community service projects.

For more information, visit the **National FFA Organization** website.

SAE for All

Foundational SAE

All students in an agricultural education program are expected to have a Foundational SAE. Students completing the APP and extensions listed below will meet the Foundational SAE qualification for the *Advanced (Grades 11-12) level*. Students should place all documented evidence in the *FFA/SAE* section of their *Agriscience Notebook* along with the *SAE for All Foundational Checksheet*.

- Employability Skills for College and Career Readiness
  - Activity 3.1.4 Guided Operation
- Personal Financial Management and Planning
  - Project 3.1.5 Cost Savings

Immersion SAE

Students interested in this lesson's topics should explore the following related Immersion SAEs. An immersion SAE is optional and replaces the agricultural literacy component of the Foundational SAE.

- Ownership/Entrepreneurship
    - **Turfgrass Management-Irrigation SAE | Tyler Hewitt**
- Placement/Internship
    - **Implement Dealership Placement SAE | Keegan Humm**
    - **Agricultural Mechanics SAE | Jeremiah Hager**

For more information on the guiding principles for implementing SAE programs, visit the **SAE for All: Evolving Essentials** site.

Critical Thinking and Application Extensions

Explanation

1. Students will present how precision agriculture systems work to local producers.

Application

2. Students will research and calculate the cost savings of using a precision system on a local farm.
3. Students will practice using a navigation system in a tractor while being directly supervised.

Lesson 3.1 Teacher Notes

Lesson 3.1 Precision Systems

In preparation for teaching this lesson, review Concepts, Performance Objectives, Essential Questions, and Key Terms, along with the PowerPoint® presentations. Also, review all activity, project, and problem directions, expectations, and work students will complete.

Students learn how precision agricultural system hardware and software work together to collect data and control agricultural equipment. They begin the lesson by calibrating equipment to understand the importance of precise applications. Next, students learn how field equipment utilizes GPS signals and sensors. Then they practice assembling the electrical components to make a model of precision agriculture devices.

PowerPoints®

Precision Systems

Use the presentation to provide students with background knowledge about GPS, GIS, and guidance systems used in agriculture.

Precision Parts

Use the presentation to provide background knowledge of precision agriculture components used by a combine to calculate yield data.

Controlling with Precision

Students use this presentation to assemble and program a model global positioning system controlling output devices.

Activities, Projects, and Problems

Activity 3.1.1 Calibration

Students measure the application rates of a handheld sprayer and broadcast spreader used for a lawn. After finding the application rates, they determine how to adjust the rates to the recommended levels listed in the activity.

Teacher Preparation
Groups and pairing
Assign students in pairs. Half of the pairs start with Parts One and Two, while the other pairs complete Parts Three and Four. Students calibrate a broadcast spreader for Parts One and Two and a sprayer for Parts Three and Four. Plan for pairs to complete the spreader portion on one day and the sprayer portion on the other.

Equipment demonstration
Before starting the activity, review and demonstrate how to use the broadcast spreader and sprayer. Use proper PPE during your demonstration. Operation procedures for each will vary based on the brand and type. Use the links for an example **spreader** and **sprayer** as a guide. You are responsible for knowing how to use all application equipment. Have a bag of cat litter for students to use as a fertilizer and a water source to fill sprayer tanks. To observe the spray and broadcast patterns, students should spray and broadcast on a smooth outdoor surface, such as concrete.

Measurement equipment
Use measuring cups with liquid ounce markings during Parts Three and Four.

Student Performance
Part One and Two
Students use an electronic balance to weigh 5 oz of kitty litter. They place the litter in the broadcast spreader and go outside. Then students mark an area with a start and finish line 10 ft apart. One student spreads the sand while walking a 10 ft distance. Their partner measures the time it takes for them to walk 10 ft. Students then inspect the broadcast pattern, determine where the broadcast becomes uneven, and measure the broadcast width. They weigh the remaining litter in the spreader and subtract from 5 oz to find the total broadcasted. Students calculate the broadcast rate by dividing the weight of litter broadcasted by the area. Finally, they answer analysis questions comparing the broadcast rate to the recommended rate. Example calculations and answers to analysis questions are in Table 1.

For Part Two, students develop and test a plan to improve the precision of the broadcast rate to match the recommended rate. Changes could include application speed, application settings, and broadcast height. Students record changes and results in their *Logbooks*.

Part Three and Four
Students fill a sprayer with one-third full of water. Then students mark an area with a start and finish line 10 ft apart. One student sprays the water while walking the 10 ft distance, and the partner measures the time needed for them to walk. Students then inspect the spray pattern, determine where the spray becomes uneven, and measure the spray width. They spray water into a measuring cup for a time equal to what it took to walk 10 ft. The amount of water in the cup equals the amount sprayed on the ground. Students calculate the spray rate by dividing the water sprayed by the area the spray covers. They answer analysis questions comparing the spray rate to the recommended rate. Example calculations and answers to analysis questions are in Table 2.

For Part Four, students develop and test a plan to improve the precision of the spray rate to match the recommended rate. Changes could include application speed, settings, and sprayer height. Students record changes and results in their *Logbooks*.

Results and Evaluation
Table 1 contains example calculations and answers to analysis questions for Part One. Answers to analysis questions are based upon example calculations. Student recommendations for Part Two will vary based on the broadcast spreader. Example changes could be settings on the spreader, walking speed, and the height the spreader is held.

Table 1. ***Example Broadcast Calculations and Analysis Question Answers***

Broadcast Area		$40\text{ft}^2 = 4\text{ft} \times 10\text{ft}$
Ounces spread over an area		5oz - 4oz of remaining fertilizer = 1oz spread
Application rate		$0.025\text{oz per square foot} = \frac{1\text{oz spread}}{40\text{ft}^2}$
Rate per 1000ft^2		$\frac{1\text{oz spread}}{40\text{ft}^2} = \frac{25\text{oz}}{1000\text{ft}^2}$
Walking speed		$5\text{ft per second} = \frac{10\text{ft}}{2\text{ seconds}}$
Example answers to analysis questions		
Q1	How does the current rate compare to the recommended rate?	*The recommended rate is 40 oz per 1000 square feet. The current rate is lower than what is recommended.*

Q2	How many feet apart should each path be to avoid skips while spreading fertilizer?	*The broadcast width is 4 feet, so each path should be 4 feet apart. Two feet would be broadcasted on each side of the path.*
Q3	How can you change the application process to increase the accuracy of the application rate?	*Decrease the walking speed, so more fertilizer is spread over the area or decrease the height spread to increase the concentration.*

Table 2 contains example calculations and answers to analysis questions for Part Three. Answers to analysis questions are based upon example calculations. Student recommendations for Part Four will vary based on the sprayer. Example changes could be pressure in the sprayer, nozzle settings, speed the student is walking, and the height of the sprayer nozzle.

Table 2. ***Example Sprayer Calculations and Analysis Question Answers***

Broadcast Area		$20ft^2 = 2ft \times 10ft$
Total time spraying		3 seconds
Ounces sprayed for 3 seconds		5 ounces
Application rate		$0.25oz \text{ per square foot} = \frac{5oz \text{ spread}}{20ft^2}$
Rate per $1000ft^2$		$\frac{0.25oz \text{ sprayed}}{20ft^2} = \frac{12.5oz}{1000ft^2}$
Walking speed		$5ft \text{ per second} = \frac{10ft}{2 \text{ seconds}}$
Example answers to analysis questions		
Q4	How does the current rate compare to the recommended rate?	*The recommended rate is 36 liquid oz per 1000 square feet. The current rate is lower than what is recommended.*
Q5	How many feet apart should each path be to avoid skips in the spray application?	*The broadcast width is 2 feet, so each path should be 2 feet apart. One foot would be sprayed on each side of the path.*
Q6	How can you change the application process to increase the accuracy of the application rate?	*Decrease the walking speed, so more herbicide is sprayed over the area or decrease the height sprayed to increase the concentration.*

Activity 3.1.2 Surrounding Satellites

Students use web-based resources to find GPS satellites in their area used for precision agriculture.

Teacher Preparation

Present *Precision Systems* to students before starting the activity.

Students can use a laptop or Chromebook for Part One. Part Two requires a mobile device with a GPS application. Students will need to the following apps.

- *GPS Status*
- *GNSS View*

Place four survey flags outside in locations that will vary in satellite signal strength, such as a clear area, under a tree, and near a building.

Student Performance

Part One

Students start the activity using **www.gnssplanning.com** to find their location and convert from decimal degrees to degrees, minutes, and seconds. Next, they map GPS satellite constellations and compare the accuracy, location, and DOP while answering analysis questions.

Part Two
Students use a mobile device and the GPS and GNSS apps to locate satellites and signal strength outside. They use their device to find and record the location and signal strength for the four locations.

Part Three
Students identify the cause and correction for three potential customer complaints regarding satellite signals.

Results and Evaluation
Use Tables 3 and 4 as a guide for assessing student work. Answers to analysis questions will vary based on location and time of day. Example causes and complaints found in Table 4 may vary.

Table 3. *Analysis Questions and Potential Responses*

Q1	Which satellite system will provide a more accurate location? Why?	*The GLONASS system had more visible satellites spread out in the sky.*
Q2	What happens to the position of the satellite throughout the day?	*The satellites move throughout the day.*
Q3	At what time of day could the accuracy of the GPS and GLONASS system decrease? Why?	*Late afternoon because fewer satellites can connect with the receiver.*
Q4	Besides the satellite locations, what other factors may impact the accuracy of the system?	*Obstructions in the sky include clouds and rain. Obstructions on the satellite receiver can also cause accuracy issues*
Q5	What is the relationship between the DOP value and the number of satellites?	*The DOP value goes up as the number of satellites goes down.*

Table 4. *Example Causes and Corrections*

Complaint	Cause	Correction
It is wintertime, and a producer is setting up his global positioning system for next spring. A producer calls and explains to the dealership that the system is not working on his tractor as he tests it while in his machine shed.	*The machine shed's roof obstructs satellite signals.*	*Move the equipment outside and check signals.*
A producer is using his global positioning system while harvesting. He has strong signals from five satellites, but his location is not accurate enough for planting	*The DGPS receiver is not receiving a signal.*	*Check the DGPS antenna for obstructions, remove the obstacles, and recheck the signal.*
While using their system throughout the fall, a producer notices that the system's accuracy continuously decreases around 3:00 each day.	*The DOP of the satellite system increases at that time of day due to fewer satellites available. The satellites may also be near each other.*	*Use a different satellite system at 3:00 each day or wait until more satellites are in the correct viewing area.*

Project 3.1.3 Precisely Put Together

Students make a mind map and complete a troubleshooting chart for a combine with precision agriculture components used for collecting yield data.

Teacher Preparation
Present *Precision Parts* before beginning this project. Arrange the availability of a combine with precision components while visiting a local dealer. Review the **Project 3.1.3 Presenter Checklist** with the technician before the visit. If this arrangement is not possible, students can use internet research to find and locate the components. Students will need mind-mapping software to complete the project. Free applications are available for Apple, Microsoft, and Android platforms.

Student Performance
Students inspect a combine while taking photos and notes about the precision component's locations. They then make a mind-map displaying an image and description of each component connected to the other parts in the system. Once the mind-map is complete, students complete a troubleshooting chart identifying the potential causes and corrections for complaints of a precision system failure. Students submit their mind-map and troubleshooting chart for assessment.

Results and Evaluation
Use **Project 3.1.3 Evaluation Rubric** to assess student work.

Activity 3.1.4 Guided Operation

Students simulate the operation of a virtual tractor and cultivator with precision agriculture technology.

Teacher Preparation
Students will need a MyJohnDeere account to complete the activity. Accounts are free and can be set up by going to **www.myjohndeere.com**. Review the activity before students complete it to ensure navigation instructions are correct. Then, change any directions if needed.

Student Performance
Students create a MyJohnDeere account and go to the **display simulator**. Students set up a simulator for operating a cultivator. During Part One, students check and record diagnostic information while entering information about the equipment. For Part Two, students enter information about the field and set up tracks for the tractor to follow. Then they practice operating the equipment and tilling a field. Note that the *Autotrac* on display needs to be on, and the *Auto* steer button needs to be activated before the tractor will follow a track. Figure 1 shows the *Autotrac* and *Auto* steer locations.

Students answer analysis questions while working on the activity.

Figure 1. Autotrac and Auto Steer

Results and Evaluation
Use Table 5 to assess student answers to analysis questions.

Table 5. ***Analysis Questions and Potential Responses***

Q1	How does the working width of an implement affect a precision system's calculations?	*The working width will impact the overlap settings.*
Q2	Why would a technician need to know an implement's offsets?	*To tell the system the location of the tractor components and implements relative to the receiver location.*
Q3	How would a technician use the information in the ISOBUS VT pop-up window?	*A technician can find diagnostic information to identify why a system fails, such as signal strength, satellite locations, and electrical connections.*
Q4	How is track spacing related to overlaps and skips in a field?	*The spacing between the tracks will directly affect the overlap of skips in the field.*
Q5	What can a producer mark in a field for future reference?	*A producer can mark weeds, rocks, obstacles, or other essential field features.*
Q6	What other information does the universal display show?	*The universal display shows field location, acres tilled, track spacing, and setting options.*

Project 3.1.5 Cost Savings

Students work individually to calculate the cost savings of using guidance systems to till a field. Then they make a one-page information sheet for a customer interested in purchasing a guidance system.

Teacher Preparation

Review math calculations before starting the activity.

Student Performance

Part One

Students work individually to calculate the fuel and labor costs for tilling a field without a guidance system. They begin by calculating the total number of square feet in the field and finding the number of trips the tractor will need to make across the field to till it. Then students calculate the distance the tractor will travel, the time it will take, and its fuel use. By knowing the fuel used and the time taken, students calculate the labor and fuel costs.

Part Two

Students use their calculations from Part One to determine the financial savings of a guidance system for a producer. Students create a one-page informational document with costs and savings for a producer using and not using a guidance system.

Results and Evaluation

Use **Project 3.1.5 Evaluation Rubric** to assess student work. Table 6 shows calculations and answers for each process in Part One. There are multiple methods for finding the cost savings for Part Two.

Table 6. ***Part One Calculations***

Process	Calculation	Answer
Calculate the total number of square feet of field.	*area (ft²) = 43560 ft² x 160 acres*	*area = 6,969,600 ft²*
Calculate the dimensions of the field.	*dimension = √6,969,600 ft²*	*dimension = 2640 ft x 2640 ft*
Subtract overlap from the total width of the chisel plow. Then find the number of trips the farmer will make across the field with the chisel plow.	*width covered = 30 ft – 3 ft* *number trips = 2604 ft / 27ft*	*width = 27 ft* *trips = 98 trips*
Calculate the number of miles the tractor travels to till the entire field.	*Each trip is 2640 feet or 0.5miles (2640/5280)* *miles = 98 trips x 0.5 miles*	*distance =49 miles*
Find the total hours it will take for the tractor and chisel plow to till the field.	*total hours = 49 miles/ 4.5 miles per hour*	*total hours = 10.89 hours*

Find the total number of gallons of fuel needed to till the field.	*total gallons = 10.89 hours x 12 gallons per hour*	*130.68 gallons*
Calculate the total cost for fuel and labor.	*fuel cost = $2.50/gallon x 130.68 gallons* *labor cost = $15/hour x 10.89 hours*	*fuel cost = $326.70* *labor cost = $163.35*
Calculate the total fuel and labor cost per acre.	*cost per acre = $490.05/160 acres*	*cost per acre = $3.06 per acre*

Activity 3.1.6 Global Irrigation

Students program a Digital Control Unit to activate an irrigation pump based upon moisture levels and geographic location.

Teacher Preparation

Play the **Breadboard Video** and present *Controlling with Precision* before starting this activity. Review how to use the **Digital Control Unit**, **Soil Moisture Sensor,** and internal GPS sensor in **LabQuest** before beginning the activity. It may take 10–15 minutes for LabQuest to find its location for the first time. Save time by turning on each LabQuest, activating the GPS sensor, and placing them outside before class. You will know the GPS sensor works when the latitude and longitude coordinates are displayed on the screen.

- Find an open area outside and place a marker or flag in the ground.
- Use LabQuest to find the latitude and longitude coordinates of the marker.
- Provide these coordinates to your students during the activity.
- Each group will need a small box for carrying the LabQuest, DCU, and breadboard outside.
- Cut a hole in the 24 oz container lid large enough for the hose to fit.

Student Performance

Part One

Students assemble the electrical connections and 9V power supply to the DCU. Students can leave the electrical connections on the DCU for future activities.

Part Two

Students assemble a series-parallel electrical circuit on a breadboard controlled by a soil moisture sensor. LED lights on the circuit will indicate if the soil is wet or dry. The pump connected to the circuit will turn on when the soil is dry and shut off when the soil is moist.

Part Three

Students draw a map with four sections in their *Logbook*. They label the directions that each side of the map represents and record the latitude and longitude of the center representing the outdoor marker. Students then program the DCU to turn the pump on based upon its location relative to the marker. They record their program in their *Logbook* and test it by going outside to the marked location. Once the pump activates in the correct areas, they add a hose and water supply to water the dry areas. Students can use a DMM to troubleshoot their pump and breadboard if the system does not work correctly.

Results and Evaluation

The first program should turn the pump on if the latitude is greater than or equal to the latitude coordinate of the marker since the latitude coordinates in the United States increase as you travel north. The second program should turn the pump on if the longitude is greater than or equal to the longitude coordinate. The longitude coordinates in the United States increase as you travel east.

Project 3.1.7 Guiding Light

Students wire and program a guidance system simulating a light bar in a tractor. The guidance system should direct students to walk in a straight line between two survey flags.

Teacher Preparation
Be sure the flags that student place are directly north and south or east and west of each other. Electrical current moves through the LED in one direction, positive to negative. Note that the shorter lead on the LED is the negative lead.

Student Performance
Students use a LabQuest3, DCU, and breadboard to make a system for navigating a straight line while broadcasting fertilizer. The output will consist of a breadboard with resistors and three light-emitting diodes (LEDs). Students will need to find the geographic coordinates of the two flags the plan to navigage between. Next, students will find the longitude and latitude coordinates of where they should walk while fertilizing in a straight line. Then they will program the DCU to light the LEDs based on location. Students will record their process and design in their *Logbooks* and use wordprocessing software to write a user manual for their system.

Results and Evaluation
Use Project **3.1.7 Evaluation Rubric** to assess the user manual. For example, if a student chooses to walk north and south, they will need to program the DCU to activate lights if they move east or west of a straight line. If the longitude coordinate students need to follow while going north is -70.45781, they could program the lights as shown in Table 7.

Table 7. ***Example Light Program***

Light Indicator	Meaning	Program
Left light	Too far west, move east	If longitude <= -70.45782, then activate left light
Center light	On track	If longitude = -70.45781, then activate center light
Right light	Too far east, move west	If longitude >= -70.45780, then activate right light

Assessment

Lesson 3.1 Check for Understanding

Lesson 3.1 Check for Understanding is included for you to use as an assessment tool for this lesson. Use **Lesson 3.1 Check for Understanding Answer Key** for evaluation purposes.

Name____

CASE

Activity 3.1.1 Calibration

Purpose

Have you seen a lawn with dark and light green stripes? Or a property with patches of weeds? Grounds with a color variation or weed patches may result from improper applications of fertilizer or herbicide. Crops also require precise treatments, such as fertilizer and herbicide, to increase production. Farmers use sprayers and dry broadcast spreaders to apply those treatments. What causes a machine to lack precision when applying fertilizer and herbicides?

The calibration and correct use of application equipment affect precision. Technicians calibrate sprayers and spreaders to apply a specific chemical amount to a field. Liquids sprayed on a field are measured in gallons per acre or liquid ounces per square foot. Technicians measure dry material spread on a field using pounds per acre or ounces per square foot. A combination of factors affects the application rate of equipment. The height at which the sprayer or broadcaster applies treatment to a field affects the application width. The speed of the equipment affects the rate. The faster the equipment travels across the field, the lower the application rate. Even if the technician calibrates the equipment for known factors, such as application height and speed, the application rate can still be affected by poor planning and improper equipment use.

When farmers treat a field, they want to avoid skips while limiting overlaps. A skip is an area where an applicator applied little or no treatment. Overlap is an area where equipment applies a chemical more than once. Skips and overlaps can be harmful to a crop and affect production. The light green stripes you see on a lawn are examples of a skip where the broadcaster did not spread enough fertilizer. A brown burnt area on a lawn may be where an overlap occurred with too much fertilizer. It is nearly impossible to avoid overlapping in a field while making an application. The edges of an application will have a reduced application rate. By slightly overlapping the broadcast or spray width edges, the producer ensures an entire treated field.

The planning process for fertilizing and spraying a field with large equipment over hundreds of acres is the same as treating a lawn with handheld equipment. How is equipment calibrated for treating a lawn with dry fertilizer and liquid herbicide?

Materials

Per class:

- Cat litter
- Outdoor area with a clean, dry surface
- Water source with hose

Per pair of students:

- Device with timer
- Masking tape
- Plastic spoon
- Tape measure, 25′
- Weighing dish

Per group of four students:

- Electronic balance
- Handheld fertilizer spreader
- Handheld sprayer
- Measuring cup (volume oz lines)

Per student:

- Nitrile gloves
- Safety glasses
- Pen
- *Agriscience Notebook*
- *Logbook*

Procedure

Work with your partner to determine the settings and walking speed for applying dry fertilizer and liquid herbicide to a lawn. Before starting the activity, your teacher will demonstrate how to use the fertilizer spreader and sprayer with appropriate PPE. Your teacher will assign half of the student pairs to complete Parts One and Two, while the other half complete Parts Three and Four. Finish your assigned parts and then swap equipment with another pair to complete the activity. Wear proper safety glasses and nitrile gloves while working with the equipment.

Part One – Broadcast Rate

The fertilizer should be spread on the lawn at a rate of 40 ounces (oz) per 1000 ft^2. Calculate the rate of your handheld spreader and determine how to adjust if necessary. Record all calculations, measurements, and answers to analysis questions in your *Logbook*. For safety purposes, you will use cat litter to simulate the fertilizer.

Procedure

1. Use an electronic balance and plastic spoon to measure 5 oz of cat litter in a weigh dish.
2. Fill the fertilizer spreader with 5 oz of cat litter.
3. Go outside to a smooth surface as instructed by your teacher.
4. Use a tape measure and masking tape to measure and mark a start and finish line 10 feet apart.
5. Hold the fertilizer spreader 3 feet above the ground.
6. Spread the cat litter while walking from the start to the finish line.
   - Spread the cat litter with the settings at the maximum rate.
   - Your partner will use a stopwatch to measure the time it takes for you to walk the distance.
7. Examine the broadcast's edges to find where a reduced rate occurs on the ground.
8. Use a tape measure to find the width of the broadcast where the rate is constant.
   - Convert inches to decimal feet when necessary.

Calculations

9. Multiply the constant broadcast width by the distance walked (10 ft) to find the area covered by the cat litter.

$$\text{area} = \text{constant broadcast width} \times 10 \text{ ft}$$

10. Put the empty weigh dish on the electronic balance and tare the weight.
11. Pour the cat litter remaining in the fertilizer spreader into the weigh dish.
12. Use an electronic balance to measure the cat litter in the weigh dish.
13. Subtract the remaining cat litter's weight from 5 oz to find the total ounces spread over the area.

$$5 \text{ oz} - \text{weight of remaining cat litter} = \text{ounces spread}$$

14. Find the rate of your fertilizer spreader by dividing the total ounces spread by the area.

$$\text{rate} = \frac{\text{ounces spread}}{\text{area (ft}^2\text{)}}$$

15. Use the following ratio to find the rate per 1000 square feet.

$$\frac{\text{ounces spread}}{\text{area (ft}^2\text{)}} = \frac{\text{ounces}}{1000\text{ft}^2}$$

16. Find your walking speed by dividing the distance (ft) by time (sec).

$$\text{speed} = \frac{\text{distance (ft)}}{\text{time (sec)}}$$

17. Answer the analysis questions in your *Logbook*.

Q1 How does the current rate compare to the recommended rate?

Q2 How many feet apart should each path be to avoid skips while spreading fertilizer?

Q3 How can you change the application process to increase the accuracy of the application rate?

Part Two – Broadcast Improvement

Work with your partner to decide on changes to the application process so the application is closer to the recommended rate. Then, test your recommended changes by repeating the *Part One Procedure* and *Calculations*. Record your recommendations, calculations, and results in your *Logbook*. You do not need to do the analysis questions again.

Part Three – Sprayer Rate

The herbicide mix should be sprayed on the lawn at a rate of 36 liquid oz per 1000 ft^2. Calculate your handheld sprayer rate and determine how to adjust if necessary. Record all calculations, measurements, and answers to analysis questions in your *Logbook*. For safety purposes, you will use water to simulate the herbicide.

Procedure

1. Fill the handheld sprayer approximately a third full with water.
2. Use masking tape to mark a start and finish line 10 feet apart on a clean hard surface.
3. Hold the spray nozzle 2 feet above the ground.
4. Spray the water while walking backward from the start to the finish line to avoid walking through the spray.
    - Spray the water while holding in the trigger.
    - Your partner will use a stopwatch to measure the time it takes for you to walk the distance.
5. On the ground, examine the spray edges with a reduced rate needing to be overlapped.
6. Use a tape measure to find the width of the spray where the rate is constant.
    - Convert inches to decimal feet when necessary.

Calculations

7. Multiply the application width by the distance walked (10 ft) to find the area covered by the spray.

$$\text{area} = \text{constant spray width} \times 10\text{ ft}$$

8. Find the amount sprayed by spraying the water into a measuring cup for the same time it took for you to spray the area.
9. Find the sprayer's rate by dividing the total ounces in the cup by the area covered.

$$\text{rate} = \frac{\text{ounces sprayed}}{\text{area (ft}^2\text{)}}$$

10. Use the following ratio to find the application rate per 1000 square feet.

$$\frac{\text{ounces sprayed}}{\text{area (ft}^2\text{)}} = \frac{\text{ounces}}{1000\text{ ft}^2}$$

11. Find your walking speed by dividing the distance (ft) by time (sec).

$$\text{speed} = \frac{\text{distance (ft)}}{\text{time (sec)}}$$

12. Answer the analysis questions in your *Logbook*.

Q4 How does the current rate compare to the recommended rate?

Q5 How many feet apart should each path be to avoid skips in the spray application?

Q6 How can you change the application process to increase the accuracy of the application rate?

Part Four – Spray Improvement

Work with your partner to decide on changes to the spraying process that will increase the precision of the spraying rate. Test your recommended changes by repeating the *Part Three Procedure* and *Calculations*. Record your recommendations, calculations, and results in your *Logbook*. You do not need to do the analysis questions again.

Conclusion

1. How does calibration prevent overlaps and skips?

2. What factors will affect the application rate of a fertilizer spreader and herbicide sprayer in a field?

3. What would happen to a lawn treated with uncalibrated equipment?

Name____ CASE

Activity 3.1.2 Surrounding Satellites

Purpose

Mobile agricultural equipment is dependent upon satellites thousands of miles above us. A satellite system called a global positioning system guides equipment across a field, increasing farmers' productivity. How do these satellites work? What do you need to know and understand about global positioning as a technician?

Receivers on equipment receive satellite signals and use trilateration to determine their location. Trilateration needs a minimum of three satellites to find a location. Trilateration is a geometric process of finding a location using circles, as shown in Figure 1. The location has a known distance from three satellites. You can find a specific location by drawing a circle around each satellite with the radius of the known distances. For a three-dimensional location on earth, a receiver needs a signal from a minimum of four satellites.

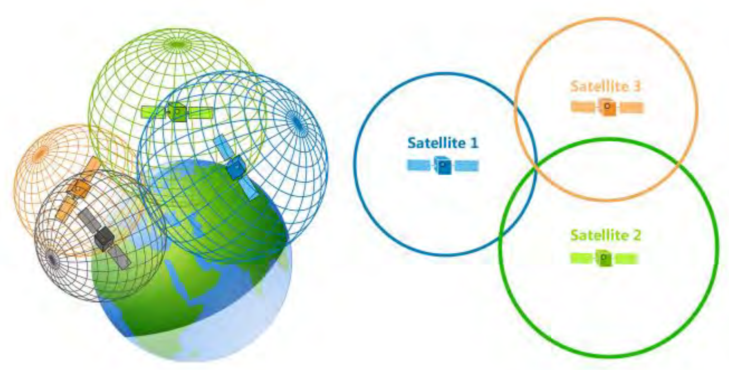


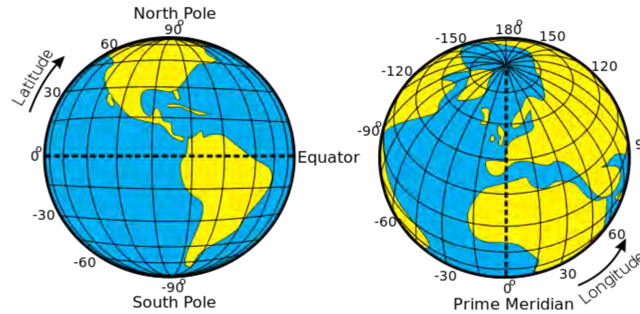
Figure 1. Trilateration

Besides the number of satellites, the satellites' location is also essential for a receiver to calculate an accurate position. Optimally, satellites should be far apart in the sky and have a direct view of the receiver. GPS has a satellite constellation continuously moving above the earth. The satellite sends predicted changes in its position called the ephemeris to reduce the possibility of location error. Satellite positions in the sky can cause a dilution of precision (DOP). DOP is an indicator of satellite geometry for a unique constellation of satellites used to determine a position. Locations with a higher DOP value generally constitute measurement results poorer than those with a lower DOP. A GPS receiver may use more than one system of the multiple GPS satellite systems available because of a system's DOP at specific times of the day.

In addition to DOP, obstructions such as buildings, hills, trees, or clouds can cause the satellite signal to take multipaths, reducing signal quality and the receiver's accuracy. Even with optimal conditions, a GPS receiver is not accurate for agricultural production and will only provide a location with an accuracy of 10 to 15 feet. Agricultural equipment uses differential GPS (DGPS) to correct satellite signals and increase location accuracy to the nearest foot. DGPS uses stations on the ground to send signals to the receiver to increase a receiver's accuracy. Agricultural equipment is dependent upon DGPS systems for reliable measurements.

After a receiver obtains satellite signals on multiple channels, one channel per satellite, the receiver provides a coordinate location. Latitude and longitude coordinates georeference information to specific two-dimensional locations. Figure 2 shows the earth with latitude and longitude lines.

Latitude lines run horizontally north and south of the equator. Latitude coordinates north of the equator are positive, and those south of the equator are negative. The equator has a latitude of zero degrees. The north pole is 90°, and the south pole is -90°. Therefore, the range of latitudinal coordinates is 90° to -90°. Longitude lines run vertically east and west of the prime meridian, which has a value of zero degrees longitude. Longitude degree coordinates to the west of the prime meridian decrease until they are halfway around the globe and have a value of -180°. Latitude degree coordinates to the east of the prime meridian increase until they are halfway around the globe and have a value of 180°. The range of longitudinal coordinates is 180° to -180°.



https://en.wikipedia.org/wiki/File:Latitude_and_Longitude_of_the_Earth.svg

Figure 2. Latitude and Longitude Lines

A receiver displays latitude and longitude readings as decimal degrees or degrees, minutes, and seconds. There are sixty seconds in one minute and sixty minutes in one degree. Altitude is the distance an object is above sea level measured in meters or feet. A three-dimensional location of an object is known when a receiver calculates the latitude, longitude, and altitude.

Which satellites are above you in the sky right now, and how accurate are they for agricultural use?

Materials

Per students:

- Device with internet access
- Mobile device with GPS Application
- Pen
- *Agriscience Notebook*

Per class:

- Outside area
- (4) Survey flags

Procedure

Research GPS satellite locations and find GPS satellites in your area. Then determine the cause and identify the correction for producer complaints.

Part One – Satellite Intel

1. Go to **GNS Planning** (https://www.gnssplanning.com) on a device with internet access.
2. Zoom in on the map to find your current location.
3. On *Activity 3.1.2 Student Data* sheet, record the altitude in meters and the latitude and longitude in degrees, minutes, and seconds in Table 1.
4. Convert the latitude to decimal degrees and record the latitude in decimal degrees in Table 1.
    - Divide the seconds by 60 and add the result to the minutes for decimal minute reading.
    - Divide the decimal minutes by 60 and add the result to the degrees for decimal degree reading
    - Show your work.
5. Repeat Step 4 for the longitude reading.
6. Select **Skyplot** at the top of the screen.
7. Unselect all satellite systems at the left of the screen, so no systems are viewable.
8. Select **GPS satellite system**.

9. Draw a map of the viewable GPS satellites in Figure 3.
10. Unselect **GPS** and select **GLONASS**.
11. Draw a map of the viewable GLONASS satellites in Figure 4.
12. Press the **play** button at the upper right of the screen to observe the satellite movement throughout the day.
13. Choose **charts** at the top of the screen to view the DOP and number of satellites.
14. Complete Table 2 by comparing the charts for GLONASS and GPS satellite systems.
15. Answer *Part One Analysis Questions*.

Part Two – Satellite Signals

1. Download the following apps to a mobile electronic device. Select the app for your operating system.
    - *GNSS View*
    - *GPS Status*
2. Go outside and find a clear area.
3. Open the *GNSS View* app and wait until your device locates the satellites and calculates your position.
4. Select AR display.
5. Point your electronic device towards the sky to locate satellites.
6. Select **Main** on the *GNSS View* app.
7. Select **Position Radar**.
8. Sketch the satellite locations in Figure 5.
    - Circle the satellites you believe will have the weakest signal.
    - Star the satellite closest to being above you.
9. Close the *GNSS View* app.
10. Open the *GPS Status* app.
11. Record your location's latitude, longitude, and altitude in Table 3.
12. Record the horizontal and vertical accuracy of the signal at your location in Table 3.
13. Find the four flagged locations marked by your instructor.
14. Record the latitude, longitude, altitude, and accuracy for the four locations,
15. Record any physical characteristics at each location that may affect the accuracy of your system.

Part Three – Signal Issues

Review the following customer complaints. Use your knowledge of GPS to suggest a potential cause and correction for their system. Record the complaint, cause, and correction in Table 4.

Complaint 1
It is wintertime, and a producer is setting up his global positioning system for next spring. A producer calls and explains to the dealership that the system is not working on his tractor as he tests it while in his machine shed.

Complaint 2
A producer is using his global positioning system while harvesting. He has strong signals from five satellites, but his location is off by 5 feet.

Complaint 3

While using their system throughout the fall, a producer notices that the system's accuracy continuously decreases around 3:00 each day.

Conclusion

1. What factors affect the dilution of precision of a global positioning system?

2. How is DGPS different from GPS?

3. How does satellite location affect GPS accuracy?

Name____

Activity 3.1.2 Student Data

Part One – Satellite Intel

Table 1. *Location*

Altitude (meters)	
Latitude (°,′,″)	
Longitude (°,′,″)	
Latitude (decimal degrees) Show your work	
Longitude (decimal degrees) Show your work	

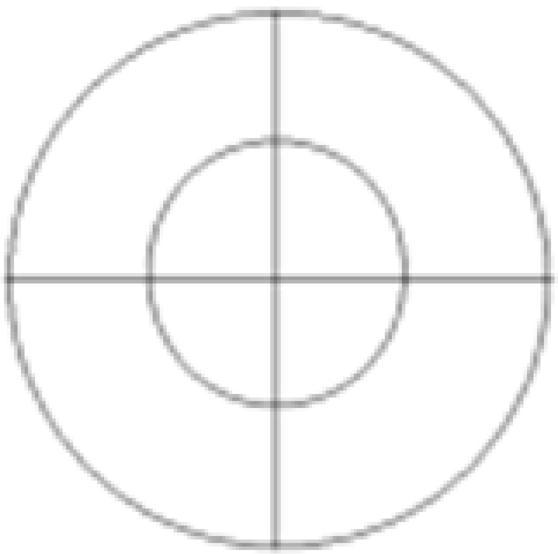


Figure 3. GPS Satellites

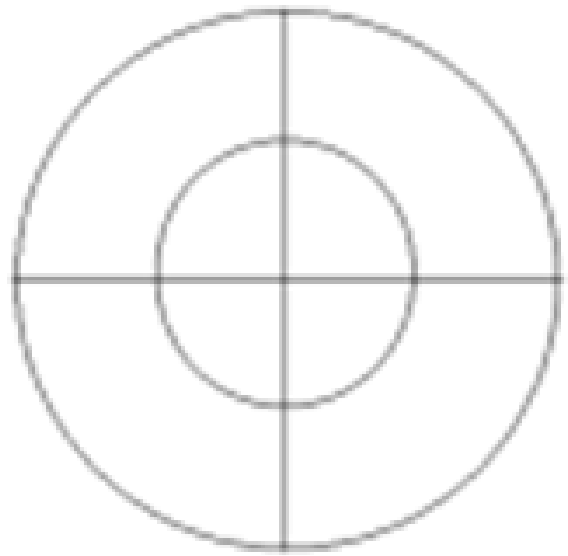


Figure 4. GLONASS Satellites

Table 2. *Satellite System Comparison*

	GPS Satellite System	GLONASS Satellite
Number of Satellites		
Most Visible Satellites • Time of Day		
Least Visible Satellites • Time of Day		
Highest DOP • Time of Day		
Lowest DOP • Time of Day		

Part One Analysis Questions

Q1 Which satellite system will provide a more accurate location? Why?

Q2 What happens to the position of the satellites throughout the day?

Q3 At what time of day could the accuracy of the GPS and GLONASS system decrease? Why?

Q4 Besides the satellite locations, what other factors may impact the accuracy of the system?

Q5 What is the relationship between the DOP value and the number of satellites?

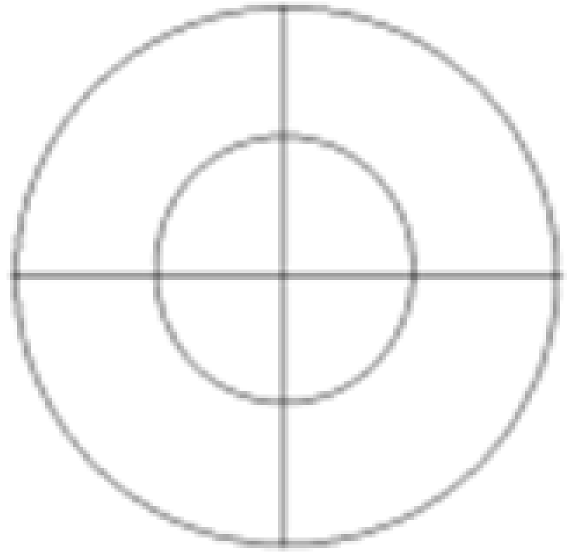


Figure 5. Satellite Sketch

Table 3. *Satellite Signals*

Location	Latitude	Longitude	Altitude	Horizontal Accuracy	Vertical Accuracy	Physical Characteristics
Clear Area						
Location 1						
Location 2						
Location 3						
Location 4						

Table 4. ***Signal Issues***

Complaint	Cause	Correction
1		
2		
3		

Name____

CASE

Project 3.1.3 Precisely Put Together

Purpose

Have you ever had a problem connecting a computer to the internet? What was the problem? Internet connection issues can vary from hardware, software, computer settings, and Wi-Fi signal to server and provider issues. Like an internet connection, precision agriculture systems depend upon multiple electrical and mechanical components to work synchronously to calculate data for a producer.

A precision agriculture system on a combine consists of multiple components and sensors collecting and sending data to a computer console. The computer console displays the data in an easy-to-read format for the producer. Additional sensors on the combine tell the console when to and when NOT to collect and analyze data. When all components work together, a producer will have an accurate record of their fields' productivity. However, if a connection to a component is faulty or a sensor becomes dirty, the entire system will not function correctly, and the calculated data will become useless.

A technician understands how the interconnected components work, where to find them, and how to determine if they may cause a system problem. Electrical wires and connections may become loose or worn over time, causing a power or signal issue. Dirt or debris on a sensor can cause an incorrect reading. Mechanical sensors can break or become stuck, also causing a poor reading.

Technicians help producers identify the causes of a precision system failure. Because all the components are interconnected, the source of the problem may not be easy to locate. For example, faulty moisture, grain flow, GPS, or speed sensors may cause incomplete yield data. What must a technician know to identify the causes of precision agriculture problems?

Materials

Per Class:

- Combine with precision components

Per student:

- Pen
- Mind mapping software
- Device with digital camera
- *Agriscience Notebook*
- *Logbook*
- *Project 3.1.3 Evaluation Rubric*

Procedure

Use your *Presentation Notes* from the *Precision Parts* presentation to identify the precision agriculture components on a combine. Then make a mind map showing how each component connects to the others. Finally, complete your project by making a troubleshooting chart for precision agriculture systems.

1. Listen and observe the technician's presentation.
2. Explore the combine and find the location of the following components. Sketch the location in your *Logbook* as you find each component and take a digital photo.
   - GPS receiver
   - Differential receiver
   - Grain flow sensor
   - Header position sensor
   - 12V power source
   - Ground speed sensor
   - Elevator mount unit
   - Moisture sensor
   - Display console

3. In your *Logbook*, list two causes for each component to malfunction.
4. Use your digital photos to sketch a mind map showing how components interconnect. The mind map should contain the following.
    - All components, including sensors, data monitors, levers, and power source
    - The flow of electrical power from the source
    - Types of data collected and where the sensors are sending the data.
    - Mechanical devices that activate or are activated by sensors.
5. Use your mind map to predict a complaint and correction for eight causes listed in your *Logbook*.
6. Record the complaint, cause, and correction in Table 1.
7. Submit your *Logbook*, mind map, and Table 1 for your teacher to assess using *Project 3.1.3 Evaluation Rubric.*

Conclusion

1. Where are sensors found on agricultural equipment?

2. Why are sensors a necessary precision agriculture component?

3. What are three potential causes of a sensor failing?

Name____

Project 3.1.3 Troubleshooting Chart

Table 1. ***Troubleshooting Chart***

Complaint	Cause	Correction

Name____

CASE

Project 3.1.3 Evaluation Rubric

Areas with Room for Improvement	Criteria	Areas that Meet or Exceed Expectations
	Logbook The sketch is neat, with all sensors and components accurately labeled. Two potential causes for each	
	Mind-map The mind-map includes the following. • All components, including sensors, data monitors, levers, and power source • The flow of electrical power from the source • Types of data collected and where the sensors are sending the data. • Mechanical devices that activate or are activated by sensors.	
	Troubleshooting Table Students record eight complaints, causes, and corrections in complete sentences. Complaints are realistic for each cause, and the correction is logical when compared to the cause and complaint.	

CASE

Project 3.1.3 Presenter Checklist

Thank you!

Thank you for providing this experience for our students! Students will learn from a technician during today's field experience. The objective of the presentation is for students to learn the components of precision agricultural systems on a combine. After learning about the components, students will sketch the locations in their notebooks, explain how they are interconnected, and identify potential causes for component failure.

Please feel free to add any pointers or extra material pertinent to your business.

Technician Checklist

Concept: Controller systems in precision agriculture include guidance systems, yield monitors, sensors, and automated outputs.

Parts Identification and Function: Detail the location and function of the following components. Feel free to add additional components you feel are important.

- GPS receiver
- Differential receiver
- Grain flow sensor
- Header position sensor
- 12V power source
- Ground speed sensor
- Elevator mount unit
- Moisture sensor
- Display console

Network: Detail the relationship between each component and how they work together.

- Simulate how a compoent failure impacts the entire system.
- Demonstrate how the equipment responds when a component does not work correctly.

Complaint, Cause, and Correction: Provide examples of customer complaints regarding the precision system on their combine.

- Detail the process of identifying the causes.
- Explain how to correct the cause.

Name____

CASE

Activity 3.1.4 Guided Operation

Purpose

Entering a new tractor cab today is like entering a computer control room. Display monitors and push buttons are more common than mechanical levers and pedals in today's agricultural equipment. Computer-based sensors in mobile agriculture equipment collect and display data and assist the operator with controlling the equipment. These new technologies require additional preparation by an operator. What does a producer need to know to set up an electronic guidance system in a tractor?

Before using a guidance system, an operator should confirm that the entire system is operational. Operators can navigate the computer console to find potential electrical, sensor, and software issues before they cause a problem in the field. Sensors throughout the machine collect voltage information for the operator to check. Sensor voltages should range between three and five volts. In comparison, the output voltage controlling motors and solenoids will be 12 volts. The console can also display GPS satellite locations, channels, and signal strength, so a producer knows their system can provide an accurate location. The console displays the dilution of precision in the form of a position (3D) dilution of precision (PDOP), vertical dilution of precision (VDOP), and horizontal dilution of precision (HDOP). DOP values range between 1 and 20. A reading between 1 and 5 is needed when using a precision agriculture system. The rate a GPS receiver is sending the data is essential as well. The standard baud rate for sending GPS information is 9600bps (bits per second).

Once an operator checks all electrical connections and sensors, they enter information about the equipment they are using in the field. Equipment information such as the width and offsets ensures the system accurately calculates equipment location. The GPS antenna receiving the signal is on top of the tractor cab, many feet from the equipment it is pulling. For the precision system to calculate the correct data, the system needs to know the tractor hitch and equipment locations relative to the receiver. These locations are called offsets. Operators measure and enter the offsets for any new equipment attached to the tractor.

After adding the equipment information, the operator enters the field location and boundaries. With field boundaries entered, the system can provide a continuous data track for the operator or guidance system to follow to complete the fieldwork. Guidance systems use GPS to prevent overlap and ensure the operator drives a straight line. One type of guidance system is a lightbar indicating whether the operator needs to move the equipment to the left or to the right to prevent overlap of an application. Newer guidance systems have taken the controls away from the operator and automatically steer the equipment, guiding it in the most efficient path for agricultural applications by decreasing overlap.

How will you operate a tractor controlled by computer settings, sensors, and GPS?

Materials

Per student:

- Pen
- Device with internet access
- *Agriscience Notebook*

Procedure

Use a virtual guidance display to set up an implement and view the operational settings. Then practice using the guidance system to navigate and till a field.

Part One – Tractor and Implement Information

1. Go to **Display Simulator** (https://displaysimulator.deere.com/html5/).
2. Create a login and password and log in to the simulator.
3. Choose **tractor** under the *Machine* heading.
4. Set the *Display* option as **4640 CommandCenter™**.
5. Choose **Tillage** under the *Implement* heading.
6. Select **Start Simulation**.
7. Wait for the simulation to load on your computer and the loading notification to disappear.
8. **Accept** the automatic guidance warning.
9. Select **Next** to set up the *Tillage* profile.
10. Record the *Working Width* of the tillage implement and *Connection Type* in Table 1 of *Activity 3.1.4 Student Observation* sheet.
11. Scroll down to find *Dimensions* and select **Lateral Offset**.
    - Sketch and label the *Lateral Offset* and *Center of Lotation* in Figure 4.
    - Select **OK**.
12. Select **Controller Settings** and choose **Diagnostics**
.
13. Record the software version, controller voltage, and sensor voltage on the student observation sheet.
14. Close the ISOBUS VT window.
15. **Save** the *Implement Profile*.
16. Select **Tractor** under the *Equipment* heading, select **Tractor** again and choose the pencil to edit the *Machine Profile*.
17. Select **GPS Lateral Offset**. Then sketch and record dimensions for the following in Figure 5.
    - GPS Lateral Offset
    - GPS Inline Offset
    - GPS Height
18. Select **OK** in the *Dimensions* window.
19. Select **Connection Offsets** and sketch the drawbar offset in Figure 6.
20. Click on **Save** and select **OK**.
21. Continue to select **OK** until you have exited out of all menu options.
22. Select the **Satellite** at the top of the display and choose **StarFire 7000**, the tractor's GPS antenna.
23. Navigate the *ISOBUS VT* pop-up window to find the following and record them in Table 2.
    - Geographic location (Latitude, Longitude, Altitude)
    - Satellite locations and signal strength 
    - PDOP, VDOP, HDOP ratings
    - Baud Rate (Serial Port tab)
24. Close the *ISOBUS VT* pop-up window.

25. *Answer Part One Analysis Questions*.

Part Two – Track and Field

1. Select **Location** and choose **South 40** and select **OK**.
2. Click on **Set Track** and choose **New Track**.
3. Select **Boundary Track** and choose **Boundary Fill**.
4. Select **Next**, name the track with your initials, and **Save**.
    - You should see a pink boundary representing the field and blue lines representing your track.
5. Choose **Guidance**  at the bottom of the screen.
6. Select **Track Spacing** and change it to **49** feet to change the overlap to 1 foot.
7. Select **Save**.
8. Turn the *AutoTrac* **On** and close the *AutoGuidance* pop-up window.
9. Open the Navigation window and virtually navigate your tractor to the blue track inside the pink boundary until the blue track becomes white, as seen in Figure 1.

Figure 1. Track Location

10. Open the CommandARM™ pop-up window and click on the auto steer icon, as seen in Figure 2.
11. Begin driving the tractor by increasing your speed to 2 mph. Do not steer the tractor.
12. Slow the tractor to 0 mph.
13. Lower the cultivator by moving the detent switch to the position shown in Figure 3.
14. Begin driving the tractor at three mph.
    - Be sure the *Autotrac* is **ON**.
    - The tractor should be following the track.
15. Stop the tractor after you have tilled 0.5 acres.
16. Click on the flag to mark the location.
17. Click on the **---** category, choose **weeds** and select **OK**.
18. Select **Area** and **Save**. Then close the menu.

Figure 2. Auto Steer

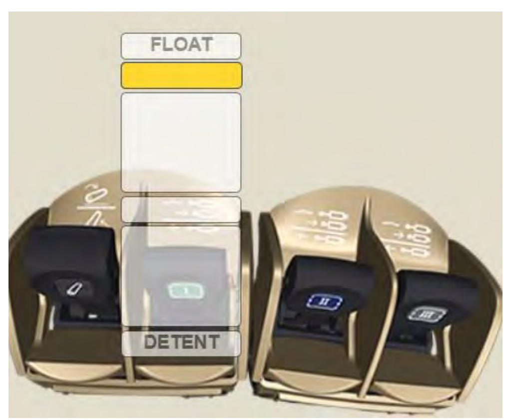


Figure 3. Hydraulic Detent Switch

19. Begin driving the tractor following the track and click on the flag to mark a weedy area in the field.
    - Dotted lines should form around the marked area.
20. Drive to the end of the field and manually turn around.
21. Follow the next track in the opposite direction and turn on the AutoTrac system once the blue line representing the track has turned white.
22. Reduce your speed to 0 mph and select **AutoTrac** to turn it off.
23. Select **Track Spacing** and change to *45 feet,* and **Save**.
24. Turn **AutoTrac** on and click on the *Autosteer button* on the CommandARM™.
25. Begin driving forward and observe the change in the overlap.
26. Stop the tractor after the observations and answer *Part Two Analysis Questions*.

Conclusion

1. What should an operator check if their precision system is not working?
2. What settings does an operator need to enter into a guidance system?
3. How can a producer use the field and track data for future fieldwork?
4. What does an operator need to know when using a guidance system to operate a tractor?

Name____

Activity 3.1.4 Student Observations

Table 1. ***Tillage Profile and Diagnostics***

Working Width	
Connection Type	
Software version	
Controller voltage	
Sensor voltage	

Figure 4. Lateral Offset and Center of Location

Figure 5. GPS Offset

Figure 6. Drawbar Offset

Table 2. ***ISOBUS VT***

Geographic Location	Lat:	Long:	Alt:
Satellite Locations and Strength			
Ratings	PDOP:	VDOP:	HDOP:
Baud Rate			

Part One Analysis Questions

Q1 How does the working width of an implement affect the precision system's calculations?

Q2 Why would a technician need to know an implement's offsets?

Q3 How would a technician use the information in the ISOBUS VT pop-up window?

Part Two Analysis Questions

Q4 How is track spacing related to overlaps and skips in a field?

Q5 What can a producer mark in a field for future reference?

Q6 What other information does the universal display show?

Name____ CASE

Project 3.1.5 Cost Savings

Purpose

Due to its size and capacity, today's agricultural equipment can quickly till, plant, spray, and harvest a field. However, due to inaccurate applications, agricultural input costs, including fuel, seed, fertilizer, and herbicide, may be wasted. For example, as a 60 ft wide boom sprayer travels back and forth across a field applying an herbicide, part of one 60 ft path may overlap with another. Where a wide overlap occurs, wasted herbicide costs a producer money. Overlap in a field can also occur with tillage, planting, and harvesting equipment. A farmer increases input costs, such as fuel and time, if a tractor makes additional trips back and forth across a field due to overlap.

As a technician, how do you explain the value of a precision system to your customers?

Materials

Per student

- Calculator
- Pen
- *Agriscience Notebook*
- *Logbook*
- *Project 3.1.5 Evaluation Rubric*

Per pair of students:

- Electronic device with word processing or presentation software

Procedure

Work individually to calculate the cost of tilling a field. Then collaborate with a partner to find the cost savings for a producer interested in adding a guidance system to their operation.

Part One – Traditional Overlap

A farmer is tilling a 160-acre square field. The tiller has a width of 30 feet. Follow the steps below to calculate the labor and fuel costs of tilling the field with a 3 ft overlap. Round to the nearest hundredth (0.00) when making calculations unless noted otherwise. Record all calculations in your *Logbook*.

1. Calculate the total number of square feet of the field. (43,560 square feet = 1 acre)

$$\text{area (ft}^2\text{)} = 43{,}560\ \text{ft}^2 \times \text{acres}$$

2. The field is a square. Solve for field dimensions by taking the square root of the square feet. Calculate the dimensions of the field.
3. Subtract the overlap from the total width of the tiller to find the tilled width for each path. Then find the number of trips the farmer will make across the field with the tiller. Round to highest whole number.

number of trips = width of field/width tilled

4. Calculate the number of miles the tractor travels to till the entire field. Refer to the field dimensions for the length of each trip. (5280 ft = 1 mile)

miles = number of trips x distance of each trip

5. Find the total hours it will take for the tractor to till the field if the tractor travels at 4.5 miles per hour.

total hours = total distance / speed

6. Find the total number of gallons of fuel needed to till the field.
    - The tractor uses 12 gallons of fuel per hour while tilling.

total gallons = total hours x gallons per hour

7. Calculate the total cost for fuel and labor based upon the following rates.
    - Fuel cost = $2.50/gallon x total gallons
    - Labor cost = $15/hour x total hours
8. Calculate the total fuel and labor cost per acre by adding fuel and labor cost and dividing by total acres.

$$\text{cost per acre} = \frac{\text{total cost}}{\text{total acres}}$$

Part Two – Precision Value

A farmer has considered adding a guidance system to his tractor. They came to your dealership to get more information about purchasing a system but is concerned about the $10,000 price tag. They would be happy to invest $10,000 if they could get a full return on their investment within three years. Use the following information about the producer and the guidance system to develop an information page showing their cost savings over three years to make an informed decision. Work with a partner to complete this project, which your teacher will assess using *Project 3.1.5 Evaluation Rubric*.

Current Operation

Tillage

- Has 1000 acre operation
- The acreage is tilled twice a year with a 30ft tiller.
- The estimated overlap is 2.5 feet
- The tractor uses 12 gallons per hour when tilling at 6 miles per hour
- Labor costs $15 per hour

Planting

- 16 row (30 inch) planter
- The tractor uses 8 gallons per hour while planting at 8 miles per hour
- Estimates 4% overlap when planting
- Seed cost is $110 per acre
- Labor costs $18 per hour

Guidance System Corrections

Tillage

- Reduce overlap to 0.5 feet

Planting

- Reduces overlap to 0.5%

Conclusion

1. How do guidance systems reduce input costs while tilling the soil?

2. What other farming equipment could a farmer use a guidance system with to save time and money?

3. What factors should a farmer consider before purchasing a guidance system for their equipment?

Name____ CASE

Project 3.1.5 Evaluation Rubric

Areas with Room for Improvement	Criteria	Areas that Meet or Exceed Expectations
	Guidance System Information The information page includes graphics and a detailed explanation of how a guidance system works, along with the advantages of adding a guidance system to an operation.	
	Operation Costs The costs of tillage and planting are calculated using labor and input costs based upon projected overlap. All calculations are shown.	
	Savings Tillage and planting savings are calculated using labor and input costs based upon projected overlap. All calculations are shown	
	Budget Summary A narrative summary explains to the customer whether they should purchase a guidance system. The narrative includes calculations and other potential savings that may not be included in the current calculations.	

Name____ CASE

Activity 3.1.6 Global Irrigation

Purpose

Today's agricultural equipment has global positioning receivers integrated with mechanical systems. The receiver processes the signal and instantly determines the machine's geographic location. Depending upon the machine's location, it can make a "decision" such as changing direction, fertility rate, or irrigation. How does GPS interact with other equipment systems?

GPS systems send coordinates to programmable logic controllers (PLC). The PLC can send instructions to other mechanical systems on a machine to control outputs based on location. For example, a GPS on an irrigation pivot can apply water to a field based on specific areas' moisture content.

A programmable logic controller (PLC) is a control system with three major components. PLCs have input devices or sensors collecting data, a computer processor or controller, reading data, and output devices directed by the computer. Automated controls in your home, such as heating and cooling, are controlled by PLCs. Technicians adjust PLC settings to control outputs based on the readings of an input. A thermostat is an example of a PLC in your home. A temperature sensor acts as an input device reading the temperature and the output device is the furnace. Homeowners program the PLC to turn off and on the furnace when the thermometer reads a specific temperature or range of temperatures.

A PLC called a digital control unit (DCU) works with LabQuest to read inputs from sensors and control outputs, such as motors, lights, and alarms. The DCU can be programmed using a simple threshold logic or compound logic statement. A simple threshold logic statement will turn on a device based on a single sensor reading. Compound logic statements control devices under a variety of readings. For example, a person can program a furnace to turn on in their home once the temperature is below 65°F. That would be a simple threshold logic statement. A compound logic statement might tell the furnace to turn on at 65°F and shut off at 68°F.

How does a technician wire and set up automated controls for agricultural equipment?

Materials

Per pair of students:

- Battery adapter, 9V
- Battery, 9-volt
- Box, small
- (7) Breadboard pin wire, male to male
- Breadboard
- Container with lid, 24 oz
- Digital Control Unit (DCU)
- Digital Multimeter (DMM)
- LabQuest
- (2) Light-emitting diodes
- (2) Resistor, 220Ω
- Screwdriver, small flathead
- Vernier soil moisture sensor
- Water pump and hose
- (6) Wire with alligator clip and pin

Per class:

- Outdoor area with marked location

Per student:

- *Agriscience Notebook*
- *Logbook*
- Pen

Procedure

Work with a partner to set up a DCU to activate an electrical circuit with LEDs and a water pump.

Part One – DCU Connections

1. Use the flathead screwdriver to attach four wire leads with alligator clips on one end to the following locations on the DCU, as seen in Figure 1.
    - D1
    - D2
    - D3
    - GND
2. Attach the 2-wire connector to XP (external power) on the DCU, as seen in Figure 1.
    - The ground wire should be closest to the black DCU box.

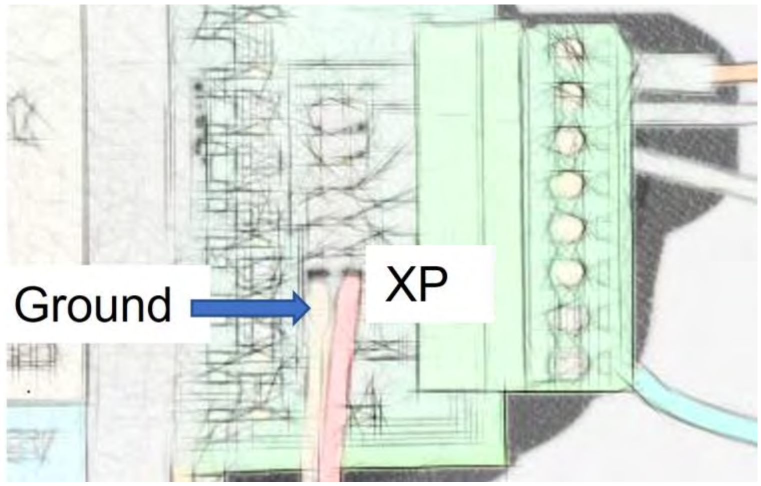


Figure 1. DCU Connections

Part Two – Electrical Circuit

1. Obtain the following materials from your teacher.
    - Red LED
    - Blue LED
    - (2) 220Ω resistors
    - (7) Wire pin leads
    - (2) Wire pin leads with alligator clips
2. Connect the LEDs, resistors, and wires to the breadboard, as seen in Figure 2.
    - The red and black wires to the far right have alligator clip ends.
    - Follow the path of electricity from the positive to the negative side on the breadboard.
    - Attach the longest end of each LED closest to the positive electrical connection.

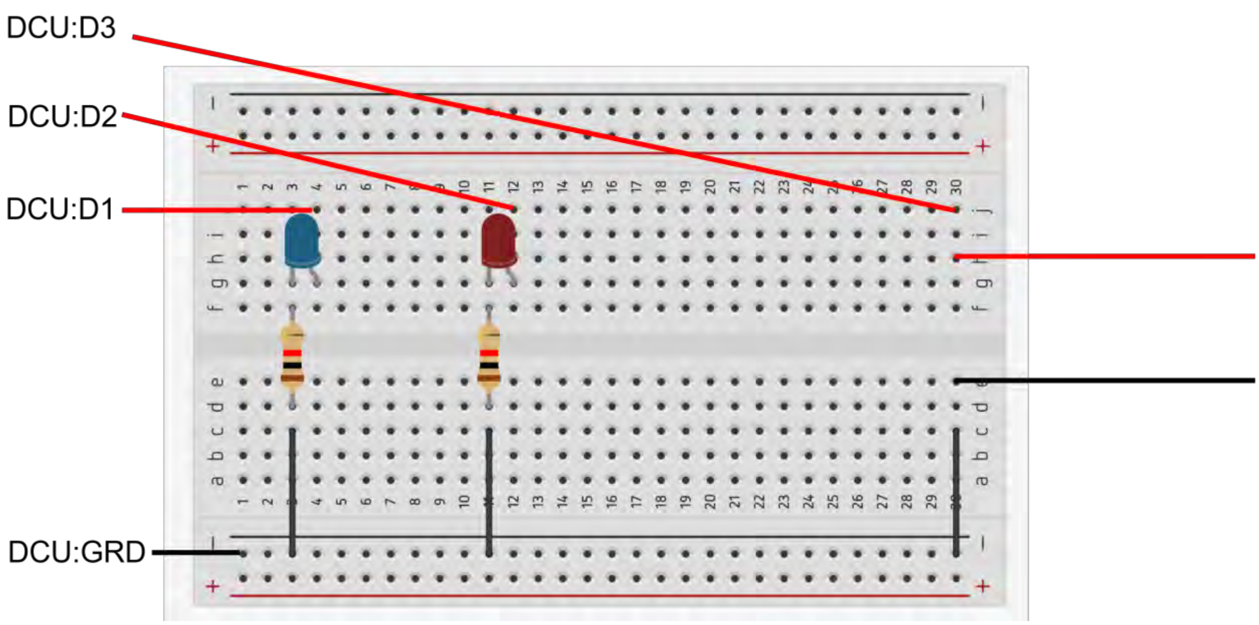


Figure 2. Breadboard Connections

4. Attach the alligator clips to the water pump.
5. Attach the GRD alligator clip on the DCU to the negative lead on the breadboard.
6. Attach the D1 alligator clip to the positive lead directing electricity to the blue LED.
7. Attach the D2 alligator clip to the positive lead directing electricity to the red LED.
8. Attach the D3 alligator clip to the positive lead directing electricity to the water pump.
9. Turn on LabQuest.
10. Plug the DCU into Dig1.
11. Plug the soil moisture sensor into CH1.
12. Attach the 9-volt battery to the DCU.
13. Tap on **Sensors** and choose **DCU Setup**.
14. Select **DIG1**
15. Select the boxes at the top of the screen to turn on each line.
    - LED lights should be on, and the pump should be running.
    - Use a DMM to check connections if a circuit is not working.
16. Uncheck the boxes to shut off each of the circuits.
17. Click the **Activate Line 1** box.
18. Change the settings for CH1 activate if the Soil moisture is > 35%.
19. Click the **Activate Line 2** box.
20. Change the settings for CH1 to activate if the Soil moisture is < 35%.
21. Click the **Activate Line 3** box..
22. Change the settings for CH1 to activate if the Soil moisture is < 35%.
23. Select **OK**.
    - The pump should be running, and the red LED should indicate that the soil is dry.
24. Hold the moisture sensor in your hand until the moisture reading is above 35%.
    - The blue light should turn on to indicate that the soil is moist and does not need irrigation.
25. Disconnect the 9-volt battery and unplug the soil moisture sensor.

Part Three – Location Sensing

Use your system to model an irrigation system that activates in specific locations.

1. Make a map with four quarter sections in your *Logbook,* as seen in Figure 3.
2. Mark the center point of the vertical and horizontal lines with an X.
    - The center point represents the center of an irrigation pivot.
    - Record the latitude and longitude at the center point.
        - Your teacher will provide you with the coordinates.
    - Label the map's north, south, east, and west sides.
    - On the map, note the direction latitude and longitude coordinates increase and decrease.

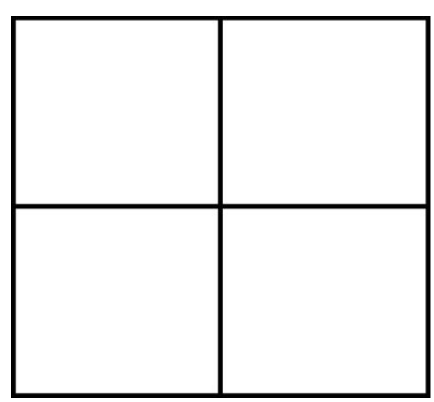


Figure 3. Quarter Section Map

3. Shade in the NE section of the map.
    - This section is dry and needs irrigation.
4. Set up the LabQuest2 and Digital Control Unit (DCU).
    - Tap on **Sensors** and choose **Sensor Setup**.
    - Place a checkmark by *GPS* to activate the GPS sensor.
    - Tap on **OK**.
        - You should see a latitude and longitude reading.
5. Tap **Sensors** and choose **DCU setup**.
    - Program the DCU to activate the pump when it is north and east of the coordinate provided by your teacher.
    - **HINT**: The irrigation system should turn on when the latitude is greater than the center point, **AND** the longitude is greater than the center point.
6. Record your program in your *Logbook*.
7. Place LabQuest, DCU, and breadboard in a small box.
8. Go outside small box of equipment and stand south of the coordinate marked with a flag.
9. Walk north and east of the flag to activate the pump.
    - Troubleshoot your connections or program if the pump and LED do not work correctly.
10. Go inside and fill a water container half full of water.
11. Place the pump in the water and thread the hose through the lid.
12. Seal the lid on the container with water and a pump to make a watering system.
13. Go outside and move into each quarter section to turn the watering system on and off.
    - Check your connections and settings if the system is not working.
    - Use the DMM if needed.

Conclusion

1. How do global positioning systems automate mechanical systems?

2. How can automation be used without GPS?

3. What geographic information does a mechanical system need to integrate with a global positioning system?

4. Besides irrigation, what are other agricultural applications of automation?

Name____

CASE

Project 3.1.7 Guiding Light

Purpose

During past activities and projects, you have learned about the operations and value of precision agricultural systems. All global positioning systems have electrical connections to a control unit or PLC that processes information and controls an output with more electrical connections turning on lights and relays. Technicians understand how electrical connections work and can troubleshoot potential problems. Once sensors are connected to a control unit with electrical outputs, the entire system can be confusing due to the wires, switches, LEDs, and other electrical components. A technician determines where wires connect and how electrical current flows to turn on and off devices.

How do the electrical circuits of a guidance system connect to GPS to aid a producer? Can you make the connections for an operable precision system as a technician?

Materials

Per pair of students:

- Device with word processing software
- Battery adapter, 9V
- Battery, 9V
- Breadboard
- Breadboard pin wire, male to male
- Digital control unit
- Digital multimeter (DMM)
- LabQuest
- (3) LEDs
- (3) Resistors
- (2) Survey flags

Per student:

- Pen
- *Agriscience Notebook*
- *Logbook*
- *Project 3.1.7 Evaluation Rubric*

Procedure

Work with your partner to develop a guidance system for applying dry fertilizer using the hand-held spreader calibrated during *Activity 3.1.1 Calibration*. The guidance system should guide the applicator in walking a straight line to prevent fertilizer overlap. Preventing overlap will reduce fertilizer waste and application costs. Use LabQuest with the GPS sensor, Digital Control Unit, and LEDs to develop a system for directing the applicator to walk in a straight line between two survey flags. Program the DCU to use LEDs as indicators for the operator to move left, right, or stay the course. Use the *Guidance System Criteria* to complete your design.

Guidance System Criteria

- The system should guide the operator walking in a north-south or east-west direction.
- LED lights only work with electrical current flowing from positive to negative.
- The negative lead on the LED is shorter than the positive.
- Due to the DCU limitations, write programmable instructions for walking a single path between two points.

Write a user manual for your guidance system. The user manual will be assessed using *Project 3.1.7 Evaluation Rubric* and include the *User Manual Criteria*.

User Manual Criteria

- Electrical schematic showing electrical connections and power supplies.
- DCU settings are used for the solution.
- A technical guide explaining how the guidance system functions.
- Troubleshooting guide with three causes and corrections for three complaints.

Conclusion

1. How does a guidance system work?

2. What types of electrical circuits do you find on a guidance system?

3. Why are electrical schematics and circuits necessary for a technician to understand when working with GPS systems?

Name____

CASE

Project 3.1.7 Evaluation Rubric

Areas with Room for Improvement	Criteria	Areas that Meet or Exceed Expectations
	Navigation System The students designed the system to keep all electrical controls and indicators organized. Controllers and indicator lights are appropriately labeled.	
	Electrical Drawing The student uses electrical symbols with a key. The reader can easily follow the electrical path from the source to the load and back to the source throughout each branch.	
	Digital Control Settings DCU settings include the geographical entries and programmable settings entered in the LabQuest.	
	Technical Guide The guide contains a list of all components and how they function with instructions on using the systems. Instructions explain where the system can be used along with its limitations.	
	Troubleshooting Guide The troubleshooting guide contains three realistic complaints with multiple causes and corrections described for each complaint.	

Name____

CASE

Lesson 3.1 Check for Understanding

1. Why do producers calibrate equipment to limit skips and overlaps?

2. How does a producer determine how efficient they use agricultural inputs?

3. What are three factors affecting the quality of a GPS satellite signal?

4. What are three settings an operator checks before using a guidance system?

5. List three precision agriculture components found on a combine?

6. What data does a precision agriculture system need to collect to calculate a producer's yield?

7. How does precision agricultural equipment increase a producer's profit?

8. How does equipment use GPS satellite signals to control and guide mobile agricultural equipment?

9. Match the following terms and definitions

______	Baud rate	A.	The technique of comparing GPS data collected in the field to GPS data collected at a known point.
______	DGPS correction	B.	Rate of processing data measured in bits per second
______	PLC	C.	Guidance system setting explaining a location relative to a specific point.
______	DOP	D.	An indicator of satellite signal quality used to determine a position.
______	Offset	E.	System of satellites in the sky used to determine a location.
______	PDOP	F.	An indicator of satellite signal quality used to determine a 3D position.
______	GPS	G.	Control unit receiving inputs and controlling outputs.

10. What complaint would a customer have if an operator entered the incorrect offset in their guidance system?

11. How could a technician determine if the GPS receiver is failing?

Name____

CASE

Lesson 3.1 Check for Understanding Answer Key

1. Why do producers calibrate equipment to limit skips and overlaps?

Producers decrease overlaps to decrease input costs such as fertilizer and seed. Producers limit skips in the field to increase crop productivity.

2. How does a producer determine how efficient they use agricultural inputs?

Producers measure inputs at a rate such as gallons or pounds per acre of an applied input.

3. What are three factors affecting the quality of a GPS satellite signal?

Signal multipaths caused by the atmosphere, trees, hills, or buildings
Satellite locations in the sky
Number of satellite signals received

4. What are three settings an operator checks before using a guidance system?

Baud rate
Sensor voltage
Satellite signal quality
DOP, HDOP, VDOP, and PDOP

5. List three precision agriculture components found on a combine?

Moisture sensor
Flow sensor (Load, light, or force sensor)
Header sensor
GPS Antenna
Monitor/Console
Elevator mount unit

6. What data does a precision agriculture system need to collect to calculate a producer's yield?

Equipment speed
Equipment location
Crop yield
Crop moisture

7. How does precision agricultural equipment increase a producer's profit?

A producer limits input costs while maximizing their yield, which increases their production efficiencies.

8. How does equipment use GPS satellite signals to control and guide mobile agricultural equipment?

GPS signals are inputs received and processed by a programmable logic controller. The programmable logic controller sends signals to mechanical outputs controlling equipment speed and steering.

9. Match the following terms and definitions

B	Baud rate	A.	The technique of comparing GPS data collected in the field to GPS data collected at a known point.
A	DGPS correction	B.	Rate of processing data measured in bits per second
G	PLC	C.	Guidance system setting explaining a location relative to a specific point.
D	DOP	D.	An indicator of satellite signal quality used to determine a position.
C	Offset	E.	System of satellites in the sky used to determine a location.
F	PDOP	F.	An indicator of satellite signal quality used to determine a 3D position.
E	GPS	G.	Control unit receiving inputs and controlling outputs.

10. What complaint would a customer have if an operator entered the incorrect offset in their guidance system?

Answers will vary.
Equipment may have large overlaps or skips because of the spacing between tracks set by the system.

11. How could a technician determine if the GPS receiver is failing?

Satellite signals, dilution of precision (DOP) readings, system voltage, data reception, electrical connections

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Curriculum for Agricultural Science Education

Agricultural Equipment Maintenance and Technology

Precise Control

Unit 3 – Lesson 3.1 Precision Systems

Programmable Logic Controller

A device using microprocessors to control machines or processes

Components

- Inputs – Sensors
- Controls – Console
- Outputs – Activated devices

Inputs

Data collecting sensors

Data read by the controller

Example data

- Temperature
- Moisture
- Location (Proximity)
- Location (GPS)

Controls

- Control the output based upon data and settings
- Regulate electrical power to an output

Outputs

Electrical Devices

- Motor or Pump
- Indicator light
- Alarm

How do controls work?

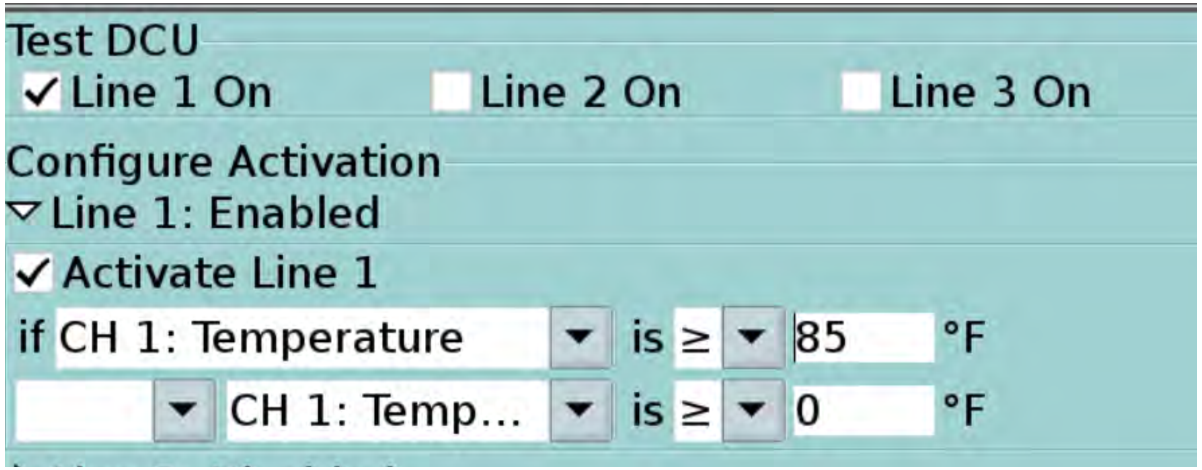
Machine settings - Logic

Tell the machine when to operate components

- If the boom is 2ft from the ground
- Turn on the warning light
- Raise to boom to 3ft

Simple Threshold Logic

- Program used to control a machine with a single statement
- If–then statement
- If the temperature is greater than 85F, then turn on the fan.

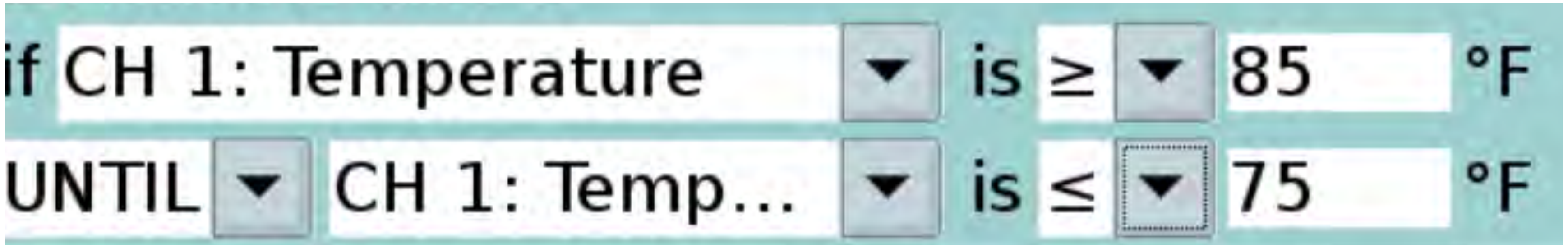


Compound Logic Statement

Controls machines under various conditions

Three functions

- UNTIL - Time based or allow cycling
- AND - Set a range of conditions
- OR - Set varying conditions



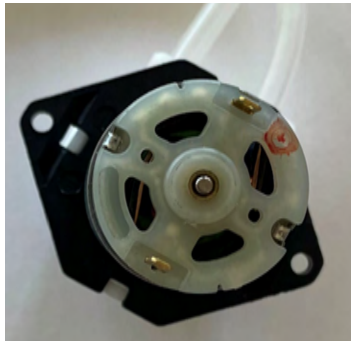
Precision System Model

CONSOLE/CONTROL UNIT

GPS SENSOR

MOISTURE SENSOR

PUMP



LIGHTS

Circuits (Outputs)

Instrument Panels

- Web of series and parallel circuits
- LEDs
- Resisters
- Signaling activated outputs

Breadboard

- Prototyping electrical circuits
- Construction base
- Simulate equipment circuits
- View the [Breadboard Video] to learn more.

Presentation Review

- Mark or highlight three key points
- List two ideas or concepts related to previous knowledge.
- List questions you have about this topic.
- Keep notes organized and available for use throughout the course.

References

- Science Buddies. (2021). *How to use a breadboard.* https://www.sciencebuddies.org/science-fair-projects/references/how-to-use-a-breadboard?from=YouTube
- Vernier (2015). *Vernier digital control unit (dcu).* Beaverton, OR: Author.

Presentation Review

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References

- Gillespie, J.R., & Flanders, F.B. (2015). *Modern livestock and poultry production (9th ed.).* Clifton Park, NY: Delmar.
- Herren, R. V., & Donahue, R. L. (2000). *Delmar's agriscience dictionary with searchable CD-ROM*. Albany, NY: Delmar.

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Curriculum for Agricultural Science Education

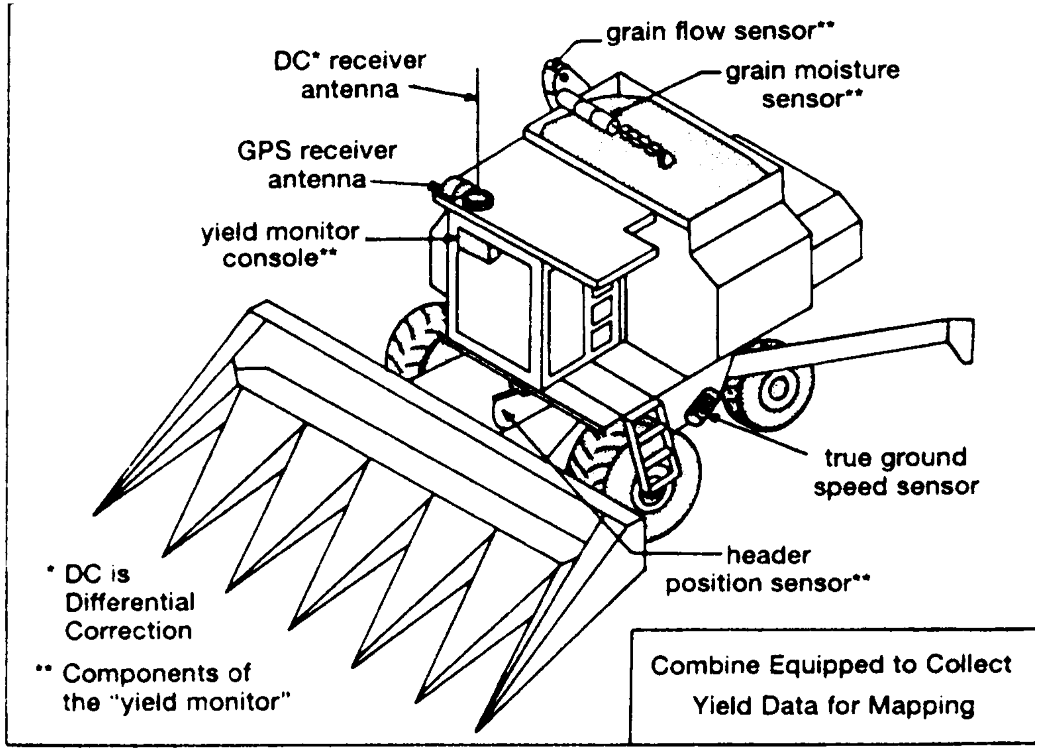
Agricultural Equipment Maintenance and Technology

Precision Parts

Unit 3 – Lesson 3.1 Precision Systems

Yield Monitor Components

- Monitor/Console
- GPS Receiver
- Differential Receiver
- Sensors
    - Grain Flow
    - Grain Moisture
    - Ground Speed
    - Header Position



GPS Antenna

- Sensor receiving signals from satellites
- Location data displayed on display console
- Coordinate data used to calculate yield and speed

Display console

<u>User Inputs</u>

- Field name
- Load name
- Cutting width
- Crop type
- Nominal weight
- Nominal moisture

<u>Sensor Inputs</u>

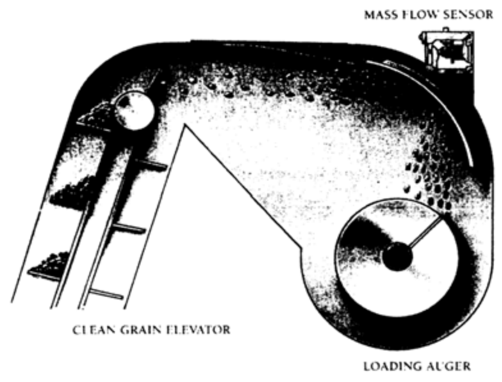
- Moisture
- Current yield
- Average Yield
- Speed
- Area harvested
- DGPS and GPS signals

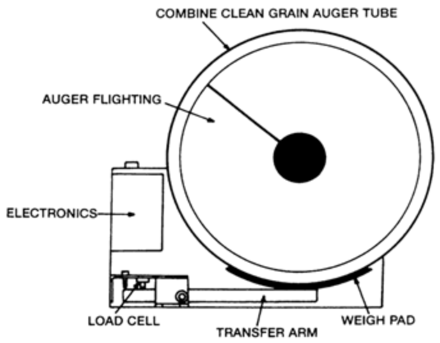
Yield Data Collection

- Sensors collect grain data during harvest
- Internal computer uses the data to convert to bushels
- Correlates production with location
  - Yield map
  - Average yield

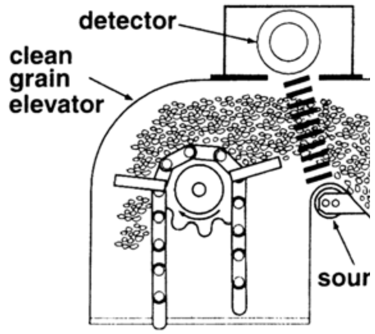
Grain Sensors

- Mass
  - oForce Sensor
- Radiant Energy
  - oRadiometric sensor
- Electrical Energy
  - oLoad sensor
- Volume
  - oLight sensor

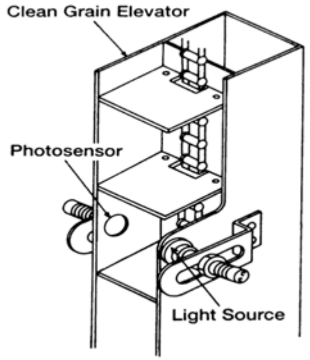




Load-cell-based grain yield measurement system



Radiometric measurement system for monitoring gr



Volume measurement system for monitoring grain yields

Sensor Location

Mounted in the clean grains
path in the combine

Installed Ag Leader unit

Elevator Mount Unit

- Chamber
  - Collects grain samples
- Measures moisture
  - Sends data to console
- Separate attachment
- Easy service and cleaning
  - Eliminates foreign material build up

Elevator Mount Sensors

- Proximity Sensor
  - Activates auger to clean chamber
- Moisture sensor
  - Measures grain moisture
  - Electrical conductivity

Ground Speed Sensors

Shaft speed sensor - Least reliable unit

Radar and ultrasonic sensors - More reliable

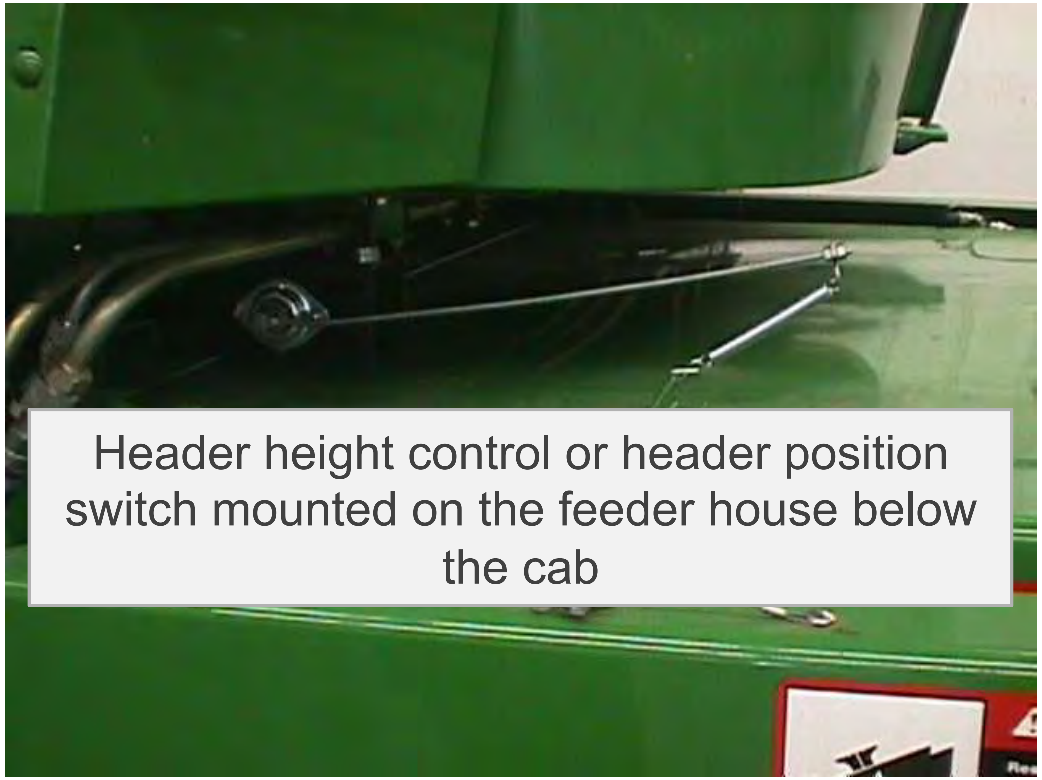
GPS sensor-Most accurate

- Output as latitude, longitude, and vehicle heading.

Header Position

Radial Sensor

- Header moves the radial sensor via mechanical arm
- Sensor stops data collection when operator raises combine header

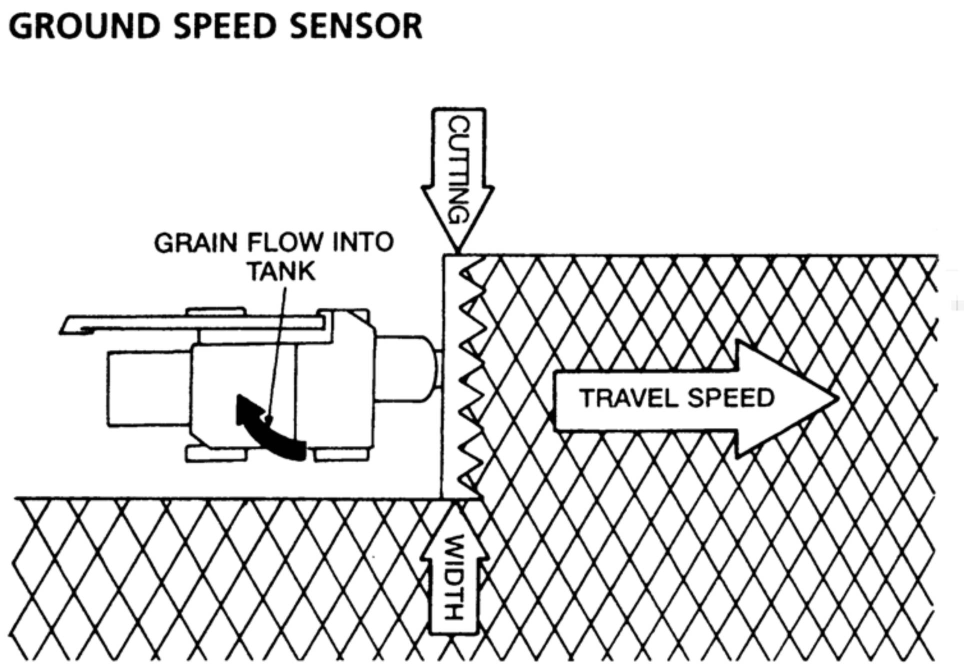


Header height control or header position switch mounted on the feeder house below the cab

Yield Calculation

Console collects and combines data to calculates average yield.

- Moisture
- Mass
- Speed
- Location



Instantaneous yield measurement by a combine in the field

Presentation Review

- Mark or highlight three key points
- List two ideas or concepts related to previous knowledge.
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- Keep notes organized and available for use throughout the course.

References

- AgLeader. (2017). *Yield sense service manual*. Ames, IA: Author
- Ess, Dan. (2003). *Precision Farming Guide for Agriculturalists*. Madison, WI: Deere and Company.

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Curriculum for Agricultural Science Education

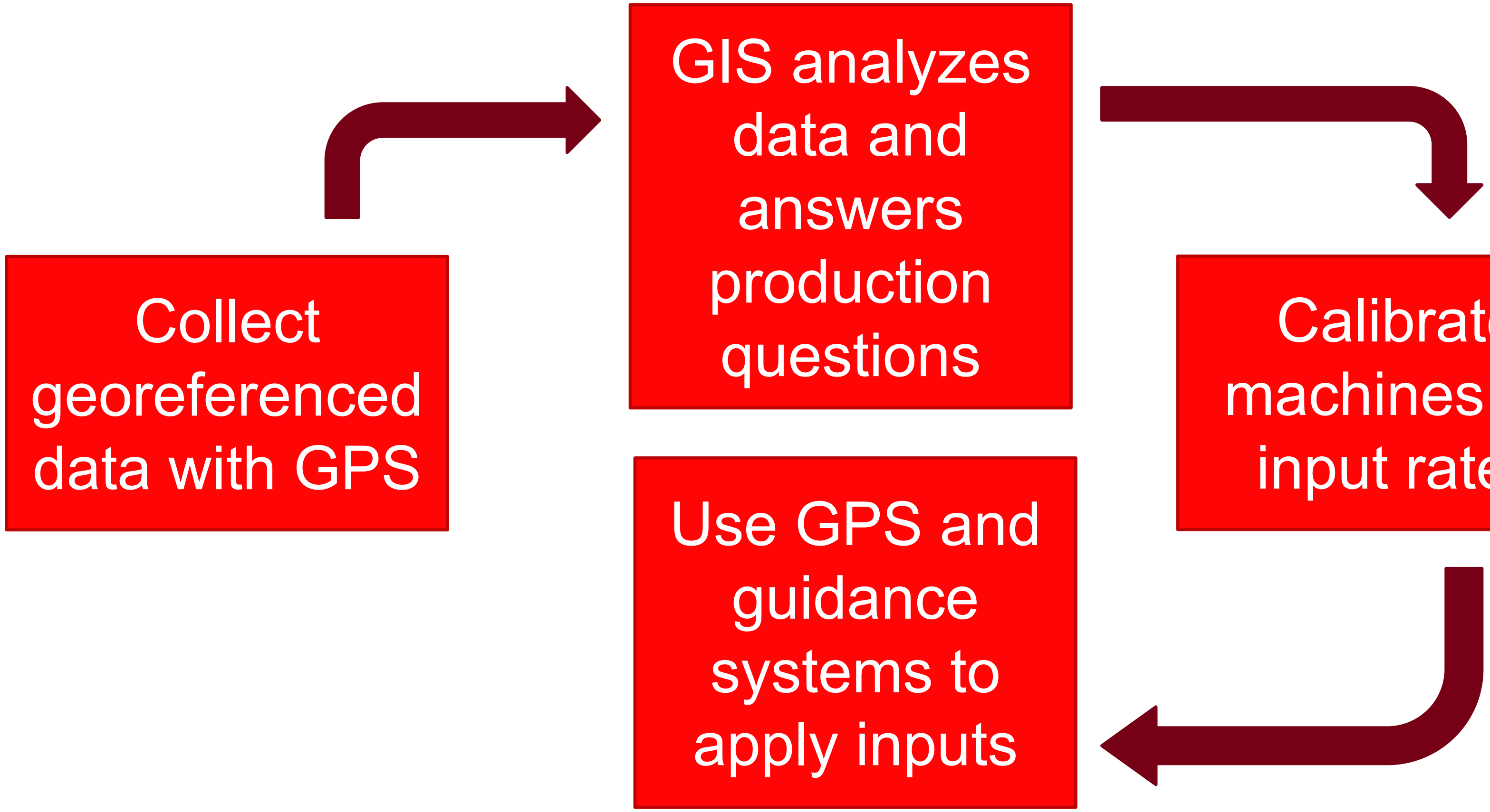
Agricultural Equipment Maintenance and Technology

Precision Systems

Unit 3 – Lesson 3.1 Precision Systems

Precision Agriculture

Systematic approach to site-specific agriculture



Precision Systems

Global Position Systems (GPS)

- Geographic locations

Geographic Information Systems (GIS)

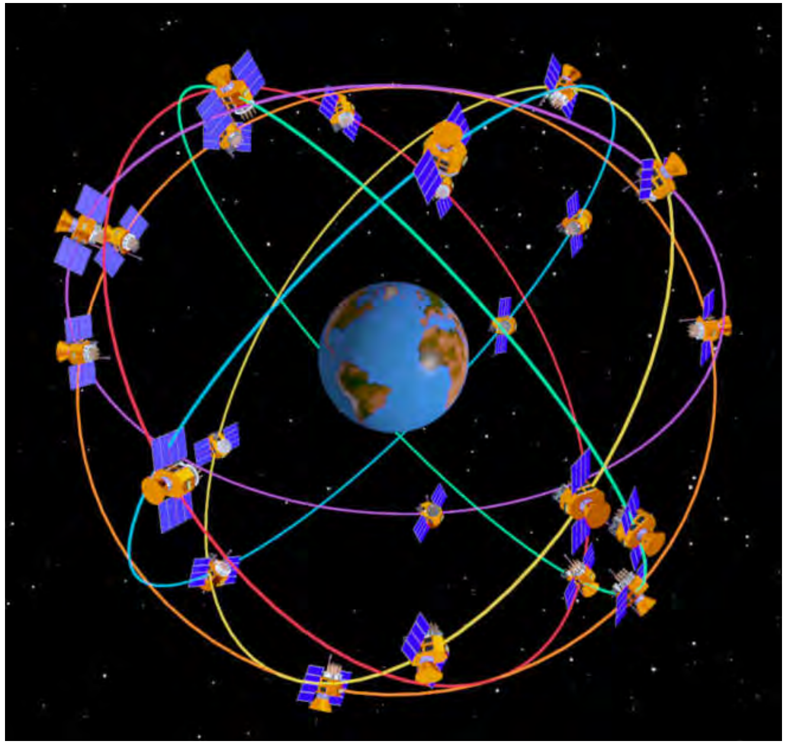
- Spatial database

Guidance Systems

- Assisted and automated navigation

Global Positioning System

- System of satellites and receivers
- Determine exact locations and elevations on the earth



http://ardupilot.org/rover/_images/gps_satellite_constellation.jpg

GPS in Agriculture

Identify locations of land features

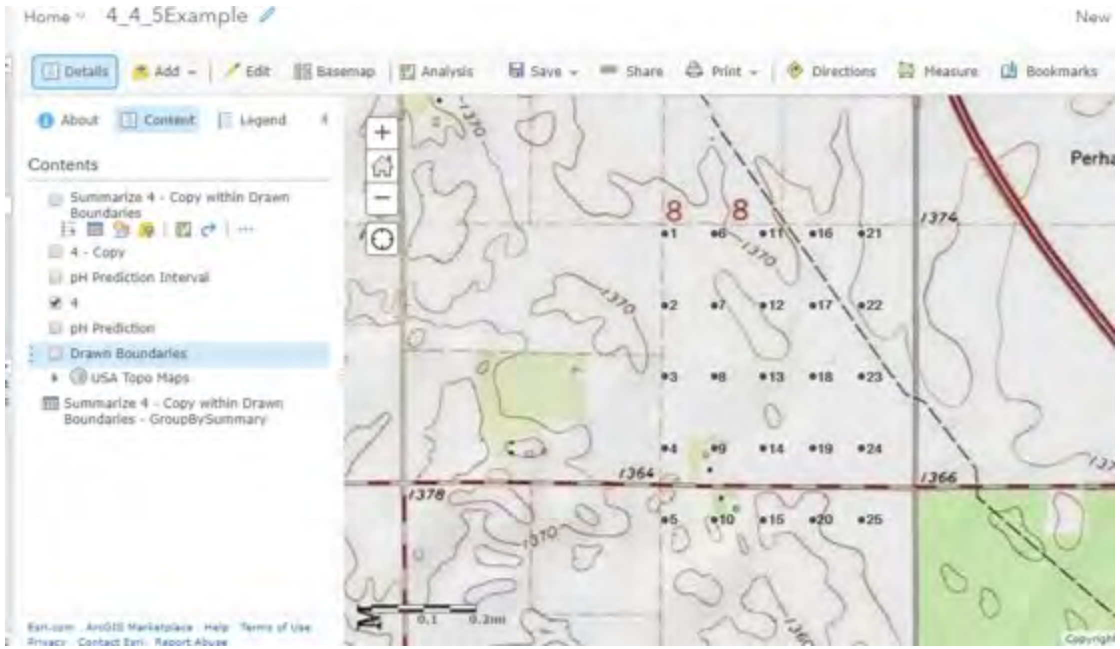
- Fences
- Boundaries
- Buildings
- Roads
- Soil samples

Navigation

https://commons.wikimedia.org/wiki/File:John_deere_8345_rt.jpg

Geographic Information Systems

- Electronic map
- Visual data representation
- Georeferenced data
- Identifies and analyzes spatial relationships



GIS Data

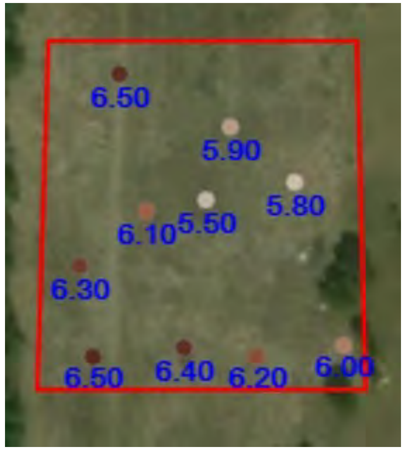
Base layer

Vectors

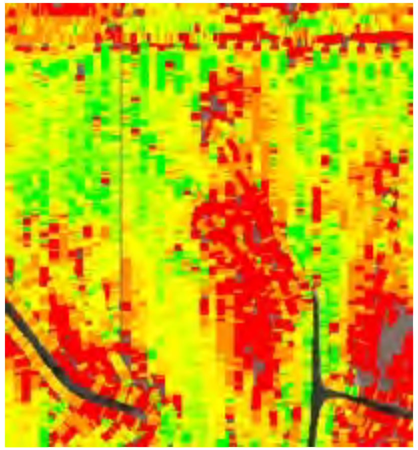
- Shapefiles (.shp)
- Points
- Lines
- Polygons

Continuous data

- Rasters
- Contour



Vector Map



Raster Map

Contour Map

Variable Rate Technology

Vary input rates based upon GIS data

Inputs

- Herbicide – kill weeds
- Fertilizer (i.e. nitrogen) – feed plants
- Lime – raise soil pH

Requires equipment with GPS and variable rate sensors

Guidance Systems

Light bar

Automated navigation

Advantages

- Limit overlaps
- Avoid skips
- Save on inputs
    - Fuel
    - Herbicide
    - Fertilizer

Presentation Review

- Mark or highlight three key points
- List two ideas or concepts related to previous knowledge.
- List questions you have about this topic.
- Keep notes organized and available for use throughout the course.

References

- Brase, Terry. (2006). *Precision agriculture*. Clifton, NY: Thomson Delmar Learning.
- ESRI. (n.d.) *Gis dictionary*. Retrieved from https://support.esri.com/en/other-resources/gisdictionary/browse/
- John Deere. (n.d.). *John deere guidance systems: guidance you can grown with*. Retrieved from https://m.deere.com/common/docs/products/equipment/agricultural_management_solutions/guidance_systems/brochure/en_GB_yy1114823_e.pdf

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Lesson 3.2 Precision Applications

Preface

Some technicians work as field applicators, applying herbicides, fertilizers, and lime. These technicians work with farmers using precision technologies to manage input applications. Farmers use geographic information systems (GIS) to calculate application rates to analyze site-specific data collected from field locations. GIS displays data as layers or maps that farmers can use to make production decisions. Once farmers make production decisions, they use equipment with precision systems to apply the inputs.

Students learn how to collect and display data using an industry-based geographic information system during this lesson. Then they use GIS to solve a production problem.

Concepts	Performance Objectives
Students will know and understand	*Students will learn concepts by doing*
1. Geographic information systems display vectors, features, and attributes.	• Use GIS to make field boundaries and display a soil sampling grid. (Activity 3.2.1)
2. A producer can predict a field's productivity by collecting data from specific locations.	• Use interpolation to display GIS data. (Activity 3.2.2)
3. Variable-rate application systems reduce producer costs while protecting the environment.	• Analyze data using GIS and recommend a seeding application based on soil type. (Activity 3.2.3) • Compare flat-rate and variable-rate applications by creating basic fertilizer recommendations for each scenario. (Project 3.2.4)

National AFNR Common Career Technical Core Standards Alignment

Career Ready Practices
2. Apply appropriate academic and technical skills.
• CRP.02.01: Use strategic thinking to connect and apply academic learning, knowledge, and skills to solve problems in the workplace and community.
• CRP.02.02: Use strategic thinking to connect and apply technical concepts to solve problems in the workplace and community.
4. Communicate clearly, effectively and with reason.
• CRP.04.02: Produce clear, reasoned and coherent written and visual communication in formal and informal settings.
5. Consider the environmental, social, and economic impacts of decisions.
• CRP.05.01: Assess, identify, and synthesize the information and resources needed to make decisions that positively impact the workplace and community.
8. Utilize critical thinking to make sense of problems and persevere in solving them.
• CRP.08.01: Apply reason and logic to evaluate workplace and community situations from multiple perspectives.
• CRP.08.02: Investigate, prioritize, and select solutions to solve problems in the workplace and community.
• CRP.08.03: Establish plans to solve workplace and community problems and execute them with resiliency.
11. Use technology to enhance productivity.
• CRP.11.01: Research, select and use new technologies, tools, and applications to maximize productivity in the workplace and community.
Agriculture, Food, and Natural Resources Career Cluster

Plant Systems (AG-PL)
1. Develop and implement a crop management plan for a given production goal that accounts for environmental factors.
• AG-PL 1.1: Develop a fertilization plan using the results of an analysis and evaluation of nutritional requirements and environmental conditions.
3. Propagate, culture, and harvest plants and plant products based on current industry standards.
• AG-PL 3.1: Develop a production plan that applies the fundamentals of plant management.
Power, Structural and Technical (AG-PST)
5. Use control, monitoring, geospatial and other technologies in AFNR power, structural and technical systems.
• AG-PST 5.3 Use geospatial technologies in AFNR applications.

Next Generation Science Standards Alignment

Science and Engineering Practices	
Asking Questions and Defining Problems	Asking questions and defining problems in 9–12 builds on K–8 experiences and progresses to formulating, refining, and evaluating empirically testable questions and design problems using models and simulations. • Ask questions that arise from careful observation of phenomena, or unexpected results · to clarify and refine a model, an explanation, or an engineering problem.
Developing and Using Models	Modeling in 9–12 builds on K–8 experiences and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed world(s). • Develop and/or use multiple types of models to provide mechanistic accounts and/or predict phenomena and move flexibly between model types based on merits and limitations. • Develop and/or use a model (including mathematical and computational) to generate data to support explanations, predict phenomena, analyze systems, and/or solve problems.
Planning and Carrying Out Investigations	Planning and carrying out investigations in 9-12 builds on K-8 experiences and progresses to include investigations that provide evidence for and test conceptual, mathematical, physical, and empirical models. • Plan an investigation or test a design individually and collaboratively to produce data to serve as the basis for evidence as part of building and revising models, supporting explanations for phenomena, or testing solutions to problems. Consider possible confounding variables or effects and evaluate the investigation's design to ensure variables are controlled.
Analyzing and Interpreting Data	Analyzing data in 9–12 builds on K–8 experiences and progresses to introducing more detailed statistical analysis, the comparison of data sets for consistency, and the use of models to generate and analyze data. • Analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in order to make valid and reliable scientific claims or determine an optimal design solution. • Apply concepts of statistics and probability (including determining function fits to data, slope, intercept, and correlation coefficient for linear fits) to scientific and engineering questions and problems, using digital tools when feasible. • Compare and contrast various types of data sets (e.g., self-generated, archival) to examine consistency of measurements and observations.
Using Mathematics and Computational Thinking	Mathematical and computational thinking in 9-12 builds on K-8 and experiences and progresses to using algebraic thinking and analysis, a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms, and computational tools for statistical analysis to analyze, represent, and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions. • Create and/or revise a computational model or simulation of a phenomenon, designed device, process, or system. • Use mathematical, computational, and/or algorithmic representations of phenomena or design solutions to describe and/or support claims and/or explanations. • Apply ratios, rates, percentages, and unit conversions in the context of complicated measurement problems involving quantities with derived or compound units (such as mg/mL, kg/m3, acre-feet, etc.).
Constructing Explanations and Designing Solutions	Constructing explanations and designing solutions in 9–12 builds on K– 8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories. • Make a quantitative and/or qualitative claim regarding the relationship between dependent and independent variables.

	• Design, evaluate, and/or refine a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations.

Crosscutting Concepts	
Patterns	Observed patterns in nature guide organization and classification and prompt questions about relationships and causes underlying them.
	• Patterns of performance of designed systems can be analyzed and interpreted to reengineer and improve the system. • Mathematical representations are needed to identify some patterns.
Systems and System Models	A system is an organized group of related objects or components; models can be used for understanding and predicting the behavior of systems.
	• Systems can be designed to do specific tasks. • When investigating or describing a system, the boundaries and initial conditions of the system need to be defined and their inputs and outputs analyzed and described using models. • Models (e.g., physical, mathematical, computer models) can be used to simulate systems and interactions—including energy, matter, and information flows—within and between systems at different scales. • Models can be used to predict the behavior of a system, but these predictions have limited precision and reliability due to the assumptions and approximations inherent in models.

Common Core State Standards for High School Mathematics

Modeling standards are indicated by the star symbol (*) throughout other conceptual categories.

CCSS: Conceptual Category – Number and Quantity	
Quantities	*Reason quantitatively and use units to solve problems.

CCSS: Conceptual Category – Statistics and Probability	
Interpreting Categorical and Quantitative Data	*Summarize, represent, and interpret data on a single count or measurement variable. *Summarize, represent, and interpret data on two categorical and quantitative variables.
Conditional Probability and the Rules of Probability	*Use the rules of probability to compute probabilities of compound events in a uniform probability model.
Using Probability to Make Decisions	*Use probability to evaluate outcomes of decisions.

Common Core State Standards for English Language Arts

CCSS: English Language Arts Standards » Science & Technical Subjects » Grade 11-12	
Key Ideas and Details	• **RST.11-12.3 –** Follow precisely a complex multistep procedure when carrying out experiments, taking measurements, or performing technical tasks; analyze the specific results based on explanations in the text.
Craft and Structure	• **RST.11-12.4 –** Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to grades 11-12 texts and topics.
Range of Reading and Level of Text Complexity	• **RST.11-12.10 –** By the end of grade 12, read and comprehend science/technical texts in the grades 11-CCR text complexity band independently and proficiently.

CCSS: English Language Arts Standards » Writing » Grade 11-12	
Production and Distribution of Writing	• **WHST.11-12.4 –** Produce clear and coherent writing in which the development, organization, and style are appropriate to task, purpose, and audience.
Research to Build and Present Knowledge	• **WHST.11-12.7 –** Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation.
Range of Writing	• **WHST.11-12.10 –** Write routinely over extended time frames (time for reflection and revision) and shorter time frames (a single sitting or a day or two) for a range of discipline-specific tasks, purposes, and audiences.

Essential Questions

1. How is information displayed on a GIS map?
2. How are GIS features different from an attribute?
3. How are data points used to predict unknown values on a map?
4. How is GIS used to save producer input costs?
5. What is a variable rate application?
6. Why does a technician need to understand GIS software applications?

Key Terms

Attribute	**Base layer**	**Database**
Feature	**Georeferencing**	**GIS database**
Interpolation	**Layer**	**Point**
Polygon	**Prescription agriculture**	**Qualitative data**
Quantitative data	**Query**	**Raster**
Site-specific management	**Spatial data**	**Variable-rate technology (VRT)**
Vector	**Value**	**Yield map**

Day-to-Day Plans
Time: 9 days

*Refer to the Teacher Resources section for specific information on teaching this lesson, in particular **Lesson 3.2 Teacher Notes**, **Lesson 3.2 Glossary**, **Lesson 3.2 Materials**, and other support documents.*

Day 1:

- Present **Concepts**, **Performance Objectives**, **Essential Questions**, and **Key Terms** to provide a lesson overview.
- Students view **Creating Field Boundaries** video.
- Provide students with a copy of **Activity 3.2.1 GIS Mapping**.
- Students work individually on *Activity 3.2.1 GIS Mapping*.

Day 2:

- Students view **Creating Soil Samples**.
- Students complete *Activity 3.2.1 GIS Mapping*.

Day 3:

- Provide students **Presentation Notes** pages to use throughout the presentation to record notes and reflections. Students add these pages to their *Agriscience Notebook*.
- Present PowerPoint® **Interpolate Maps**.
- Students take notes using the *Presentation Notes* pages provided by the teacher.
- Students view **Interpolation** video as homework.
- Provide students with a copy of **Activity 3.2.2 Interpolate Mapping**.
- Students work individually on *Activity 3.2.2 Interpolate Mapping*.

Day 4:

- Students complete *Activity 3.2.2 Interpolate Mapping*.

Day 5:

- Provide students *Presentation Notes* pages to be used throughout the presentation to record notes and reflections. Students add these pages to their *Agriscience Notebook*.
- Present PowerPoint® **Prescription Maps**.
- Students take notes using the *Presentation Notes* pages provided by the teacher.
- Students view **Prescriptions** video as homework.

Day 6:

- Provide students with a copy of **Activity 3.2.3 Crop Prescription**.
- Students complete *Activity 3.2.3 Crop Prescription*.

Day 7 – 8:

- Provide students with a copy of **Project 3.2.4 Prescribed Solution** and **Project 3.2.4 Evaluation Rubric**.
- Students work individually on *Project 3.2.4 Prescribed Solution*.
- Use *Project 3.2.4 Evaluation Rubric* to assess *Project 3.2.4 Prescribed Solution*.

Day 9:

- Distribute **Lesson 3.2 Check for Understanding**.
- Students complete *Lesson 3.2 Check for Understanding* and submit it for evaluation.
- Use **Lesson 3.2 Check for Understanding Key** to evaluate student assessments.

Instructional Resources

PowerPoint® Presentations

Interpolate Maps

Prescription Maps

Videos

Creating Field Boundaries

Creating Soil Samples

Interpolation

Prescriptions

Student Support Documents

Lesson 3.2 Glossary

Presentation Notes

Activity 3.2.1 GIS Mapping

Activity 3.2.2 Interpolate Mapping

Activity 3.2.3 Crop Prescription

Project 3.2.4 Prescribed Solution

Teacher Resources

Lesson 3.2 Precision Applications PDF

Lesson 3.2 Teacher Notes

Lesson 3.2 Materials

Lesson 3.2 Check for Understanding

Answer Keys and Assessment Rubrics

Lesson 3.2 Check for Understanding Answer Key

Project 3.2.4 Evaluation Rubric

Reference Sources

Brase, Terry. (2006). *Precision Agriculture*. Clifton, NY: Thomson Delmar Learning.

ESRI. (n.d.) *Gis dictionary*. Retrieved from **https://support.esri.com/en/other-resources/gis-dictionary/browse/**

Ess, Dan. (2003). Precision Farming Guide for Agriculturalists. Madison, WI: Deere and Company

Herren, R. V., & Donahue, R. L. (2000). *Delmar's agriscience dictionary with searchable CD-ROM*. Albany, NY: Delmar.

FFA Connections

This lesson provides conceptual and procedural knowledge required for participation in the following FFA activities:

- Agricultural Proficiency
  - **Agricultural Mechanics Repair and Maintenance –Placement**
  - **Agricultural Mechanics Repair and Maintenance –Entrepreneurship**
- Agriscience Fair
  - **Power, Structural and Technical Systems**
- Career Development Events
  - **Agricultural Technology & Mechanical Systems**
- Educational Resources
  - **SAE Idea Cards-Power, Structural and Technical Systems**
  - **Power, Structural and Technical System Careers**
  - **Power, Structural and Technical Systems Career Focus Area Resources**
  - Agricultural Mechanics (**Word)** (**PDF**)
  - Keegan Humm-SAE-Placement-Implement Dealership Lesson Plan (**Word**) (**PDF**)
  - Power, Structural and Technical Careers **(Word)**

For more information, visit the **National FFA Organization** website.

SAE for All

Foundational SAE

All students in an agricultural education program are expected to have a Foundational SAE. Students completing the APP and extensions listed below will meet the Foundational SAE qualification for the *Advanced (Grades 11-12) level*. Students should place all documented evidence in the *FFA/SAE* section of their *Agriscience Notebook* along with the *SAE for All Foundational Checksheet*.

- Employability Skills for College and Career Readiness
  - Project 3.2.4 Prescribed Solution

Immersion SAE

Students interested in this lesson's topics should explore the following related Immersion SAEs. An immersion SAE is optional and replaces the agricultural literacy component of the Foundational SAE.

- Ownership/Entrepreneurship

- **Turfgrass Management-Irrigation SAE | Tyler Hewitt**

- Placement/Internship
  - **Implement Dealership Placement SAE | Keegan Humm**
  - **Agricultural Mechanics SAE | Jeremiah Hager**

For more information on the guiding principles for implementing SAE programs, visit the **SAE for All: Evolving Essentials** site.

Critical Thinking and Application Extensions

Explanation

1. Students will make a presentation to a group of producers about GIS technology.

Application

2. Students will use producer data to make a yield map and prescription.

Perspective

3. Students will explain how precision agriculture contributes to sustainability goals.

Lesson 3.2 Teacher Notes

Lesson 3.2 Precision Applications

In preparation for teaching this lesson, review Concepts, Performance Objectives, Essential Questions, and Key Terms, along with the PowerPoint® presentations. Also, review all activity, project, and problem directions, expectations, and work students will complete.

Students practice using geographic information system software to make field maps with boundaries and soil sample information. Then they interpolate the information to predict a field's fertility and develop a prescription. Finally, students complete the lesson using geographic information to calculate a producer's input costs.

PowerPoints®

Interpolate Maps

Use this presentation to introduce students to using GIS to interpolate data.

Prescription Maps

Students view the presentation before creating a fertilizer prescription for a field.

Videos

Creating Field Boundaries

Students view the video to learn how to make field boundaries.

Creating Soil Samples

The video introduces students to creating soil sampling locations.

Interpolation

Students view this video before completing *Activity 3.2.2 Interpolate Maps*.

Prescriptions

Students view this video before completing *Activity 3.2.3 Interpolate Crop Prescription*.

Activities, Projects, and Problems

Activity 3.2.1 GIS Mapping

Students individually use SMS to create a map with boundaries and soil sample locations.

Teacher Preparation

Students will PC computers with SMS software for this activity. Prepare SMS and example projects by completing the following.

1. Download the SMS software and Training Project from the **Ag Leader® Class Resources**.
2. Install the SMS software on each computer.

3. Open and register the SMS software on each computer by selecting **Help** at the top of the screen and choosing **Register…**
4. Upload the project to each computer by opening SMS, selecting **Services**, and choosing **Backup/Restore Project Options**.
5. Select **Restore Project Data** and navigate the files to find the *Customer Training Project Folder*.
6. Select the **Customer Training Project Folder** and choose **Load** to install the project.
7. You should see example projects in the SMS Management Tree, as seen in Figure 1.

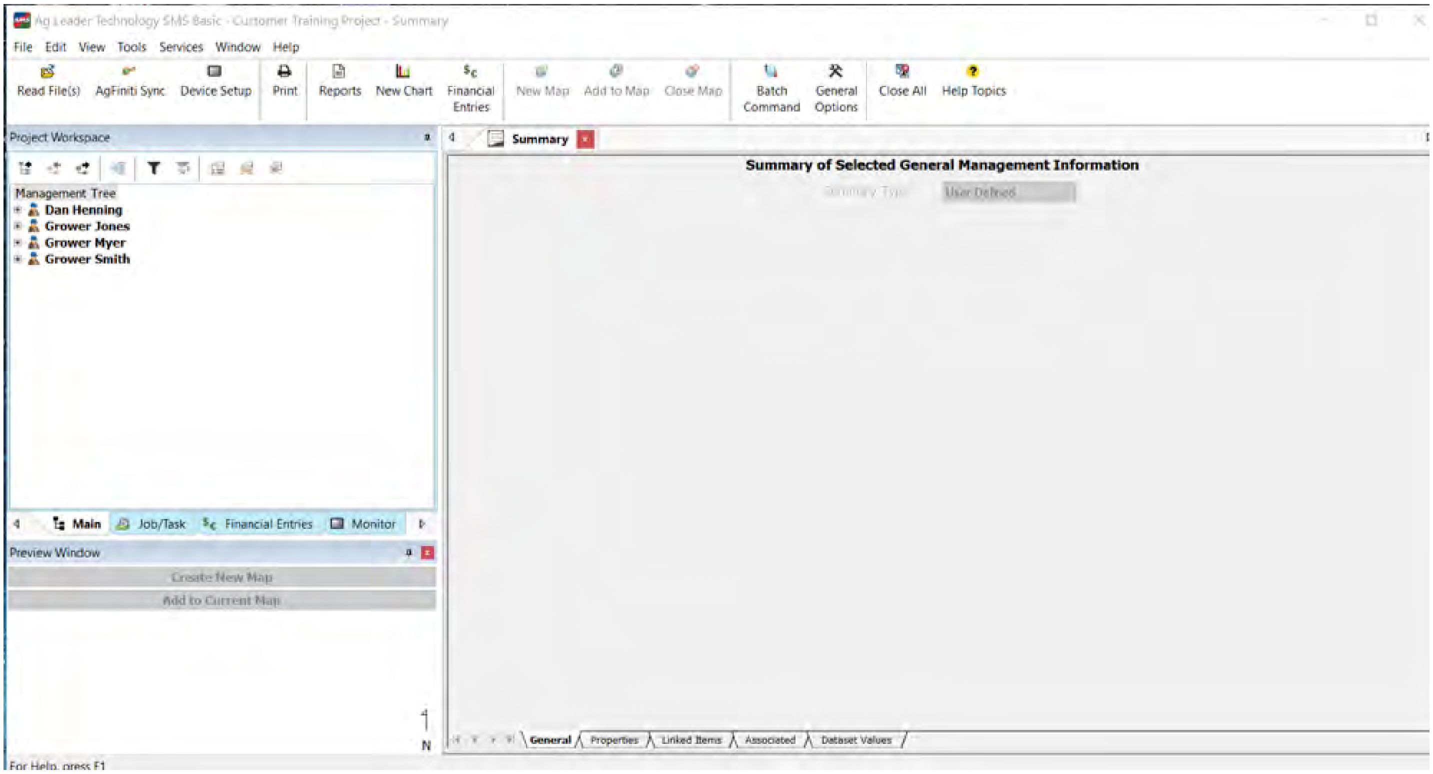


Figure 1. SMS Management Tree

Student Performance

Students view *Creating Field Boundaries* before starting the activity. Next, students locate a field and create a boundary. Then students view *Creating Soil Samples* and make a soil sampling grid for an existing field boundary. Finally, students answer analysis questions as they complete the activity.

Results and Evaluation

Use the answers to analysis questions in Table 1 to assess student understanding of vectors, features, and attributes.

Table 1. *Analysis Questions and Potential Responses*

Q1	What type of vector did you make?	*Polygon*
Q2	What feature does the vector represent?	*A producer's field.*
Q3	What attributes can you use to describe the vector?	*Geographic location, soil fertility, and past production are examples of attributes.*
Q4	What type of vector did you make?	*Point.*
Q5	What feature does the vector represent?	*Soil sampling locations.*
Q6	What attributes can you use to describe the vector?	*pH, fertility, soil texture, and soil moisture are example attributes.*

Activity 3.2.2 Interpolate Mapping

Students learn to use GIS to interpolate data and present information in multiple layers.

Teacher Preparation

Students need PC computers with SMS software for this activity. Present *Interpolate Maps* before starting this activity.

Student Performance

Students use SMS to open a project with soil sampling field data. Next, they interpolate the data to predict the field's potassium level. Then students add a layer to the map to display the potassium level at the specific sampling sites.

Results and Evaluation

Use the answers to analysis questions in Table 2 to assess student understanding of maps, layers, and interpolation.

Table 2. ***Analysis Questions and Potential Responses***

Q1	What type of map does the software display?	*Raster*
Q2	How is the map different from a soil sample grid?	*The map represents fertility throughout the entire field.*
Q3	What are the two layers displayed on the map?	*A raster map and soil sampling grid.*
Q4	How are the two layers different?	*The grid represents specific points, and the raster represents data interpolation.*
Q5	How do the map values compare with the sample sites?	*The values are different from the sample sites. The closer a location is to a sample site, the closer the sample value is to the location value.*
Q6	How could a producer use the interpolated data on this map?	*A producer can determine where to apply potassium fertilizer on the field.*
Q7	What other data would a producer want to interpolate?	*Other fertility data, soil moisture, and pH are other data types to interpolate.*
Q8	What is a production question or query a producer could answer using this map combined with data you recommend interpolating?	*What is the relationship between the field's potassium content and soil moisture?*

Activity 3.2.3 Crop Prescription

Students create a fertilizer prescription for a field.

Teacher Preparation

Students need PC computers with SMS software for this activity. Present *Prescription Maps* before starting this activity.

Student Performance

Students create a map showing the different soil types in a field. Then they develop a seeding rate prescription for the field based on the varying soil types.

Results and Evaluation

Use the answers to analysis questions in Table 3 to assess student understanding of prescription maps.

Table 3. ***Analysis Questions and Potential Responses***

Q1	How is the prescription map different from the interpolated map created during *Activity 3.2.2 Interpolate Maps*?	*Prescription maps use data to determine what to apply to a field, while interpolated data is used to determine the current attributes.*
Q2	What questions could this information answer for a producer?	*How much seed should I plant in the field? What will be the seed costs for the field? Where should I plant the most seed?*

Project 3.2.4 Prescribed Solution

Students use what they have learned about GIS data analysis to make a lime prescription for a field and calculate the application costs.

Teacher Preparation

Students need PC computers with SMS software for this activity.

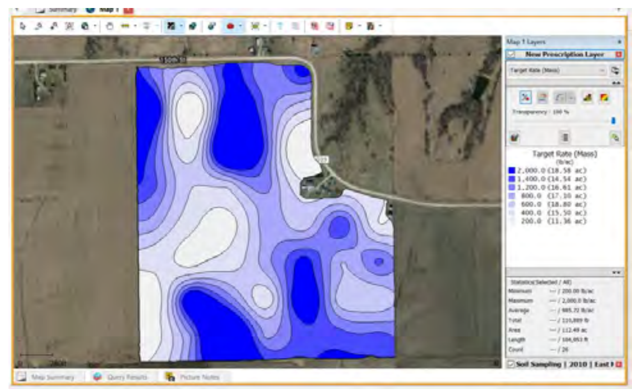
Student Performance

Students work individually, making a plan for applying lime to a field. First, they use SMS to interpolate pH data and prescribe lime. Then students calculate the input costs of spreading the lime on the field.

Results and Evaluation

Assess student projects using **Project 3.2.4 Evaluation Rubric**. An example interpolated pH map and prescription map are in Figure 2.

Interpolated pH Map



Lime Prescription Map

Figure 2. Example Maps

Assessment

Lesson 3.2 Check for Understanding

Lesson 3.2 Check for Understanding is included for you to use as an assessment tool for this lesson. Use **Lesson 3.2 Check for Understanding Answer Key** for evaluation purposes.

Name____

CASE

Activity 3.2.1 GIS Mapping

Purpose

When was the last time you used a paper map or atlas to plan a trip or find a location? You probably use more electronic maps on a computer or phone than paper maps. How are digital maps created?

A digital map is a database of visually displayed information for comparing geographic data. Computer software called GIS, geographic information systems visually display spatial data georeferenced to specific earth locations. Georeferencing aligns geographic data to a known coordinate system to be viewed, queried and analyzed with other geographic data.

Geographic information systems use vectors, features, attributes, and layers to organize and display spatial data. Maps contain three types of vectors called points, lines, and polygons.

- Points represent a single georeferenced coordinate.
- Lines on a map are connected series of coordinates.
- Polygons use connected lines to define specific geographic areas.

Points, lines, and polygons represent real-world objects called features. Features include human-made structures such as roads, buildings, and fences, along with natural objects, including trees, rivers, and lakes. Information about a specific feature has values assigned to it called an attribute. For example, a field’s attributes include its area, soil type, and fertility. Values may be qualitative or quantitative. For example, the area, soil depth, and productivity are quantitative and represented with numbers. The type of crop on the field is qualitative and represented by a written description or name.

GIS displays spatial data in layers for comparison, analysis, and reference. A layer contains features represented by colors and shapes to describe the feature’s attributes. GIS maps have a base layer with multiple layers placed on top representing features. A base layer is a map with physical features a researcher can use for reference when analyzing their data and comparing features.

Collecting GIS data about a farmer’s field often involves collecting soil samples and production data. Soil sample locations would be an example of a feature on a map. Soil pH and fertility are examples of attributes you can measure and display on the map. Farmers can use GIS to compare soil fertility to production data to determine relationships and make a production plan.

How is field information georeferenced in a geographic information system?

Materials

Per student:

- Computer with SMS software
- Pen
- *Agriscience Notebook*

Procedure

Part One – Field Boundary

1. Open the *Customer Training Project* data on the SMS software.
2. Select **Grower Smith** client to expand the menu below it.
3. Select and expand **Home Farm**.
4. Select and expand the **East McMains** field.
5. Select **Boundary** and choose **Create New Map,** as seen in Figure 1.
6. Select the pan tool and pan your screen to the lower right so the field in Figure 2 is in view.
7. Click on the drop arrow next to the New Generic Layer/tool on the toolbar.
8. Select **New Boundary Layer** from the list to open the *Boundary Edit- New Layer* box.
9. Select the **Add Polygon Tool**.
10. Create the boundary by placing your cursor on the corner of the new field and left-clicking.
    - Drag the cursor to another corner and left-click again.
    - Continue this process until you complete the boundary.
    - Right-click to complete the boundary.
11. Create a new field boundry.
    - Choose **Set Field Boundary** in the lower-left corner to open the *Management Selection* box.
    - Complete the management selection box as shown in Figure 3.
    - Select **Add New** for the field name.
    - Name the field *South McMains*.
    - Select **Accept** to return to the *Boundary Edit- New Layer* box.
    - Choose **Save** in the lower-left corner to open the *Save Dataset* box.
    - Set the field name to *South McMains*.
    - Select **OK** to return to the “Boundary Edit-New Layer” box and **Close** in the lower-left corner.
12. View the field boundary in the management tree.
    - Expand *Grower Smith*
    - Expand *Home* to see the fields.
    - Select *South McMains*.
    - Choose **Create New Map**.
13. Answer *Part One Analysis Questions* on *Activity 3.2.1 Student Worksheet*.

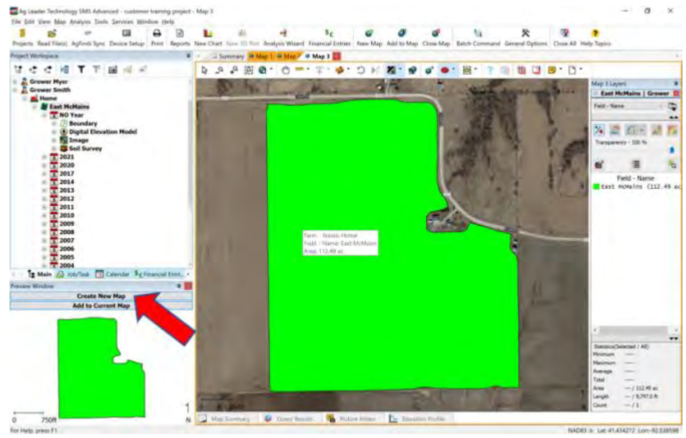


Figure 1. Create New Map

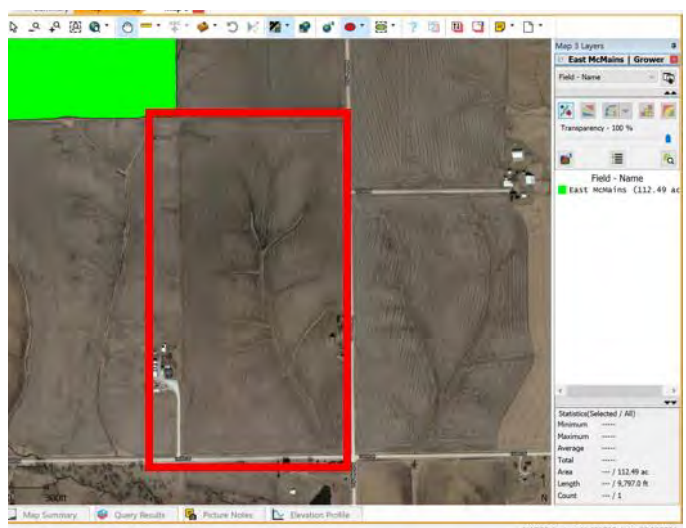


Figure 2. New Field

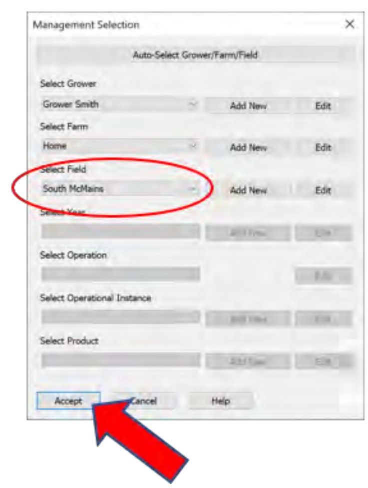


Figure 3. Management Selection

Part Two – Soil Samples

1. Open your customer training project data created in Part One.
2. Select **Grower Smith** client to expand the menu.
3. Select and expand **Home Farm**.
4. Choose **East McMains** field and **Create New Map**
5. Find the *Transparency* setting at the far right of the screen and change it to *30 percent*.
6. Select the drop arrow next to the New Generic Layer/tool on the map tools toolbar, choose **Soil Sampling Layer**, and open the *Select Data Creation Method* box.
7. Choose **Use a Wizard Tool to Create New Data** and select **OK,** as seen in Figure 4.
8. Select **Next** in the *Select Layer* box to open the *Select Layer Objects* box.
9. Select **Next** to open the *Sampling Parameters* box.
10. Set the parameters to the example shown in Figure 5 and select next.
    - The *Sampling Preview* box will open.

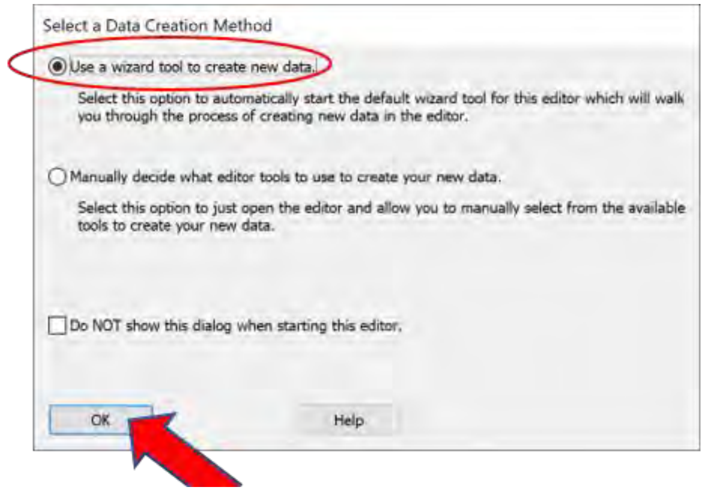


Figure 4. Wizard Tool

Figure 5. Parameters

11. Choose the **Shift Grid**/tool and align the grid with the southwest corner of the boundary, as shown in Figure 6 by left-clicking and holding on the grid and sliding it into position.
12. Select **Finish** to open the *Soil Sampling Editor-New Layer* box.
    - Use the default locations for the sampling points.
13. Select **Save** in the lower-left corner to open the **Save Dataset** box.
14. Use all of the defaults as shown in Figure 7 and select **OK** to return to the *Soil Sampling Editor-New Layer* box.
15. Close the box by selecting **Close** in the lower left-hand corner.

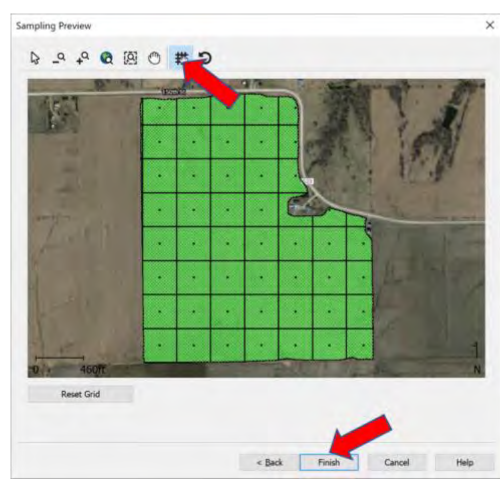


Figure 6. Grid Alignment

16. Practice viewing the new data set in the management tree.
    - Expand Grower Smith
    - Expand Home to see the fields.
    - Select *South McMains*.
    - Expand *East McMains* field.
    - Expand 2021 (or the year they created)
    - Expand *Soil Sampling*.
    - Select the soil sampling data set.
    - Click **Create New Map**
17. Answer the *Part Two Analysis Questions* on the student worksheet.

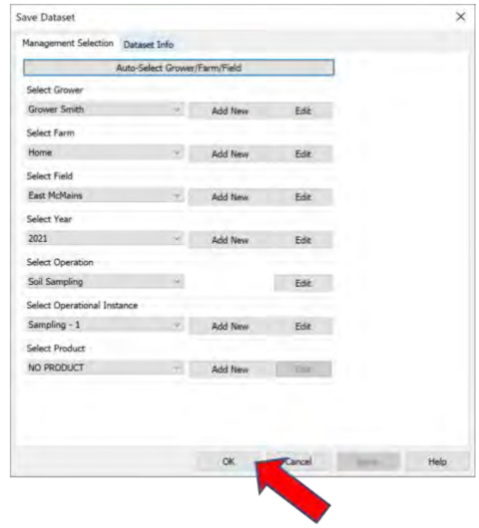


Figure 7. Defaults

Conclusion

1. After identifying soil sampling locations, what would be the next step for a producer?

2. What attributes would a producer want to know about each soil sample to make production decisions?

3. How would agriculture equipment with GPS use the field boundary information?

Name____

Activity 3.2.1 Student Worksheet

Part One Analysis Questions

Q1 What type of vector did you make?

Q2 What feature does the vector represent?

Q3 What attributes can you use to describe the vector?

Part Two Analysis Questions

Q4 What type of vectors did you make?

Q5 What feature do the vectors represent?

Q6 What attributes can you use to describe the vector?

Name____

CASE

Activity 3.2.2 Interpolate Mapping

Purpose

Precision agriculture combines global positioning systems (GPS) and geographic information systems (GIS) to improve profitability. A farmer with a field covering hundreds of acres faces challenges collecting and analyzing production data about their land. Once a producer has collected data about their field, they will use the data to increase production or reduce input costs. How is data analyzed to make production decisions?

Producers begin the analysis process by sampling soil from the field. Vectors represent the data points in the field, which are individual points. Even though producers collect data in a limited number of locations, they can use that data to find information about the entire field by displaying it on a map in the form of rasters or contours. Rasters and contours are areas with values predicted from known data points. The process of predicting unknown data areas is called interpolation. Interpolation estimates data point values by using measurable values at specific coordinates. Geographic information systems calculate interpolated maps displaying values for all data points shown in a layer. Producers use the data in layers to visually display variations in a field.

Once a person uses GIS to interpolate data points, they can answer productivity questions by calculating selected attributes about specific features. For example, if a producer wanted to know the relationship between a field's crop production and soil type, a query could summarize yield data by soil type. A farmer could use that query to determine how to treat different soil types in the field to increase productivity.

Soil fertility is an attribute that a producer can interpolate and summarize to manage their crop. Nitrogen, if appropriately applied, can increase crop productivity. However, variations in soil fertility can cause a farmer to over-fertilize some areas of a field. Over-fertilization leads to a loss in profitability, decreased efficiency, and waste. A field needs the right combination of fertilizer in precise locations to maximize productivity. Once a farmer has analyzed GIS fertility maps, they can find that combination.

Materials

Per student:

- Computer with SMS software
- Pen
- *Agriscience Notebook*

Procedure

Work individually to interpolate fertility data collected at specific locations in a field.

1. Open the SMS software.
2. Open and expand **Grower Smith** in the management tree.
3. Expand the **Home Farm**.
4. Expand **East McMains**.
5. Expand **2010 year**, scroll down, expand **Soil Sampling** data, and select that last set of data.

6. Choose **Create New Map** to map soil test data as seen in Figure 1.
    - Note that the attribute defaults to soil organic matter
7. Change the attribute to *Soil K* and select the Map format **Grid Button** as seen in Figure 2.
8. Answer *Step 8 Analysis Questions* on *Activity 3.2.2 Student Worksheet*.
9. At the left side below the map preview, select **Add to Current Map,** as seen in Figure 3.
10. Change the attribute for this layer to Soil K to show the potassium content of the soil.

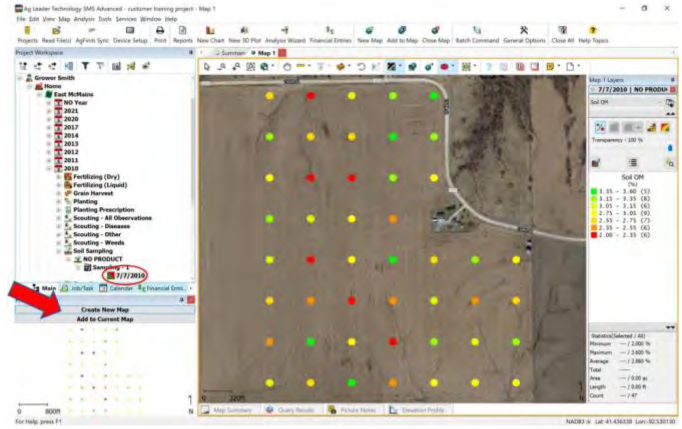


Figure 1. Sampling Grid

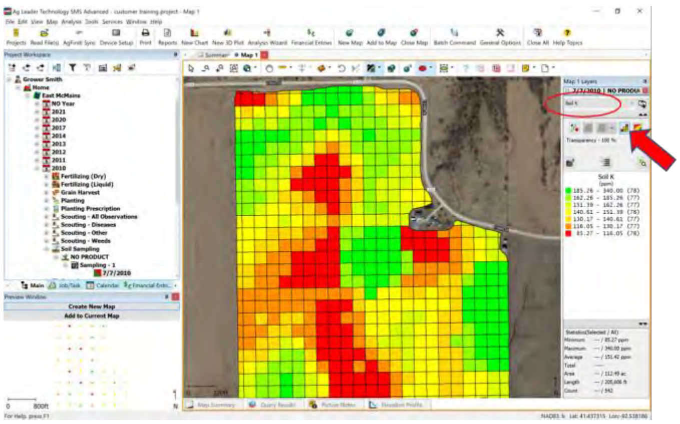


Figure 2. Attribute Selection

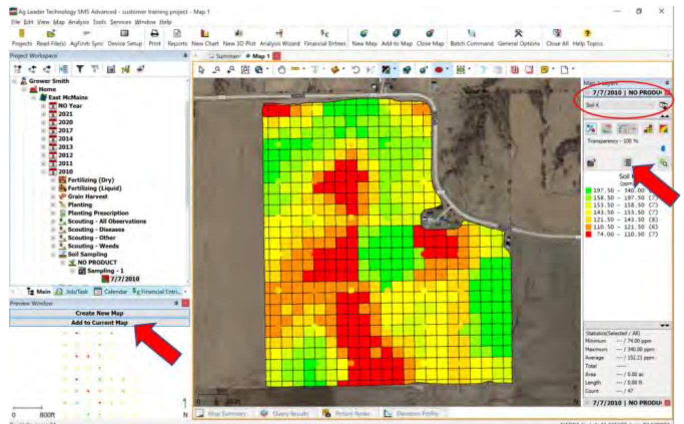


Figure 3. Attribute Values

11. Click the edit legend button and set the number of ranges to 1 and blue color
    - Change the color by double-clicking in the color box.
    - Use Figure 4 for reference.
12. **Apply** your new settings.
13. Select **OK**.
14. Answer *Step 14 Analysis Questions.*
15. Select the **Edit Layers Options** button, as seen in Figure 5.
16. Complete the layering properties as shown in Figure 6.
    - Select **Label Selection**.
    - Place a checkmark in show labels for base and swath maps.
    - Select **Change**.

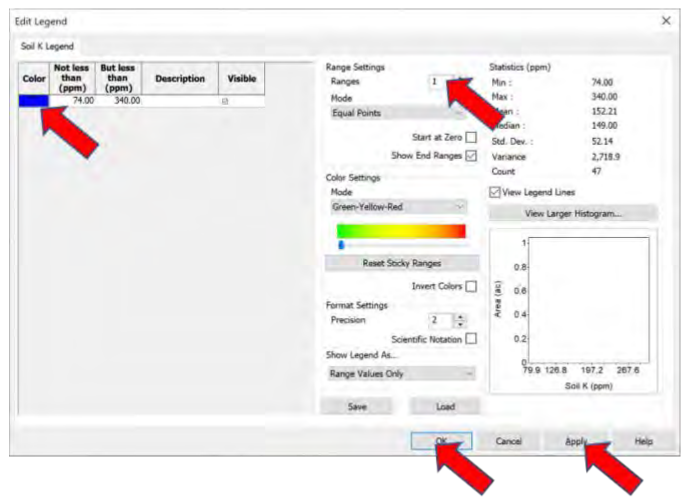


Figure 4. Legend Settings

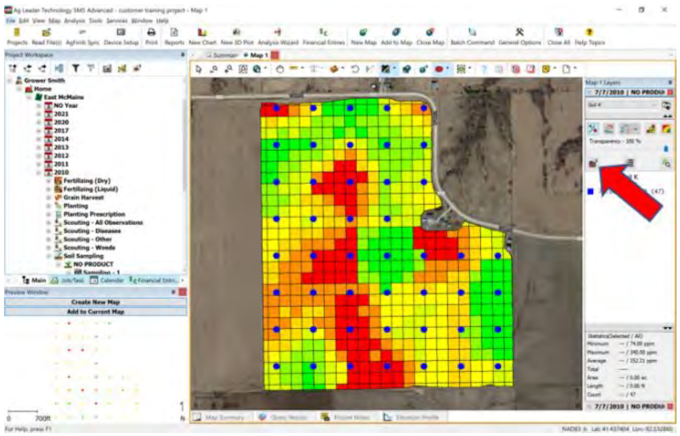


Figure 5. Interpolate and Sample Layers

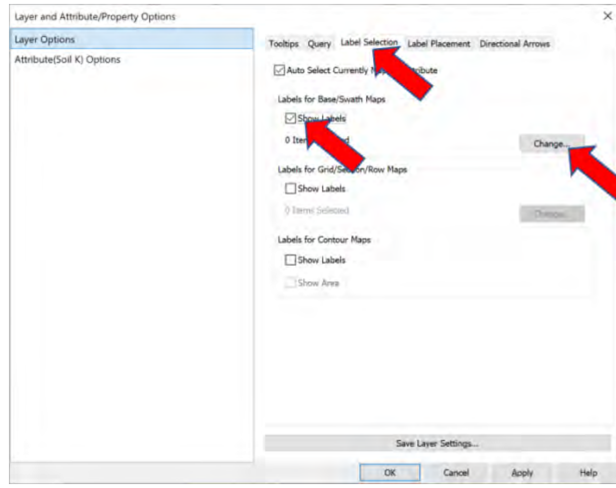


Figure 6. Layer Properties

17. Complete the item selection as shown in Figure 7.
    - Choose **Soil K** from the attribute list.
    - Select **Add** to add Soil K to the *Selected Items*.
    - Select **OK**.
18. Complete the labels as shown in Figure 8.
    - Select the **Label Placement** tab.
    - Under *Background Style*. Make sure the circled options are selected.
    - Select **Apply** and **OK**.
19. Answer *Step 19 Analysis Questions*.

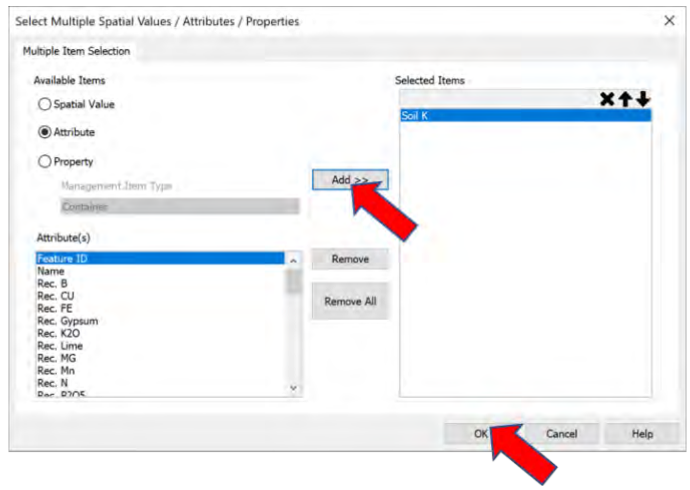


Figure 7. Item Selection

Conclusion

1. How could you use interpolated data to calibrate agricultural equipment?

2. How is interpolated data different from a set of data points?

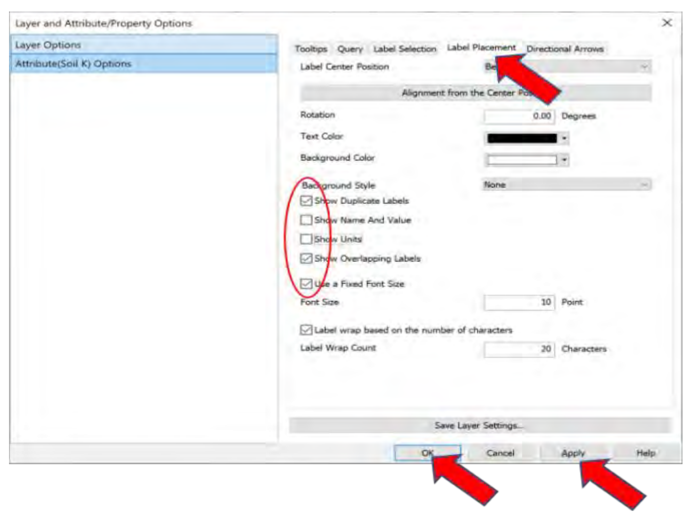


Figure 8. Labels

Name____

Activity 3.2.2 Student Worksheet

Step 8 Analysis Questions

Q1 What type of map does the software display?

Q2 How is the map different from a soil sample grid?

Step 14 Analysis Questions

Q3 What are the two layers displayed on the map?

Q4 How are the two layers different?

Step 19 Analysis Questions

Q5 How do the map values compare with the sample sites?

Q6 How could a producer use the interpolated data on this map?

Q7 What other data would a producer want to interpolate?

Q8 What is a production question or query a producer could answer using this map combined with data you recommend interpolating?

Name____

CASE

Activity 3.2.3 Crop Prescription

Purpose

After collecting field information, producers use the data to develop a production plan. That plan will include a prescribed planting rate for a planter. Planters with precision agriculture components use field data to plant seeds at an optimum rate to increase farmers' productivity while reducing costs. How does a farmer make a prescription for their equipment to follow?

A producer can assign a planting rate, measured in seeds per acre, to a field using an assigned rate to legend prescription. A typical seeding rate for corn will vary between 30,000 and 40,000 seeds. Higher producing areas have a higher seeding rate, while lower producing areas have a lower seeding rate. A typical rate to legend prescription assigns a seeding rate to different soil types mapped in a field. If a producer knows the attributes of a specific soil type, such as texture, pH, moisture, and fertility, they can assign a seeding rate to optimize production for each soil type found in a field.

How will you use GIS software to prescribe a seeding rate for a crop?

Materials

Per student:

- Computer with SMS software
- Pen
- *Agriscience Notebook*

Procedure

Work individually to complete a prescription using the assigning rates to legend method based upon soil types.

1. Open the customer training project data in the pop-up window.
2. Click **Grower Smith** to expand the menu.
3. Expand **Home Farm**.
4. Expand **East McMains field**.
5. Expand **No Year**.
6. Expand **Soil survey**.
7. Choose the soil survey dataset as seen in Figure 1.
    - The actual name/date may be different depending on when the soil survey data was initially downloaded.
8. Select **Create New Map**.

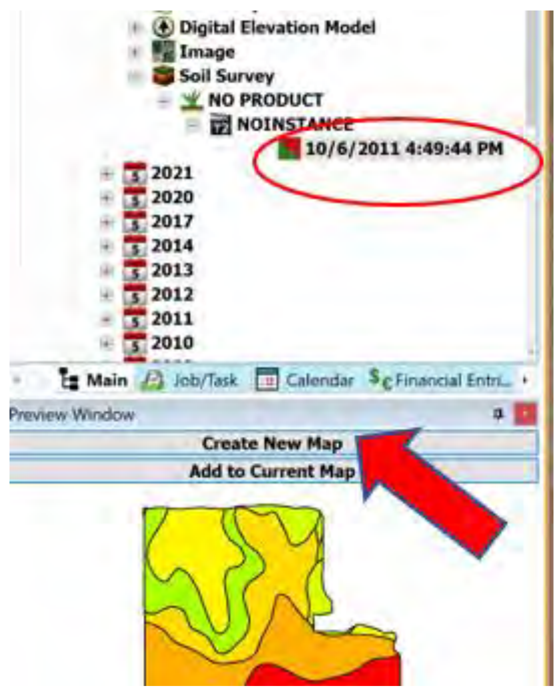


Figure 1. Create New Map

9. Select the drop arrow next to the *New Generic Layer* tool on the toolbar, as seen in Figure 2.
10. Choose **New Prescription Layer** from the list to open the *Prescription Reference Layer Selection* box.
11. Select **Next,** and the *Prescription Settings* dialog box will open.
12. Set the three options as indicated in Figure 3 below.
13. Enter the values for the rates you want to apply in the *target rates box*, as seen in figure 4 below.
    - ksds=1000seeds/per acre.
    - You are just entering values to create a prescription for this exercise. These values may not be the optimum rates for these soil types. Much research goes into determining the best rates when making variable rate applications.

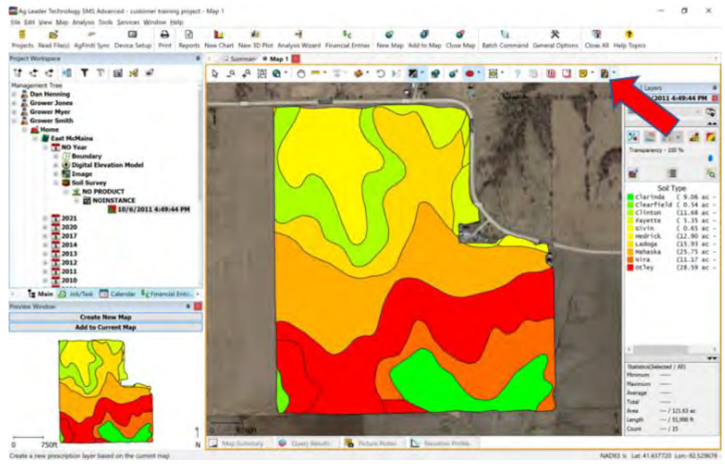


Figure 2. New Generic Layer

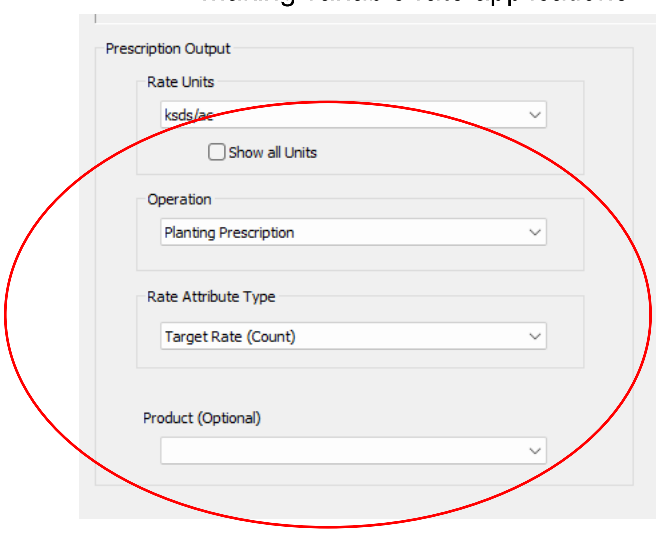
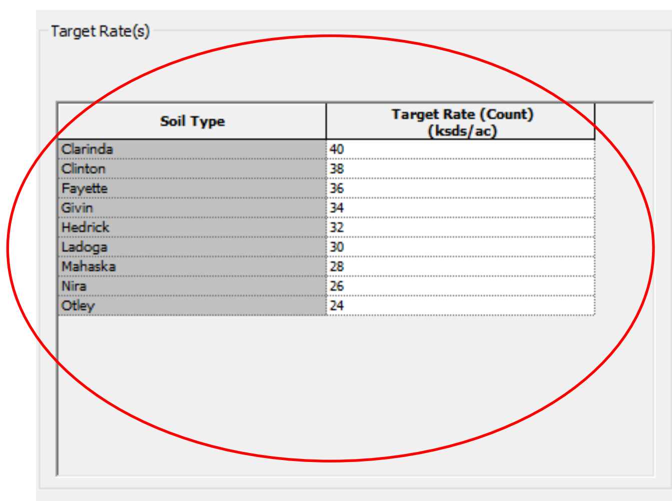


Figure 3. Prescription Outputs



Target Rate(s)

Soil Type	Target Rate (Count) (ksds/ac)
Clarinda	40
Clinton	38
Fayette	36
Givin	34
Hedrick	32
Ladoga	30
Mahaska	28
Nira	26
Otley	24

Figure 4. Target Rates

14. Select **Finish** to open the *Prescription Editor* box and choose **Save**.
    - A *Save Dataset* box will appear on the screen.
15. Set the product to **CORN** and select **OK,** as seen in Figure 5, to close the *Save Dataset* box.
16. **Close** the *Prescription Editor* box.

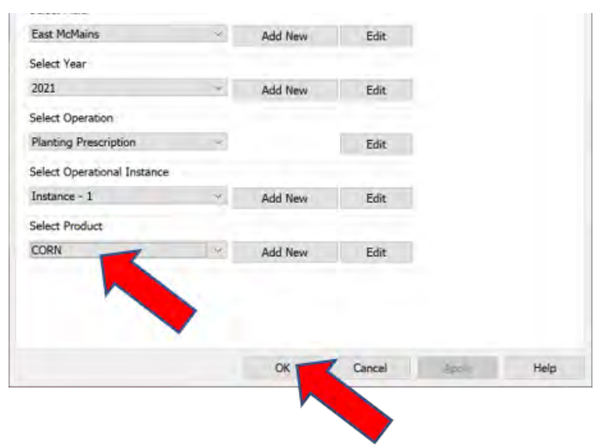


Figure 5. Assigned Crop

17. Open the prescription to review and analyze.
    - Expand *2022* in the management tree (or the year created).
    - Expand *Planting Prescription*.
    - Select the **Planting Prescription** data set.
    - Select **Create New Map**.
18. Answer *Analysis Questions* on the *Activity 3.2.3 Student Worksheet*.

Conclusion

1. How will a producer use the map to calibrate equipment with global position systems?

2. How could a prescribed seeding rate save producer input costs?

3. What prescription types are more accurate than the assigned rate to legend? Why?

4. What information would you need for a different type of prescription method?

Name____

Activity 3.2.3 Student Worksheet

Analysis Questions

Q1 How is the prescription map different from the interpolated map created during *Activity 3.2.2 Interpolate Maps*?

Q2 What questions could this information answer for a producer?

Name____

CASE

Project 3.2.4 Prescribed Solution

Purpose

Owning a farm requires a person to be mindful of equipment, management costs, and operating machines. Farmers spend just as much time planning how to use equipment as they do operating their equipment. So how does a producer determine input costs for managing the land and equipment for their business?

Developing a plan for using equipment and calculating input costs involves a combination of GPS, GIS, and guidance system planning. Farmers consider several factors before deciding how to calibrate and use the equipment to treat a field. First, soil scientists analyze the soil where the crop will grow. Once soil data is received, the data is georeferenced and analyzed using GIS similar to *Activity 3.2.2 Interpolate Mapping* and *Activity 3.2.3 Crop Prescription*. Then, when a producer has the needed information, they can determine the input costs for following the plan. Those costs include the fuel and labor as calculated during *Project 3.1.5 Cost Savings*.

In addition to the input cost of fuel, farmers consider fertilizer and lime costs. Farmers broadcast lime on fields to increase a soil's pH. A correct soil pH is essential for maximizing crop production. Lime applications on a field are measured in pounds per acre and purchased by the ton. One ton equals 2000 lbs. Each type of crop requires a different soil pH. Therefore, the lime application rate depends on the current soil pH and how much the pH needs to be raised.

How will you use GIS to manage field equipment and pH input costs?

Materials

Per student:

- Calculator
- Computer with word processing software
- Pen
- SMS account
- *Agriscience Notebook*
- *Logbook*

Procedure

Work individually to develop a production plan for applying lime to a field. Record all data, calculations, and procedures used for developing the plan in your *Logbook*. Then type an application plan including GIS maps and an input cost analysis.

Scenario
Grower Smith needs to determine the liming costs of the same field analyzed during *Activity 3.2.3 Crop Prescription*. The farmer plans to grow corn, which requires a 6.5 soil pH. Spatial data viewed during *Activity 3.2.3 Crop Prescription* includes pH data for the soil. Analyze the pH data using GIS to determine the liming needs of the field.

Table 1 shows the liming requirements of a field based on soil pH. The broadcaster spreading the lime has a broadcast width of 40 feet. The farmer uses a guidance system to reduce his overlap to 1 foot. Calculate the input costs for lime, fuel, and labor for the field based on the costs shown in Table 2. Fuel usage for a tractor pulling the broadcaster is 5 gallons per hour while traveling at 10 miles per hour.

Once you have completed your analysis and calculations, submit a typed final plan and *Logbook.* Include all *Production Plan Criteria.* Your teacher will acess your project using *Project 3.2.4 Evaluation Rubric*.

- Interpolated pH and prescription maps
- Summarized pH and lime application data
- Lime, fuel, and labor costs for the field

Table 1. ***Liming Requirements***

pH	Lime to maintain 6.5 pH (lbs/acre)
7.0	0
6.9	0
6.8	200
6.6	700
6.5	900
6.4	1200
6.3	1400
6.2	1700
6.1	1900
6.0	2200
5.9	2400
5.8	2600
5.7	2900

Table 2. ***Input Costs***

Input	Units	Cost per Unit
Lime	Ton	$8.00
Fuel	Gallon	$2.50
Labor	Hour	$15.00

Conclusion

1. When using mechanical equipment to manage and produce an agricultural crop, what information does a farmer need?

2. How are GIS and GPS used together to increase a farmer’s efficiency?

3. What other information should a farmer analyze to determine costs?

Name____

CASE

Project 3.2.4 Evaluation Rubric

Areas with Room for Improvement	Criteria	Areas that Meet or Exceed Expectations
	GIS Maps Two GIS maps, one for pH and one for lime application, include the following. • Interpolated data • Field boundaries • Labeled locations of samples • Legend	
	Georeferenced Data Tables Data tables provide pH ranges, lime amounts, and total acreage.	
	Input Data Tables Input data tables for fuel, lime, and labor costs are 100% complete.	
	Logbook The *Logbook* is organized and contains all sketches, calculations, formulas, and procedures for developing the application plan.	

Name____ CASE

Lesson 3.2 Check for Understanding

1. What are three examples of features you can display on a GIS map?

2. Select one of the features recorded above and list three attributes you could use to describe the feature?

3. What types of GIS data can help a farmer make production decisions?

4. How can GIS and GPS technologies improve agricultural production?

5. How does a variable rate application system reduce a producer's cost?

6. Which of the following is an example of a polygon on a GIS map?
   a) Field boundary
   b) Soil sample
   c) Track line
   d) Rock location

7. Match the following GIS terms and definitions.

______	Attribute	A.	A closed plane figure having three or more straight sides.
______	Vector	B.	A representation of a real-world object on a map.
______	Polygon	C.	A characteristic of a location in a geographic information system (GIS).
______	Layer	D.	A thematic set of spatial data described and stored in a digital database or map library.
______	Point	E.	A specific location represented by latitude and longitude coordinates.
______	Feature	F.	A coordinate-based data structure commonly used to represent geographic features.

8. What are four examples of GIS data a producer would need to make a prescription?

Name____ CASE

Lesson 3.2 Check for Understanding Answer Key

1. What are three examples of features you can display on a GIS map?

Answers will vary but may include:
Roads, trees, soil samples, buildings

2. Select one of the features recorded above and list three attributes you could use to describe the feature?

Feature: soil sample
Example attributes: fertility, soil texture, pH

3. What types of GIS data can help a farmer make production decisions?

Answers will vary but may include:
Yield, fertility, soil moisture, soil type, topography, weeds

4. How can GIS and GPS technologies improve agricultural production?

Farmers can use GIS and GPS to identify where their fields need inputs such as fertilizer, lime, and herbicides. By knowing the specific needs of a location, farmers can reduce their inputs and increase production efficiencies.

5. How does a variable rate application system reduce a producer's cost?

Variable-rate applications allow a producer to apply lime, fertilizer, spray, and seed inputs to specific field locations and not as a general broadcast.

6. Which of the following is an example of a polygon on a GIS map?

a) **Field boundary**
b) Soil sample
c) Track line
d) Rock location

7. Match the following GIS terms and definitions.

C	Attribute	A.	A closed plane figure having three or more straight sides.
F	Vector	B.	A representation of a real-world object on a map.
A	Polygon	C.	A characteristic of a location in a geographic information system (GIS).
D	Layer	D.	A thematic set of spatial data described and stored in a digital database or map library.
E	Point	E.	A specific location represented by latitude and longitude coordinates.
B	Feature	F.	A coordinate-based data structure commonly used to represent geographic features.

8. What are four examples of GIS data a producer would need to make a prescription?

Field boundary
Soil fertility
Past production data
Soil moisture
Soil pH
Soil texture
Past crops

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Curriculum for Agricultural Science Education

Agricultural Equipment Maintenance and Technology

Interpolate Maps

Unit 3 – Lesson 3.2 Precision Applications

What is interpolation?

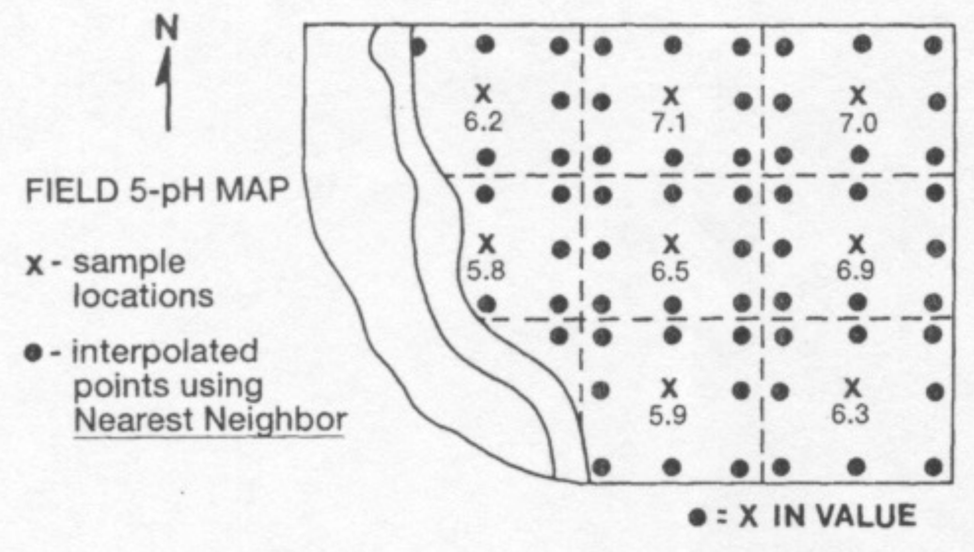
A mathematical process of using known values to determine unknown values.

Type of Interpolation

- Nearest Neighbor
- Local Average
- Inverse Distance Weighting
- Kriging

Nearest Neighbor

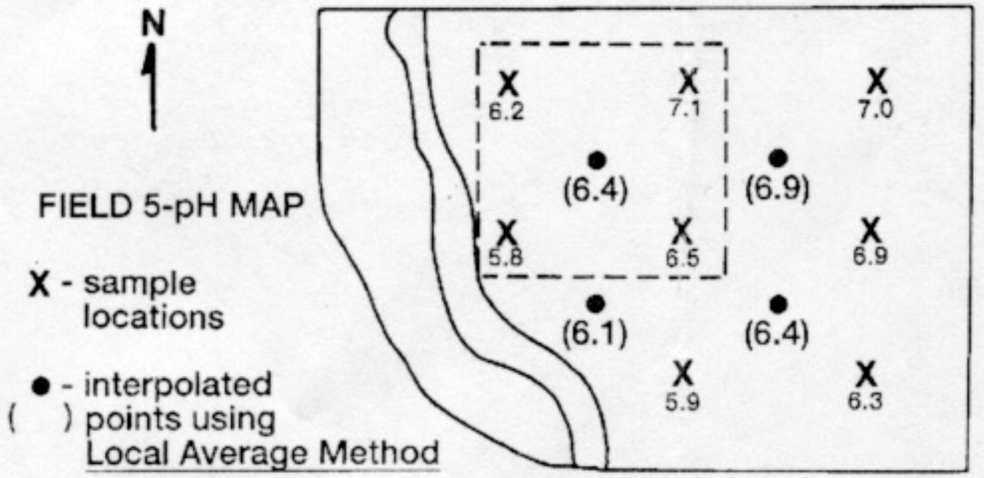
- Simplest method.
- Closest sample to the unknown location is used as an estimate.
- The unknown value is set equal to its nearest neighbor.



Grid points interpolated using the nearest neighbor method

Local Average

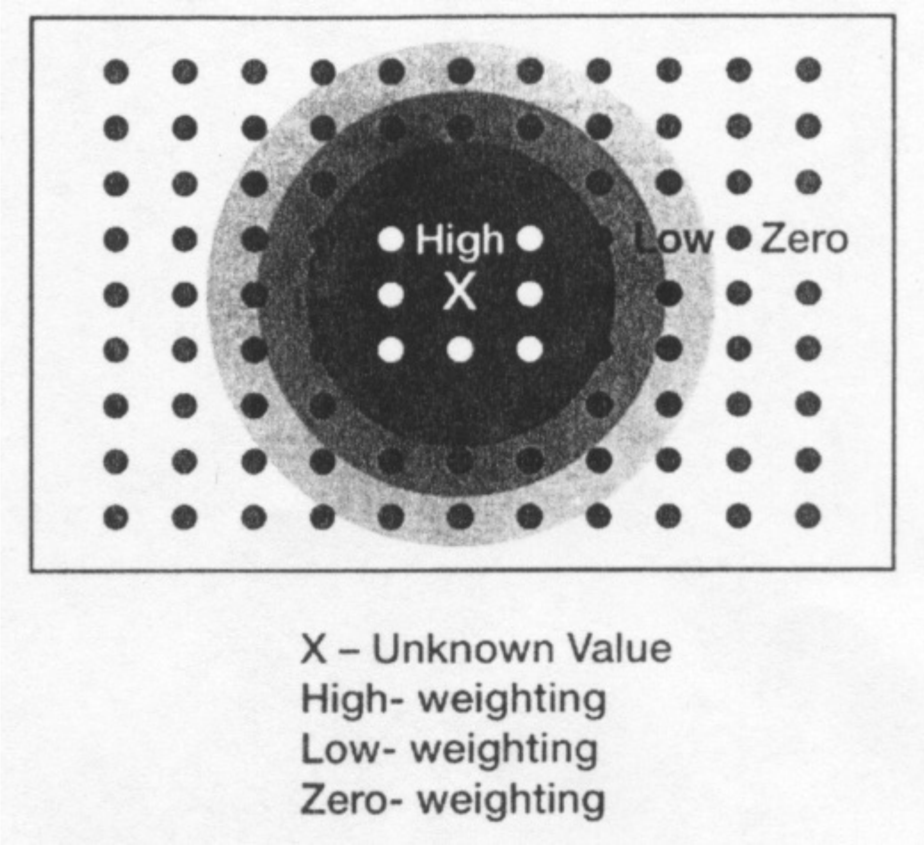
- Estimates the unknown values by averaging a selected number of points around a desired location.
- Either a fixed number of neighboring points or all known points within a fixed area are averaged.
- Using more samples will produce a smoother transition between points.



Grid points interpolated using the local average method. Four points averaged to estimate the value of 6.4 in their center

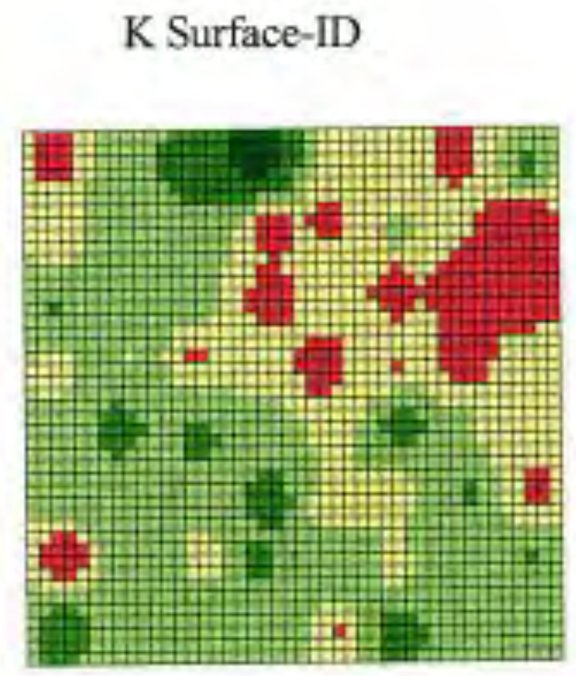
Inverse Distance Weighting

- Similar to local average.
- Samples closer to the unsampled location have more influence on estimate than samples further away.
- Assumes unknown point is more likely to have a value similar to points closer to it.
- Points close to the unknown are weighted heavier when averaged.



Inverse Distance Weighting

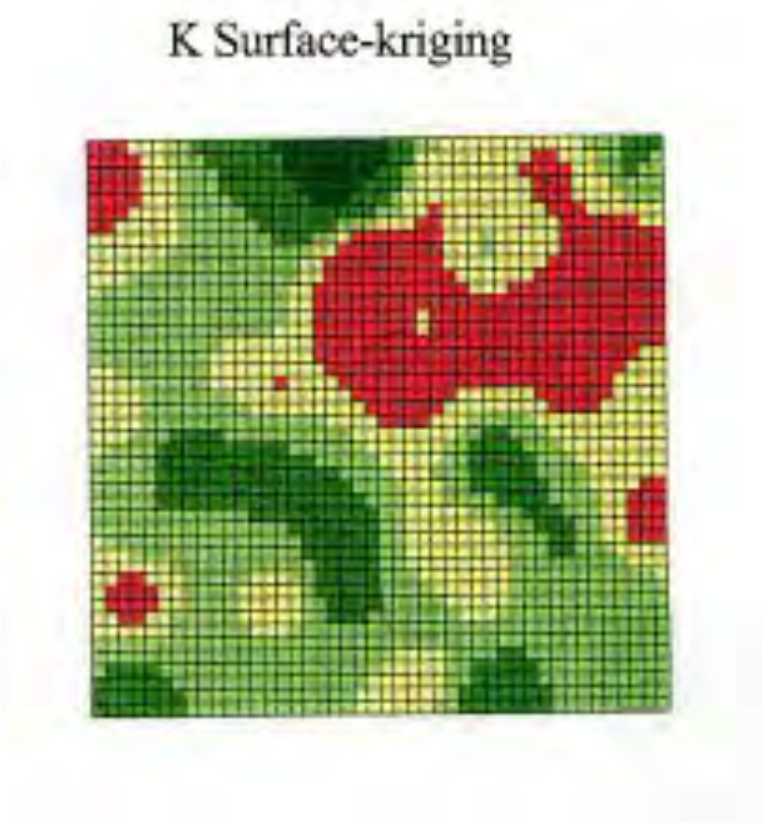
- Specify a distance where the weighting goes to zero.
- Only points closer than this distance influence the value at the interpolation point.



Kriging

- Most complex
- Very good interpolation when enough data is collected
- Follows two basic steps:
  1. Estimate is made of variability existing in the raw data
  2. Interpolation performed using basic principles as simpler methods

If you don’t have enough data, use a simpler method



Presentation Review

- Mark or highlight three key points
- List two ideas or concepts related to previous knowledge.
- List questions you have about this topic.
- Keep notes organized and available for use throughout the course.

References

- Brase, Terry. (2006). *Precision Agriculture*. Clifton, NY: Thomson Delmar Learning.
- Ess, Dan. (2003). *Precision Farming Guide for Agriculturalists*. Madison, WI: Deere and Company.

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Curriculum for Agricultural Science Education

Agricultural Equipment Maintenance and Technology

Prescription Maps

Unit 3 – Lesson 3.2 Precision Applications

What is prescription agriculture?

- Algorithms, equations or instructions given to a control module to vary the rate of an actuator.
- A set of instructions can be given to a controller to vary the seed population according to different soil types within a field.

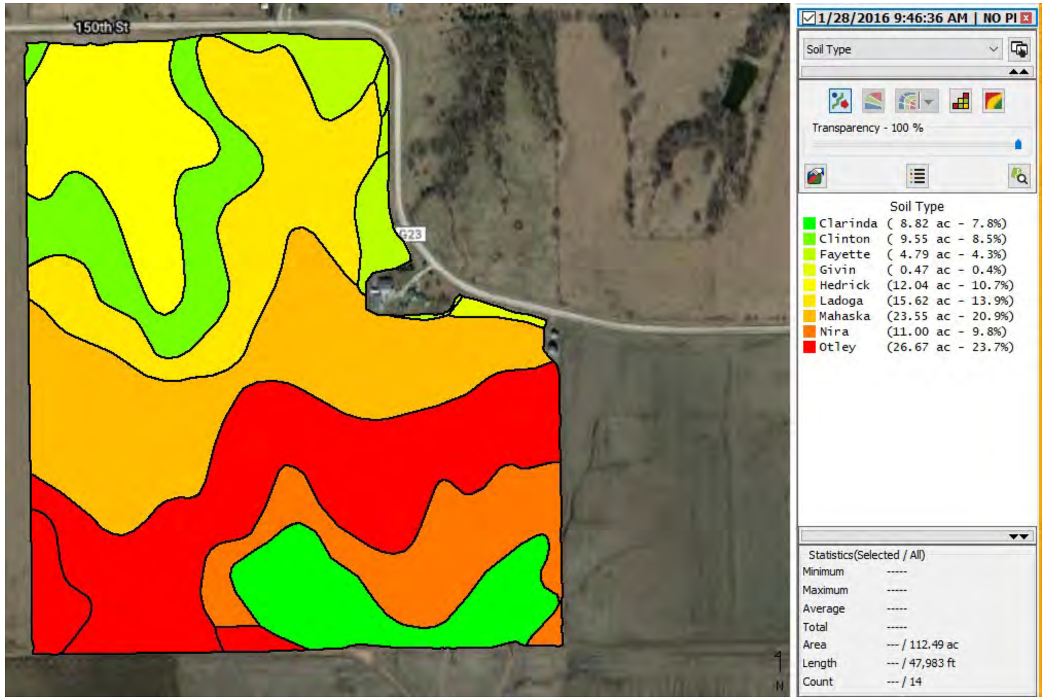
Types of Prescriptions

All prescriptions should be based off of sound agronomic principles.

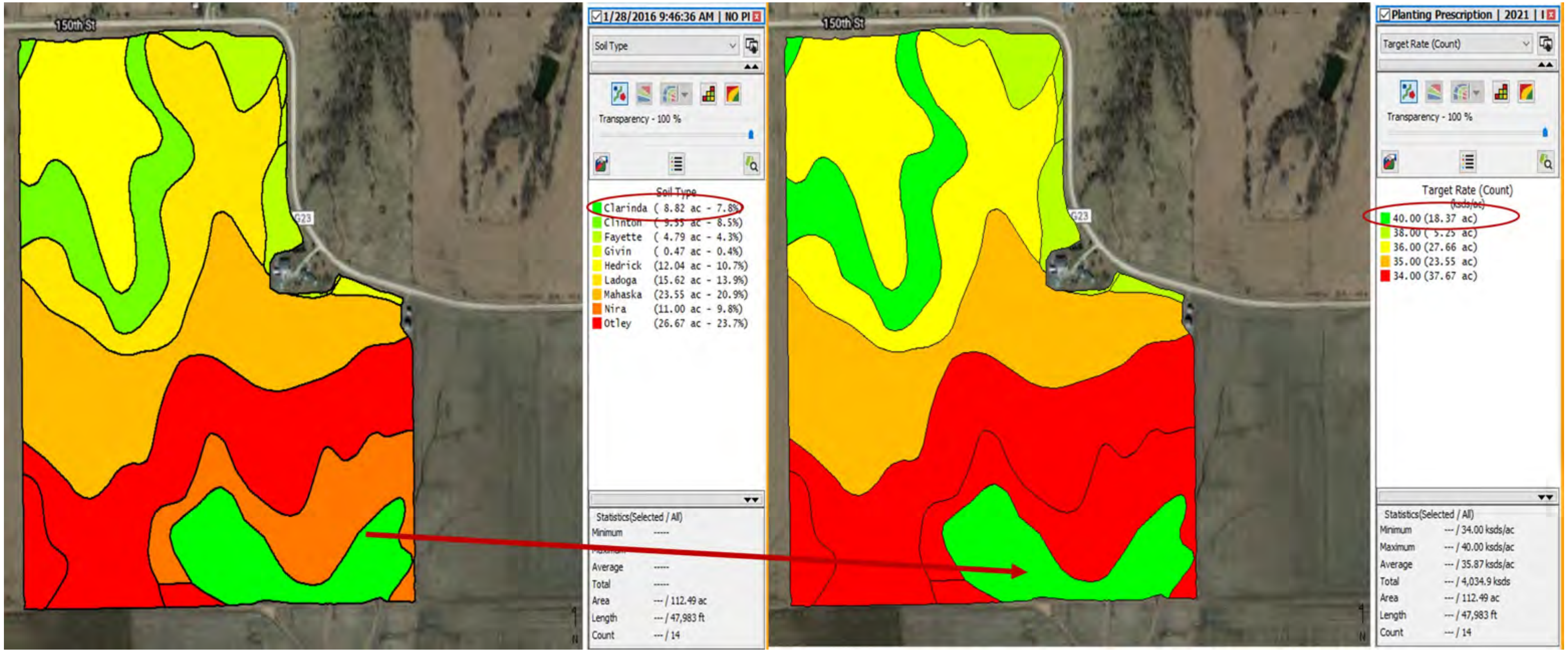
1. Assign rates to GIS legends
2. Stair step prescriptions
3. Linear equation prescriptions

Assign rate to legends

- Simplest method.
- Each attribute or combination of attributes in the legend is given a value.
- Interpolation may not be necessary.
- May not be the Agronomically best solution.
- Example
  - Soil type “Clarinda” could be given a specific seeding rate.



Assign Rates Example



The soil type “Clarinda” was given a planting rate of 40,000 seeds per acre

Stair Step Prescription

- Specific flat rates of product.
- Number of steps depends on input data.
- Interpolation will be necessary.
- Consist of If-Then statements
- Example:
  - Soil categories of very low to high are used to create a variable fertilizer rate prescription

Table 11. Broadcast (Bdcst) and band potash guidelines for corn production in Minnesota.*										
	Soil test K (ppm)									
	Very Low		Low		Medium		High		Very High	
Expected	0-50		51-100		101-150		151-200		200+	
Yield	Bdcst	Band	Bdcst	Band	Bdcst	Band	Bdcst	Band	Bdcst	Band

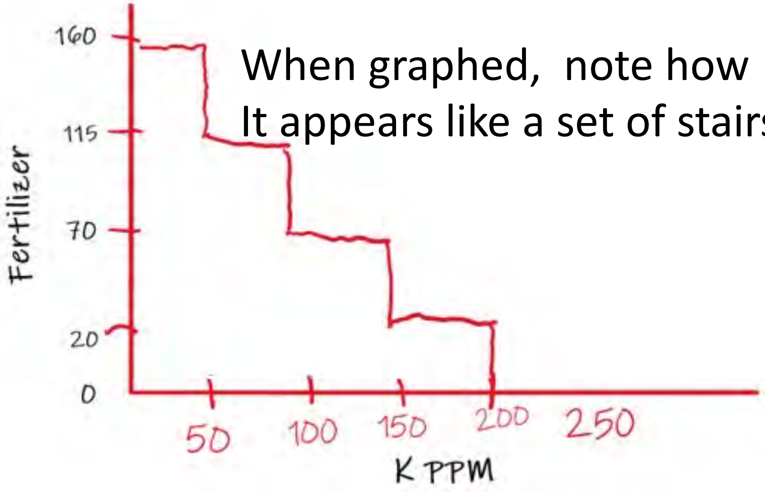
Example Stair Step Prescription

Table 11. Broadcast (Bdcst) and band potash guidelines for corn production in Minnesota.*										
	Soil test K (ppm)									
	Very Low		Low		Medium		High		Very High	
Expected	0-50		51-100		101-150		151-200		200+	
Yield	Bdcst	Band	Bdcst	Band	Bdcst	Band	Bdcst	Band	Bdcst	Band
bu/acre	K$_2$O per acre to apply (lbs per acre)									
151 – 175	160	75	115	60	70	45	20	10-15	0	10-15
176 – 200	185	90	135	70	80	50	25	10-15	0	10-15
201 – 225	210	105	155	80	90	55	30	10-15	0	10-15
226 -250	235	120	165	85	100	60	35	10-15	0	10-15
250 +	255	130	180	90	110	65	40	15-20	0	10-15

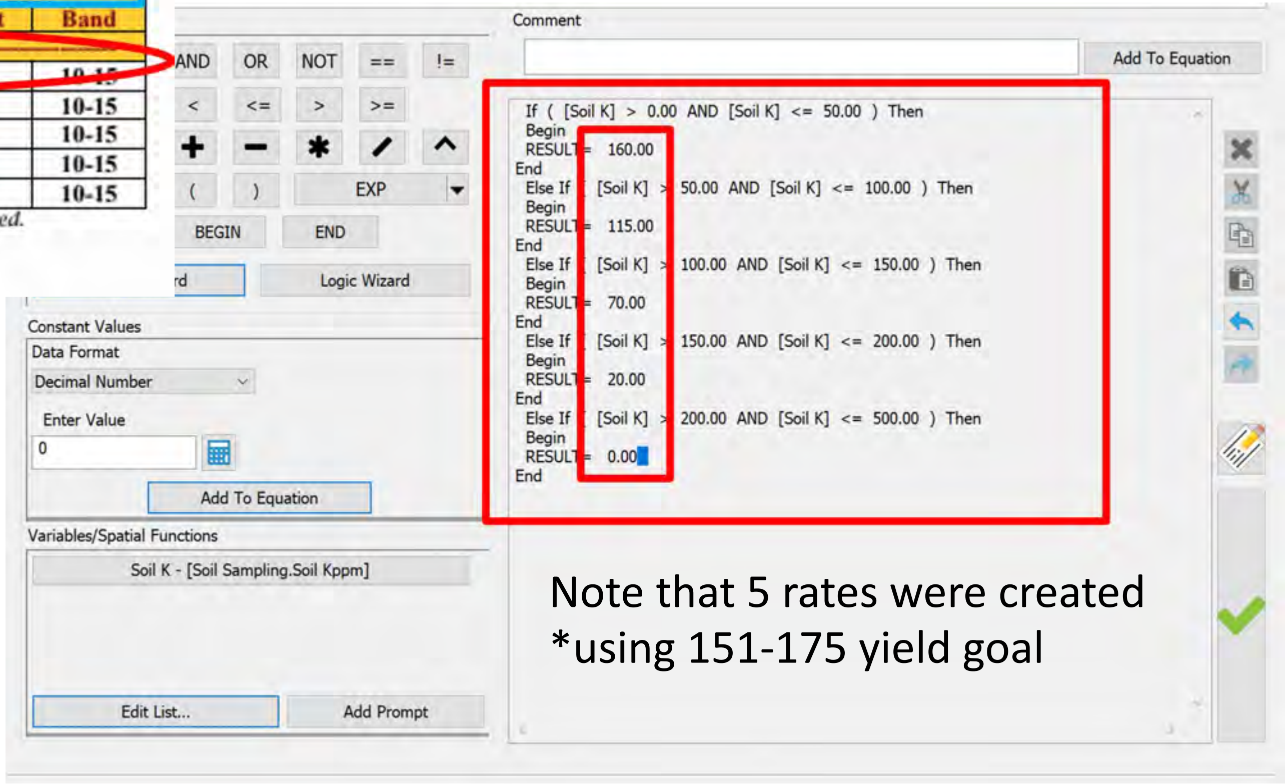
* *Use one of the following equations if a K$_2$O guideline for a specific soil test value and a specific expected yield is desired.*

$K_2O_{suggested}$ = [1.12 - 0.0056 (Soil Test K, ppm)] (expected yield)

No potash fertilizer is suggested if the soil test for K is 200 ppm or greater.



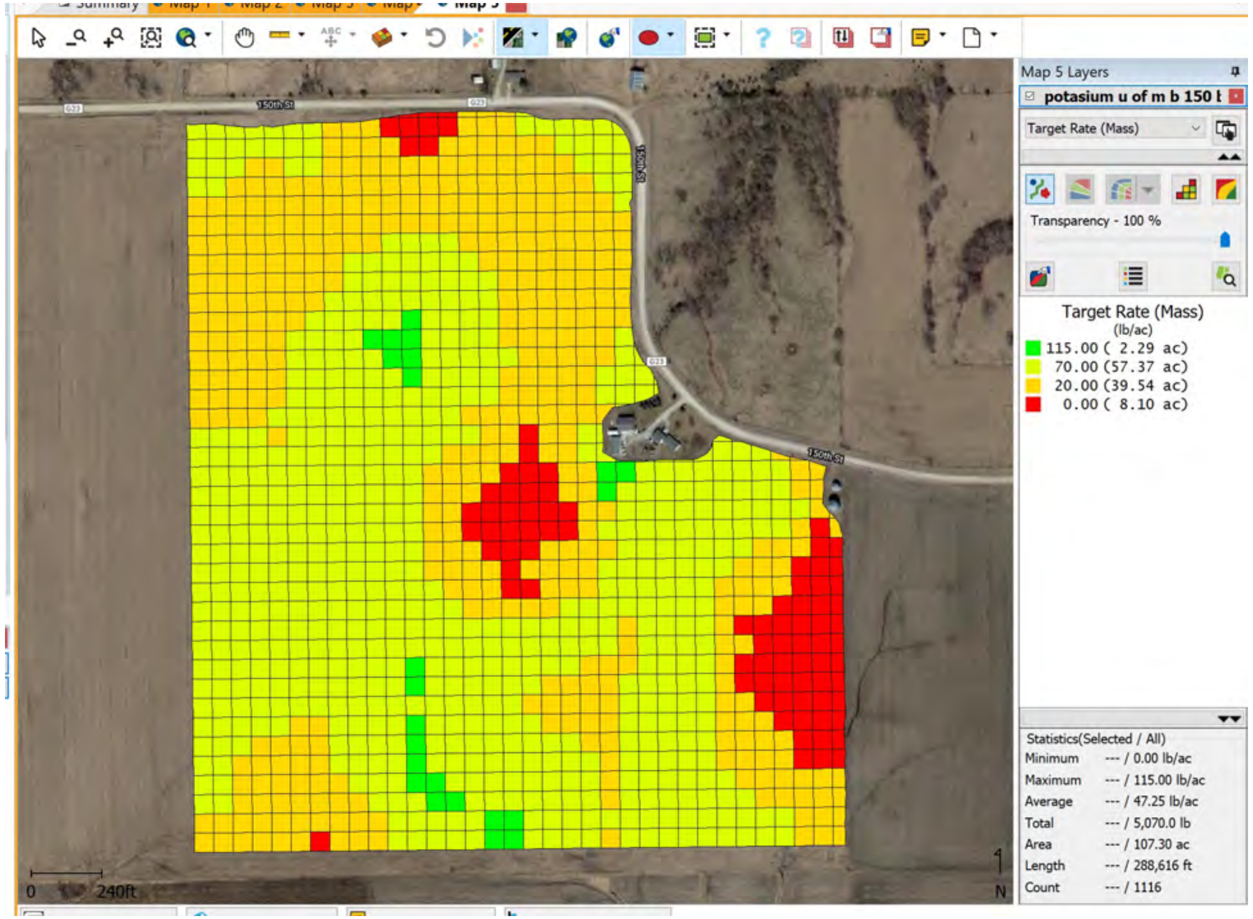
When graphed, note how
It appears like a set of stairs.



Note that 5 rates were created
*using 151-175 yield goal

Example Stair Step Prescription

- No soil tests with less than 50ppm K.
- 160 lb/acre rate not used.



Linear Equation Prescription

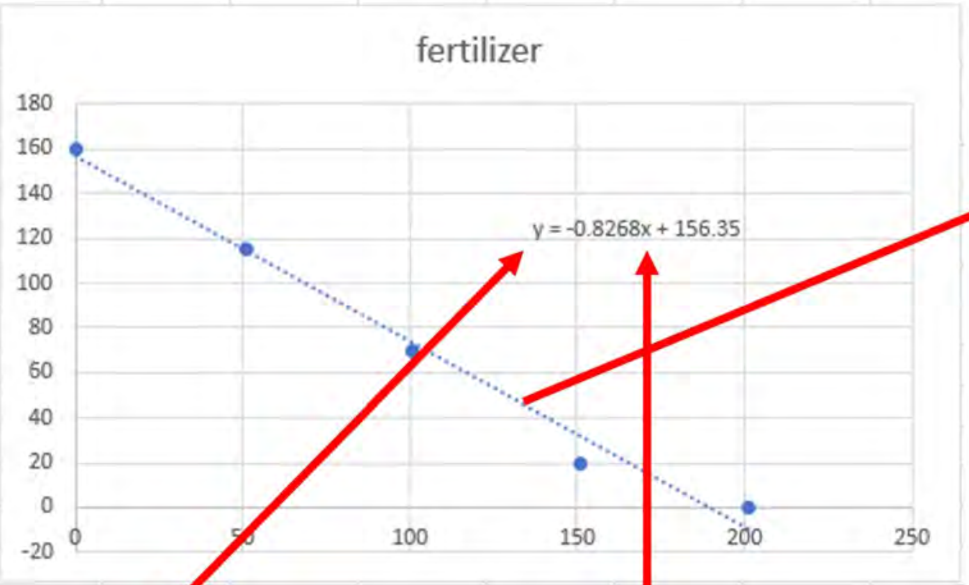
- Results in multiple rates
- Soil test categories of Very Low to Very High are used to create a prescription for a variable rate application.
- Data points are used to create a linear equation.
- Y = mx+b

Table 11. Broadcast (Bdcst) and band potash guidelines for corn production in Minnesota.*

	Soil test K (ppm)									
	Very Low		Low		Medium		High		Very High	
Expected	0-50		51-100		101-150		151-200		200+	
Yield	Bdcst	Band	Bdcst	Band	Bdcst	Band	Bdcst	Band	Bdcst	Band

Linear Prescription Example

K ppm	fertilizer
0	160
51	115
101	70
151	20
201	0



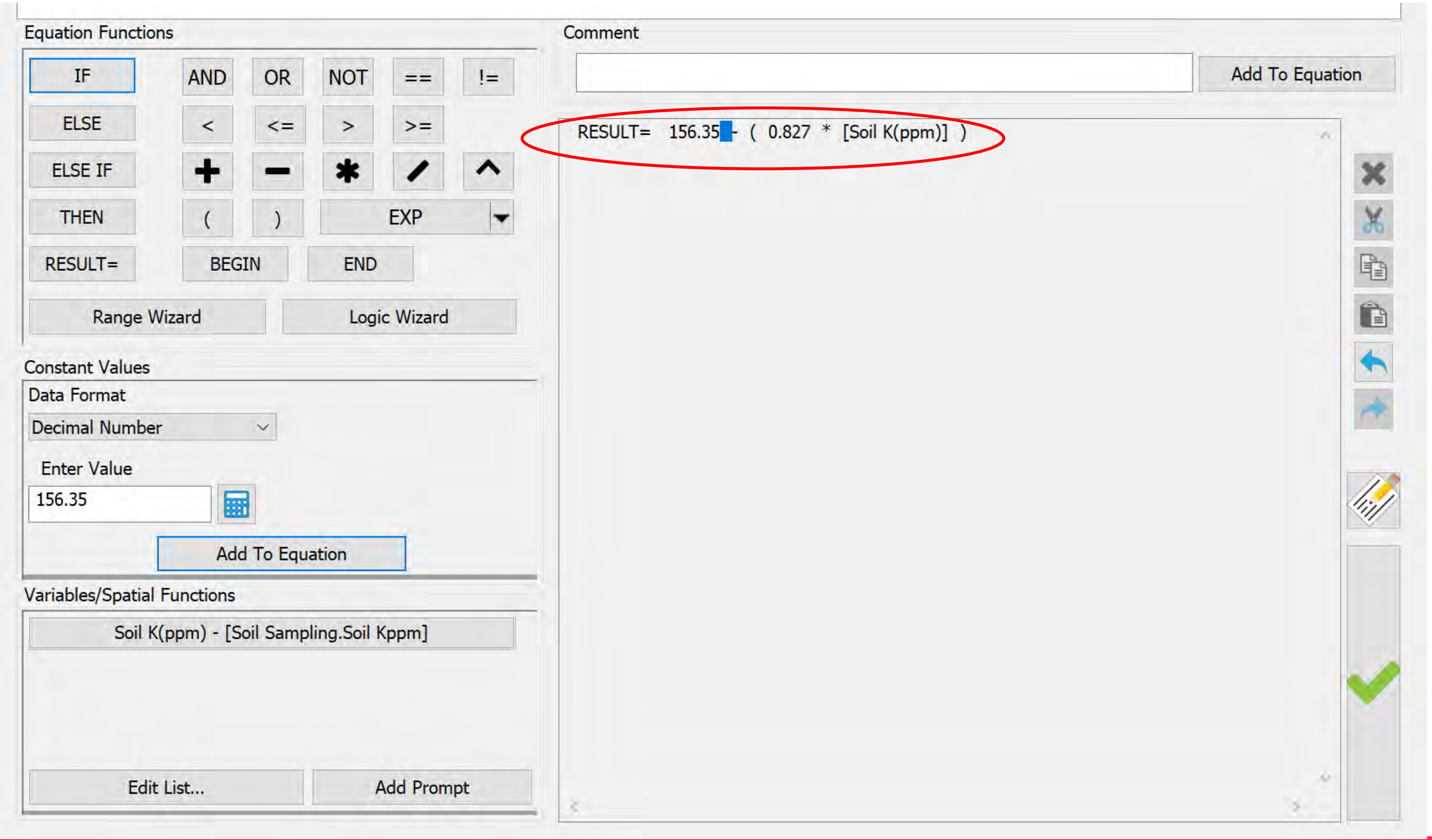
Note the linear line instead
Of the stair steps as before. This will result in infinite rates.

Change the equation order to:
$Y=156.35 - 0.8268x$

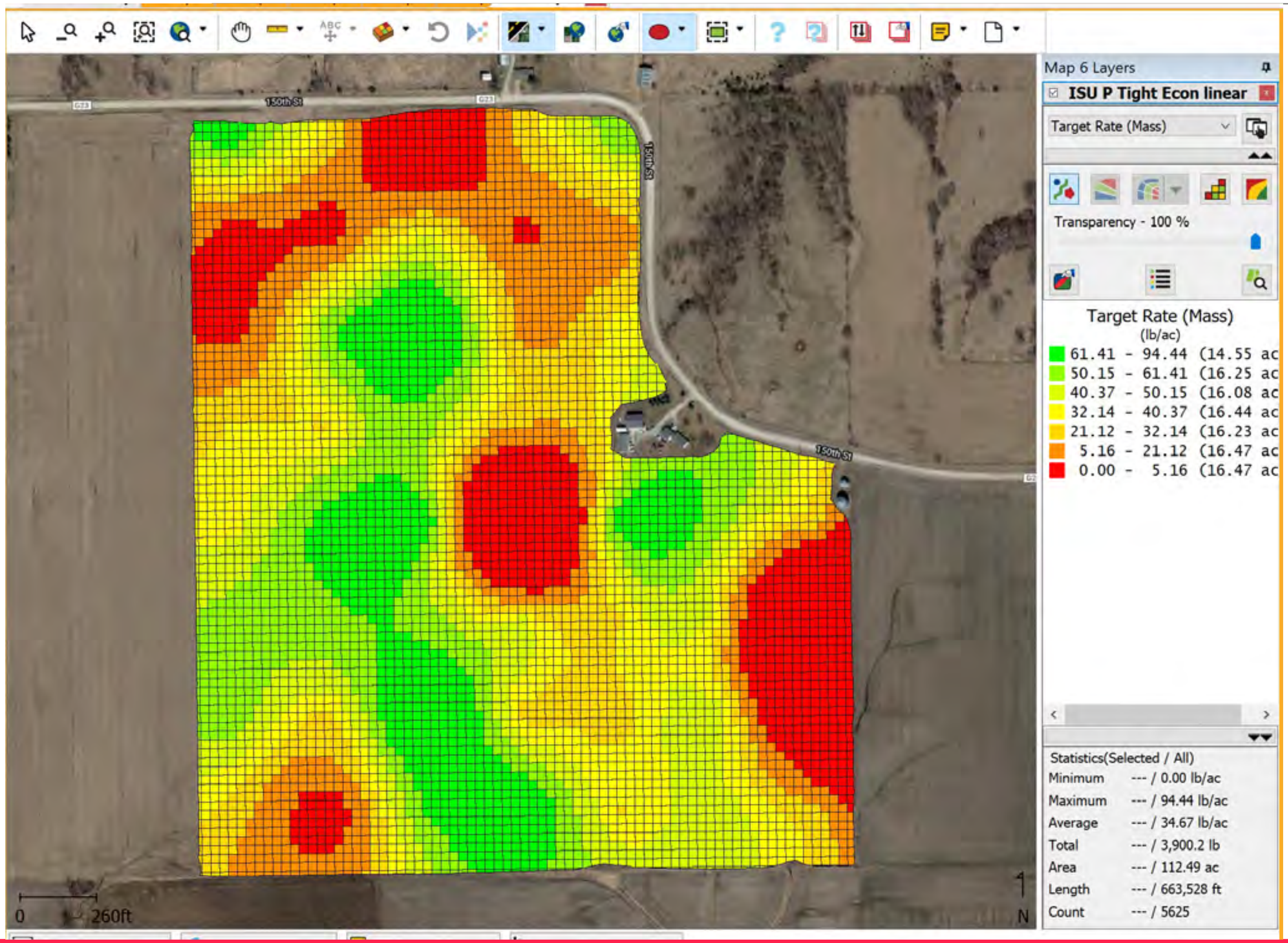
Y= Pounds of Fertilizer

X=Soil Test PPM

Linear Equation Prescription

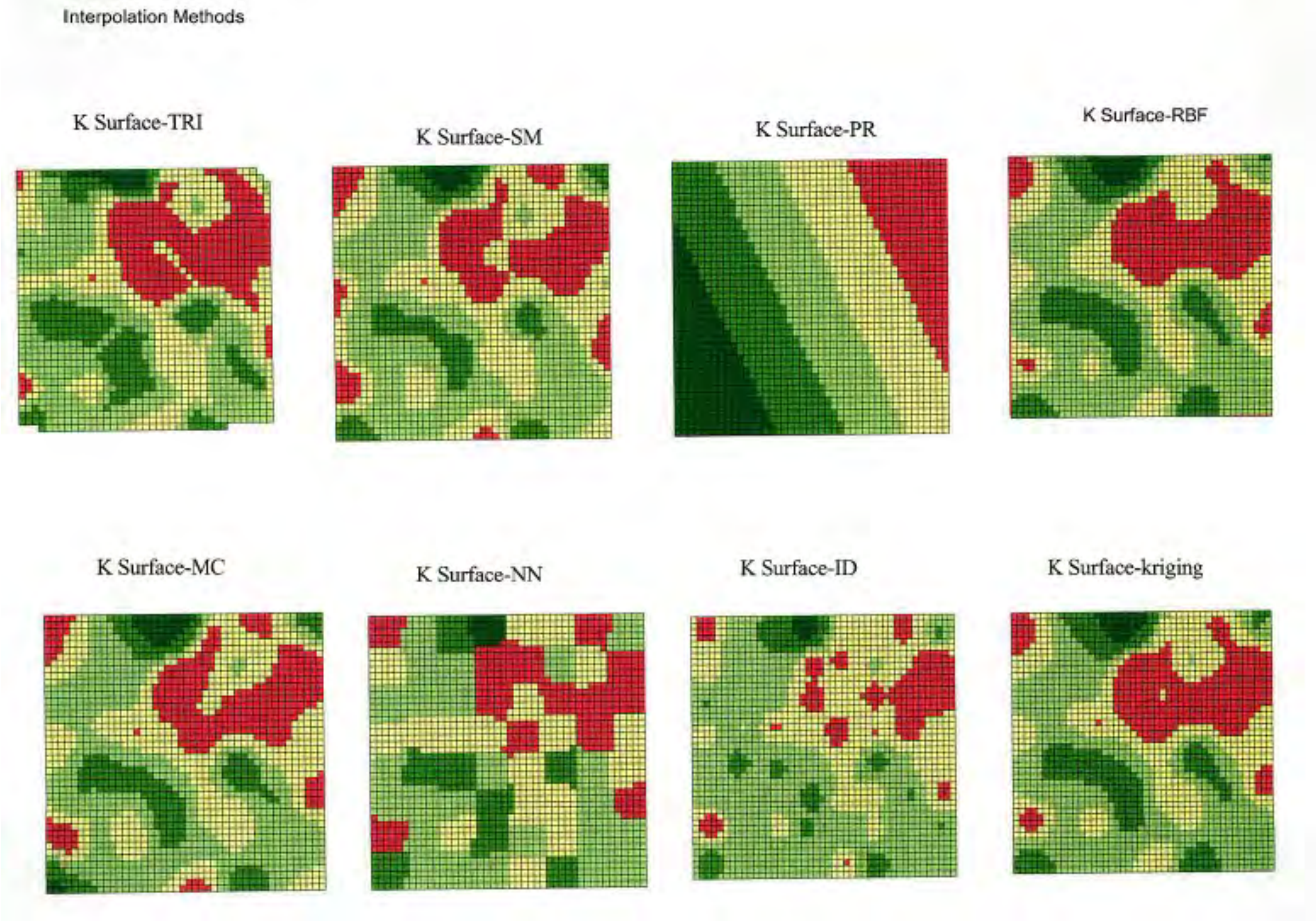


Linear Equation Prescription



Note the additional rates used with the linear method

Additional prescription types



There are other methods and agronomic principles to consider when making a prescription.

Presentation Review

- Mark or highlight three key points
- List two ideas or concepts related to previous knowledge.
- List questions you have about this topic.
- Keep notes organized and available for use throughout the course.

References

- Brase, Terry. (2006). *Precision Agriculture*. Clifton, NY: Thomson Delmar Learning.
- Ess, Dan. (2003). *Precision Farming Guide for Agriculturalists*. Madison, WI: Deere and Company.

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Lesson 3.3 The Data Advantage

Preface

Agricultural producers continue to find new and innovative means to collect and utilize crop, land, and equipment data. Besides collecting planting and harvest data, sensors on equipment provide a producer with information on their machine's performance. In addition, producers utilize drones to collect real-time data during their crop's primary growth period. Machines such as irrigation and application equipment can interpret this real-time data. A machine's computer can learn from data to determine how much of an input, such as water and fertilizer, it should apply.

Sensors on planting equipment send detailed data about each row planted in the field. Besides seeding rate information, GIS can map data showing how and where a planter places each seed. A producer can read a GIS map and identify if any row is prone to skips in a field, along with seeding depths affected by the gauge wheel's down force for each planter row.

Students start the lesson by simulating a drone using remote sensors to collect data for machine learning. Then students use GIS data to identify a component failure on a corn planter to complete the lesson.

Concepts	Performance Objectives
Students will know and understand	*Students will learn concepts by doing*
1. Agricultural producers use remote sensing devices to collect data for making production decisions.	• Use machine learning software to simulate remote sensing and data analysis. (Activity 3.3.1)
2. Technicians use data to predict future repairs and maintenance.	• Interpret GIS data and identify machine failure. (Activity 3.3.2)

National AFNR Common Career Technical Core Standards Alignment

Career Ready Practices
11. Use technology to enhance productivity.
• CRP.11.01: Research, select and use new technologies, tools, and applications to maximize productivity in the workplace and community.
Power, Structural and Technical (AG-PST)
5. Use control, monitoring, geospatial and other technologies in AFNR power, structural and technical systems.
• AG-PST 5.3 Use geospatial technologies in AFNR applications.

Next Generation Science Standards Alignment

Disciplinary Core Ideas	
Engineering, Technology, and the Application of Science	
ETS1: Engineering Design	
ETS1.A: Defining and Delimiting Engineering Problems	• Criteria and constraints also include satisfying any requirements set by society, such as taking issues of risk mitigation into account, and they should be quantified to the extent possible and stated in such a way that one can tell if a given design meets them. • Humanity faces major global challenges today, such as the need for supplies of clean water and food or for energy sources that minimize pollution, which can be addressed through engineering. These global challenges also may have manifestations in local communities.

ETS1.B: Developing Possible Solutions	• When evaluating solutions, it is important to take into account a range of constraints including cost, safety, reliability and aesthetics and to consider social, cultural and environmental impacts. • Both physical models and computers can be used in various ways to aid in the engineering design process. Computers are useful for a variety of purposes, such as running simulations to test different ways of solving a problem or to see which one is most efficient or economical; and in making a persuasive presentation to a client about how a given design will meet his or her needs.
ETS1.C: Optimizing the Design Solution	• Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (tradeoffs) may be needed.

Science and Engineering Practices	
Developing and Using Models	Modeling in 9–12 builds on K–8 experiences and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed world(s). • Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system. • Develop and/or use multiple types of models to provide mechanistic accounts and/or predict phenomena and move flexibly between model types based on merits and limitations. • Develop and/or use a model (including mathematical and computational) to generate data to support explanations, predict phenomena, analyze systems, and/or solve problems.
Analyzing and Interpreting Data	Analyzing data in 9–12 builds on K–8 experiences and progresses to introducing more detailed statistical analysis, the comparison of data sets for consistency, and the use of models to generate and analyze data. • Compare and contrast various types of data sets (e.g., self-generated, archival) to examine consistency of measurements and observations. • Analyze data to identify design features or characteristics of the components of a proposed process or system to optimize it relative to criteria for success.
Using Mathematics and Computational Thinking	Mathematical and computational thinking in 9-12 builds on K-8 and experiences and progresses to using algebraic thinking and analysis, a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms, and computational tools for statistical analysis to analyze, represent, and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions. • Use mathematical, computational, and/or algorithmic representations of phenomena or design solutions to describe and/or support claims and/or explanations. • Apply ratios, rates, percentages, and unit conversions in the context of complicated measurement problems involving quantities with derived or compound units (such as mg/mL, kg/m3, acre-feet, etc.).

Crosscutting Concepts	
Cause and Effect: Mechanism and Prediction	Events have causes, sometimes simple, sometimes multifaceted. Deciphering causal relationships, and the mechanisms by which they are mediated, is a major activity of science and engineering.
	• Systems can be designed to cause a desired effect. • Changes in systems may have various causes that may not have equal effects.
Systems and System Models	A system is an organized group of related objects or components; models can be used for understanding and predicting the behavior of systems.
	• Systems can be designed to do specific tasks. • When investigating or describing a system, the boundaries and initial conditions of the system need to be defined and their inputs and outputs analyzed and described using models.

Understandings about the Nature of Science	
Scientific Investigations Use a Variety of Methods	• New technologies advance scientific knowledge.

Common Core State Standards for High School Mathematics

Modeling standards are indicated by the star symbol (*) throughout other conceptual categories.

CCSS: Conceptual Category – Number and Quantity	
Quantities	*Reason quantitatively and use units to solve problems.

CCSS: Conceptual Category – Statistics and Probability	
Making Inferences and Justifying Conclusions	*Make inferences and justify conclusions from sample surveys, experiments, and observational studies.

Common Core State Standards for English Language Arts

CCSS: English Language Arts Standards » Science & Technical Subjects » Grade 11-12	
Key Ideas and Details	• **RST.11-12.3 –** Follow precisely a complex multistep procedure when carrying out experiments, taking measurements, or performing technical tasks; analyze the specific results based on explanations in the text.
Craft and Structure	• **RST.11-12.4 –** Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to grades 11-12 texts and topics.
Integration of Knowledge and Ideas	• **RST.11-12.9 –** Synthesize information from a range of sources (e.g., texts, experiments, simulations) into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible.
Range of Reading and Level of Text Complexity	• **RST.11-12.10 –** By the end of grade 12, read and comprehend science/technical texts in the grades 11-CCR text complexity band independently and proficiently.

CCSS: English Language Arts Standards » Writing » Grade 11-12	
Production and Distribution of Writing	• **WHST.11-12.4 –** Produce clear and coherent writing in which the development, organization, and style are appropriate to task, purpose, and audience.
Range of Writing	• **WHST.11-12.10 –** Write routinely over extended time frames (time for reflection and revision) and shorter time frames (a single sitting or a day or two) for a range of discipline-specific tasks, purposes, and audiences.

Essential Questions

1. How do agricultural producers use aerial pictures to increase production?
2. Why do farmers use drones?
3. How can machines use data to make decisions?
4. How do technicians use GIS to identify mechanical failures?
5. What is the relationship between sensors on equipment and GIS data?

Key Terms

Doubles	**Down force**	**Drone**
Gauge wheel	**Machine learning**	**Remote sensing**
Singulation	**Singulation quality**	**Unmanned aerial vehicle (UAV)**

Day-to-Day Plans
Time: 3 days

Refer to the Teacher Resources section for specific information on teaching this lesson, in particular ***Lesson 3.3 Teacher Notes****,* ***Lesson 3.3 Glossary****,* ***Lesson 3.3 Materials****, and other support documents.*

Day 1:

- Present **Concepts**, **Performance Objectives**, **Essential Questions**, and **Key Terms** to provide a lesson overview.
- Provide students with a copy of **Activity 3.3.1 Remote Sensing**.
- Students work in pairs to complete *Activity 3.3.1 Remote Sensing*.

Day 2:

- Provide students with a copy of **Activity 3.3.2 Broken Row**.
- Students work in pairs on *Activity 3.3.2 Broken Row*.

Day 3:

- Students complete *Activity 3.3.2 Broken Row*.
- Students complete **Lesson 3.3 Check for Understanding** and submit it for evaluation.
- Use **Lesson 3.3 Check for Understanding Key** to evaluate student assessments.

Instructional Resources

Student Support Documents

Lesson 3.3 Glossary

Activity 3.3.1 Remote Sensing

Activity 3.3.2 Broken Row

Teacher Resources

Lesson 3.3 The Data Advantage PDF

Lesson 3.3 Teacher Notes

Lesson 3.3 Materials

Lesson 3.3 Check for Understanding

Answer Keys and Assessment Rubrics

Lesson 3.3 Check for Understanding Answer Key

Reference Sources

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Funk, Joe. (2018). The science behind seed singulation. *Seed World*. Retrieved from **https://seedworld.com/the-science-behind-seed-singulation/**

Precision Planting. (2021). *Products that improve planter performance*. Retrieved from **https://www.precisionplanting.com/**

Sylvester, Girard. (2018). *E-agriculture in action: drones for agriculture*. Bangkok, Thailand: Food and Agriculture Organization of the United Nations.

University of Indiana. (). *What are gis and remote sensing?*. Retrieved from **https://kb.iu.edu/d/anhs**

FFA Connections

This lesson provides conceptual and procedural knowledge required for participation in the following FFA activities:

- Agricultural Proficiency
    - **Agricultural Mechanics Repair and Maintenance –Placement**
    - **Agricultural Mechanics Repair and Maintenance –Entrepreneurship**
- Agriscience Fair
    - **Power, Structural and Technical Systems**
- Career Development Events
    - **Agricultural Technology & Mechanical Systems**
- Educational Resources

- **SAE Idea Cards-Power, Structural and Technical Systems**
- **Power, Structural and Technical System Careers**
- **Power, Structural and Technical Systems Career Focus Area Resources**
- Agricultural Mechanics (**Word)** (**PDF**)
- Jacob Reed-Drones in Agriculture **(Word) (PDF)**
- From Drone to Tractor **(Word)**
- Keegan Humm-SAE-Placement-Implement Dealership Lesson Plan (**Word**) (**PDF**)
- Power, Structural and Technical Careers **(Word)**

For more information, visit the **National FFA Organization** website.

SAE for All

Immersion SAE

Students interested in this lesson's topics should explore the following related Immersion SAEs. An immersion SAE is optional and replaces the agricultural literacy component of the Foundational SAE.

- Ownership/Entrepreneurship
  - **Turfgrass Management-Irrigation SAE | Tyler Hewitt**
- Placement/Internship
  - **Implement Dealership Placement SAE | Keegan Humm**
  - **Agricultural Mechanics SAE | Jeremiah Hager**
  - **Drones in Agriculture SAE | Jacob Reed**

For more information on the guiding principles for implementing SAE programs, visit the **SAE for All: Evolving Essentials** site.

Critical Thinking and Application Extensions

Application

1. Students will use producer data from a planter to identify mechanical failures.

Perspective

2. Students will research and write a short essay explaining how remote sensors and machine learning improve sustainability practices.

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Lesson 3.3 Teacher Notes

Lesson 3.3 The Data Advantage

In preparation for teaching this lesson, review Concepts, Performance Objectives, Essential Questions, and Key Terms. Also, review all activity, project, and problem directions, expectations, and work students will complete.

Students discover how technicians use data collected by sensors to repair equipment and improve agricultural production. Students start the lesson by simulating a drone collecting images and using the image data for machine learning. To complete the lesson, students use GIS data to identify component failures on a corn planter.

Activities, Projects, and Problems

Activity 3.3.1 Remote Sensing

Students work in pairs using machine learning and image collection to identify low and high moisture soil.

Teacher Preparation

Download and install the **Lobe Application** onto the computers used by each student pair. Next, attach a webcam to each computer via a USB cord. Students need a versatile webcam to take overhead pictures of soil samples with different moisture levels.

Student Performance

Students fill three sample trays with media. One media tray will be left dry, another moist with a light spray of water, and the final one saturated with water. Next, students use the Lobe application to take overhead pictures of each dry, moist, and saturated cell. The Lobe application will develop a program to identify soil at each moisture level. Students complete the lesson by simulating a drone using the program and sketching a flow chart explaining how a drone could work with an irrigation system.

Results and Evaluation

Use the example answers in Table 1 to assess student understanding.

Table 1. ***Analysis Questions and Potential Responses***

Q1	What happens to the accuracy of the data as the speed of the camera and image quality change?	*The accuracy decreases as the movement of the camera changes or when a lens is partially blocked.*
Q2	What technical problems would a technician need to know when using drones and remote sensing for machine learning?	*Example answers include clear pictures by traveling at a consistent height and speed while keeping the camera clean.*

Activity 3.3.2 Broken Row

Students work in pairs using GIS data to identify broken components on a planter.

Teacher Preparation

Students use PC computers with SMS software for this activity. Complete the following to prepare SMS and example projects.

1. Download the SMS software and Training Project from the **Ag Leader® Class Resources**.
2. Install the SMS software on each computer.

3. Open and register the SMS software on each computer by selecting **Help** at the top of the screen and choosing **Register…**
4. Upload the project to each computer by opening SMS, selecting **Services**, and choosing **Backup/Restore Project Options**.
5. Select **Restore Project Data** and navigate the files to find the *Customer Training Project Folder*.
6. Select the **Customer Training Project Folder** and choose **Load** to install the project.
7. You should see example projects in the SMS Management Tree, as seen in Figure 1.
    - Students will use Grower Smith data found in the management tree.

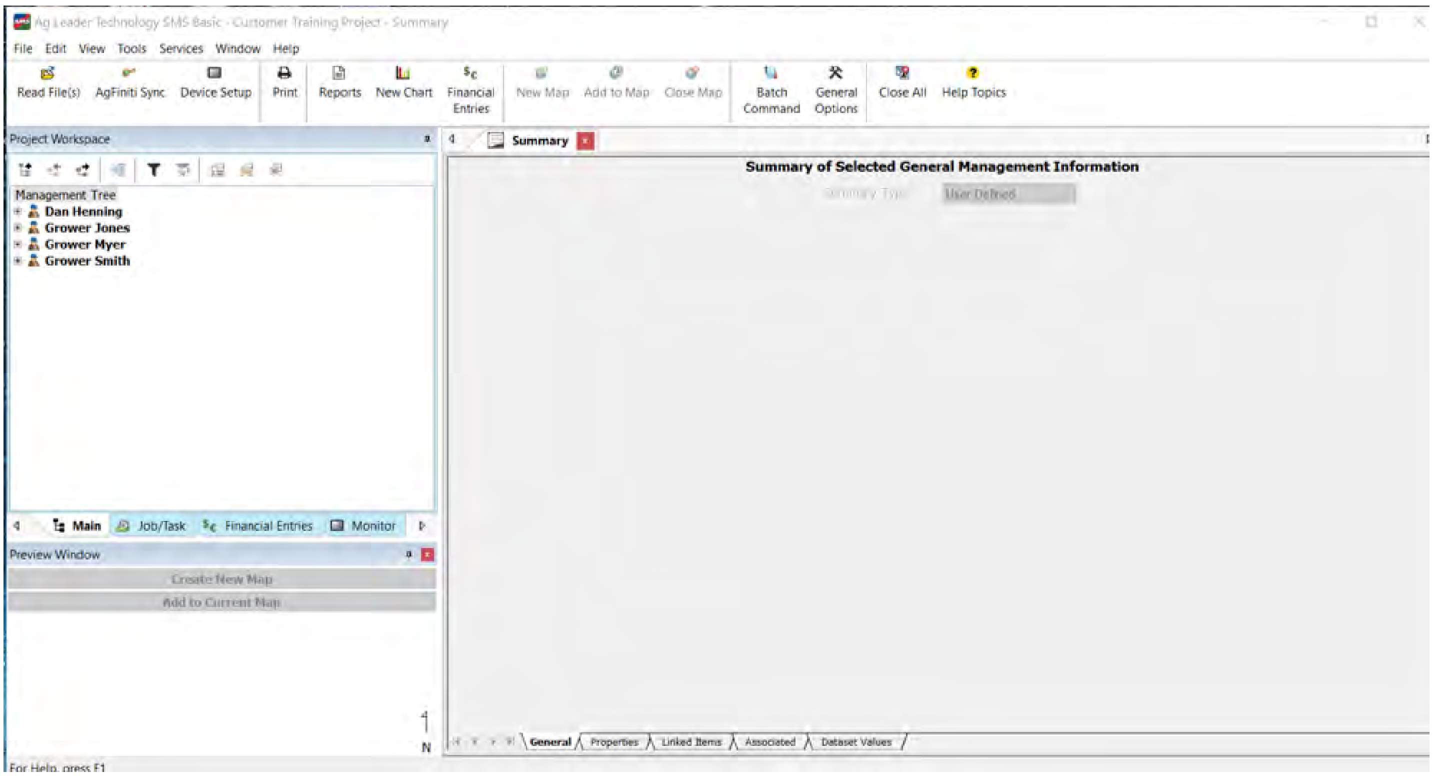


Figure 1. SMS Management Tree

Student Performance

Part One

Students go to the Precision Planting website and identify the components in a precision planter. They record the name and description of each component in the student observations sheet.

Part Two

Students open SMS on a computer and find the 2018 planting data for West McMains on Grower Smith's home farm. Next, students use the singulation, singulation quality, and down force (gauge) attributes to view variances in each row planted in the field. Then, students use the attributes and row information to answer analysis questions.

Results and Evaluation

Use the example data and answers to analysis questions in Tables 2–4 to assess student understanding.

Table 2. ***Field Information***

Percent Doubles	0.2%
Percent Good	94.7%
Percent Skips	5.2%
Row 5 Doubles Percentage	0.6%
Row 5 Good Percentage	93.2%
Row 5 Skips Percentage	6.2%

Table 3. ***Planter Information***

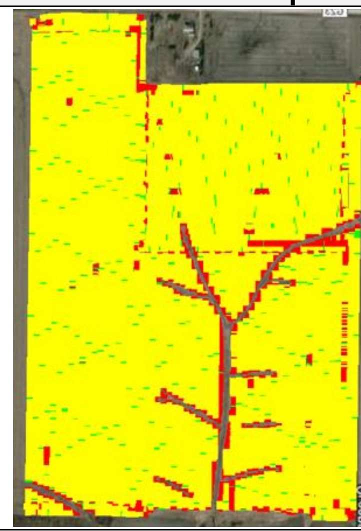
Row Number	Singulation (Acres)		Avg. Pressure (lbf)	Seed Count Map
	98.00–100.00%	0.00–98.0%		
Field	141.64	36.63	81.78	
Row 1	18.977	3.349	79.55	
Row 2	12.02	2.865	119.2	
Row 3	10.772	4.116	0.00	
Row 4	9.410	5.507	84.83	
Row 5	11.143	3.784	169.44	
Row 6	13.328	1.593	84.62	
Row 7	12.142	2.754	84.38	
Row 8	11.537	3.326	84.51	
Row 9	12.168	2.658	58.88	
Row 10	18.318	3.798	77.95	
Row 11	5.426	1.929	117.09	
Row 12	6.40	0.95	0.00	

Table 4. ***Analysis Questions and Potential Responses***

Q1	How many rows does the planter seed at one time?	*The planter plants twelve rows at one time.*
Q2	What does the data in Tables 2 and 3 indicate about row 5 of the planter??	*Row five may be the cause of skips and doubles since it is higher than the field average.*
Q3	Which row is the most efficient? Why?	*Row six and twelve have the lowest acreage with a singulation rate below 98%. Or Row 10 because it has the highest amount of acres in the 98-100% range.*
Q4	Which row is the least efficient? Why?	*Row four has the highest acreage with a singulation rate below 98%.*
Q5	Which row(s) may be planting at the wrong seed depth? Why?	*Row three and twelve have a pressure of zero pounds.*
Q6	What features on the base map indicate possible causes for the range in the seed count?	*Gullies in the field where the planter did not plant any seeds.*

Assessment

Lesson 3.3 Check for Understanding

Lesson 3.3 Check for Understanding is included for you to use as an assessment tool for this lesson. Use **Lesson 3.3 Check for Understanding Answer Key** for evaluation purposes.

Name____ CASE

Activity 3.3.1 Remote Sensing

Purpose

A small object is hovering over a field. As you look closer, you realize it is a drone. What is the drone doing, and how are drones involved in agriculture?

Drones, called Unmanned Aerial Vehicles, can collect data other agricultural equipment cannot. Heavy equipment collects GIS data by driving through a field during planting, applications, and harvest. However, a producer collects very little data during the crop's primary growth period. Drones equipped with a GPS receiver and cameras can quickly photograph an entire field for a producer to view and analyze. Once a producer analyzes the photographs, they can make production decisions based upon what they see, such as weed patches and plant growth.

There are many production factors a farmer may not be able to detect from an image with their own eyes. Remote sensors attached to a drone use precise field measurements to create a map. A producer can use the map to identify productivity factors they cannot see from a traditional photograph, such as nutrient deficiencies, soil moisture percentage, and plant productivity. Machines can learn from the remote sensor's data and aid a producer in immediately identifying and responding to those factors. For example, once a machine learns what dry and moist soil look like in an image, an irrigation system can learn when to water.

How do machines learn from images collected by a drone?

Materials

Per pair of students:

- Computer with Lobe software
- Masking tape
- Permanent marker
- (3) Planting tray with holding tray, 12-cell
- Soil media
- Spray bottle
- Webcam with USB cord

Per student:

- Pen
- *Agriscience Notebook*

Procedure

Collect data to program a machine to measure soil moisture. Then use machine learning to determine soil moisture.

1. Fill three 12-cell trays with soil media.
2. Label a holding tray *Dry*.
   - Place a 12-cell tray with dry soil in the holding tray.
3. Label a second holding tray *Moist*.
   - Place a 12-cell tray with dry soil in the holding tray.
   - Spray the cells with water until they become moist. Do not soak
4. Label a third holding tray *Wet* and fill one-third full with water.
   - Place a 12-cell tray with dry soil in the holding tray.
   - Spray the cells with water until each cell wicks water from the bottom and becomes soaked.

5. Attach the webcam to your computer.
6. Open Lobe on your computer.
7. Select the lines at the top left and choose **New Project…**
8. Name the project *Soil Moisture*.
9. Select **Label**.
10. Select **Import** and choose **Camera**.
11. Type *Dry* for a label name.
12. Hold the camera over a dry cell.
13. Select the circle in the center to take a picture of a dry cell.
14. Repeat steps 12–13 for each dry cell
    - Take a minimum of 12 pictures.
15. Type *Moist* for a label name.
16. Hold the camera over a moist cell.
17. Select the circle in the center to take a picture of a moist cell.
18. Repeat steps 16–17 for each moist cell
    - Take a minimum of 12 pictures.
19. Type *Wet* for a label name.
20. Hold the camera over a wet cell.
21. Select the circle in the center to take a picture of a wet cell.
22. Repeat steps 20–21 for each wet cell
    - Take a minimum of 12 pictures.
23. Select **Train**.
24. Select **Use**.
25. Move the camera over wet, dry, and moist cells.
    - Select the green box if the prediction is correct.
    - Select the red box if the prediction is incorrect.
26. Move the camera over the trays to simulate a drone flying over a field collecting images. Note how the label changes.
    - Changing the speed and height as you move the camera over the soil samples.
    - Place your hand or sheet of paper to cover part of the camera while scanning the soil samples.
    - Answer the analysis question on *Activity 3.3.1 Student Worksheet*.
27. Sketch a flowchart in Figure 1 on the student worksheet explaining how remote sensing on a drone could work with an irrigation system to water a field.

Conclusion

1. How do machines use images to make production decisions?

2. Why are drones used for collecting field data instead of heavy equipment?

3. What are some other agricultural applications of remote sensing and machine learning?

Name____

Activity 3.3.1 Student Worksheet

Analysis Questions

Q1 What happens to the accuracy of the data as the speed of the camera and image quality change?

Q2 What technical problems would a technician need to know when using drones and remote sensing for machine learning?

Figure 1. Remote Sensing and Irrigation Flowchart

Name____

CASE

Activity 3.3.2 Broken Row

Purpose

As a farmer walks through their field, they notice areas where plants are far apart and too close together, as shown in Figure 1. How could a technician use sensors and GIS data to identify the cause of the producer's problem?

Figure 1. Plant Spacing

Equipment manufacturers design planters to evenly space and place seeds into each row in a field. Planters contain sensors working with a global navigation satellite system (GNSS) to monitor where, when, and how a planter places each seed. The sensors send the data to a geographic information system that visually maps the data for producers and technicians to analyze.

Sensors can identify the seeding rate, spacing between each seed, and down force pressure affecting the seed's depth and contact with the soil. Each of these factors impacts production. Likewise, component failure and calibration affect a planter's efficiency. Failed and miscalibrated components can be identified by analyzing GIS data. This data analysis can be an important task in which a technician can help a farmer calibrate, fix, and improve planter performance.

The planter's speed and down force impact the seed spacing and depth. A planter has down force applied to a gauge wheel to ensure the planter places each seed at the proper depth. A down force sensor monitors the weight applied to the gauge wheel. The planter continually adjusts the down force as it travels across a field to maintain a consistent depth.

Seed singulation is a planter's ability to place seeds without skips and doubles to maintain a seeding rate. When planter speed increases, the seeds are planted faster to avoid skips and maintain the target rate. As the planter slows down, the seeds are released at a lower rate to avoid overlaps called doubles and maintain the target planting rate. Precision planters can adjust the seed delivery rate on the fly to maintain the target seed rate regardless of planter speed and other factors that could decrease the rate. Conventional planters are set by adjusting chains and sprockets based on a target speed. Precision planters can change its setting on the fly. Singulation quality is the rate a planter places a single seed. For example, a planter with a 97% singulation quality has skips or doubles in 3% of the field. When operating correctly, sensors and controls in a planter keep the singulation quality above 98%. High singulation quality reduces input costs and increases a producer's efficiency.

As a technician, how can you use down force and singulation data to determine if a planter is operating at its peak efficiency?

Materials

Per pair of students:

- Computer with SMS software
- Green highlighter
- Pink highlighter
- Yellow highlighter

Per student:

- Pen
- *Agriscience Notebook*

Procedure

Work individually to identify the components of a precision planter. Then use GIS software to analyze visual data to determine if equipment components need repair.

Part One – Planter Row Components

1. Go to **Precision Planting** (https://www.precisionplanting.com) and scroll down to view the image of a planter's single row.
2. Select each circle on the planter and record each component and function in Table 1 of *Activity 3.3.1 Student Observations* sheet.

Part Two – Planter Row Analysis

1. Open the SMS software.
2. Open and expand **Grower Smith** in the management tree.
3. Expand **Home Farm**.
4. Expand **West McMains**.
5. Expand *2018*, scroll down, and choose **Planting**.
6. Select **Create New Map** to map corn planting data.
7. Change the attribute to *Singulation Quality*.
8. Select **Section Row Map**, and choose **Show All Row/Sections** from the drop-down menu, as seen in Figure 1.
9. Record the percent doubles, good, and skips in Table 2.
10. Select **Section Row Map**, choose **Configure Row/Sections**, **Selected Sections/Row**, check *Section/Row 5* from the drop-down menu, and select **OK**.
11. Record the percent doubles, good, and skips for row five 5 in Table 2.
12. Change the attribute to *Singulation*.
13. Select **Section/Row Map**, and choose **Show All Rows/Sections.**
14. Select **Edit Legend** as seen in Figure 2.
15. Change the *Ranges* to **2**.
    - Enter 98-100% for the green range.
    - Enter 0-98% for the red range.
    - Select **Apply** and choose **Ok**.
16. Record the acres for each range for the field in Table 3.
17. Select **Section Row Map**, choose **Configure Row/Sections**, **Selected Sections/Row**, and check *Section/Row 1* from the drop-down menu.
    - All other rows should be unchecked.
18. Choose **OK**.
19. Record the acres for each range for Row 1 in Table 3.

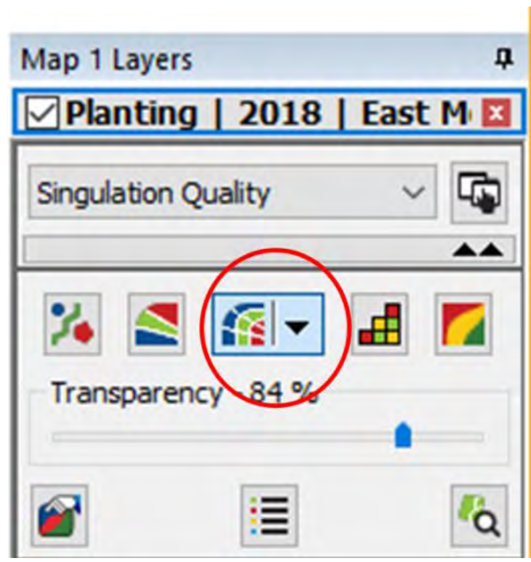


Figure 1. Configure Row/Sections

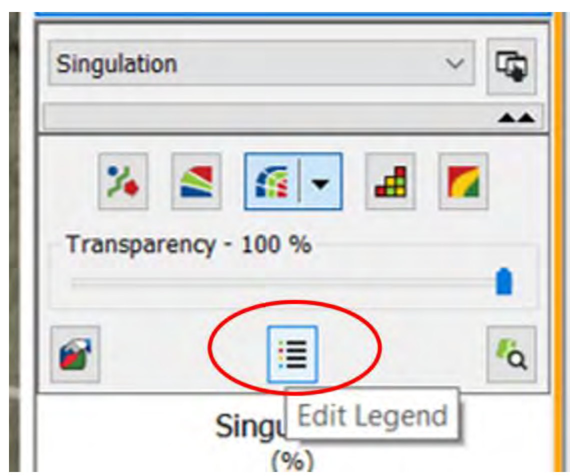


Figure 2. Edit Legend

20. Repeat Steps 17–19 for each row.
21. Change the attribute to *Down Force (Applied)*.
22. Select **Section/Row Map**, and choose **Configure Rows/Sections.**
23. Check **Selected Sections/Rows** and check *Section/Row 1*.
    - All other rows should be unchecked.
24. Choose **OK**.
25. Find the average force for Row 1 in the lower right corner, as seen in Figure 3.

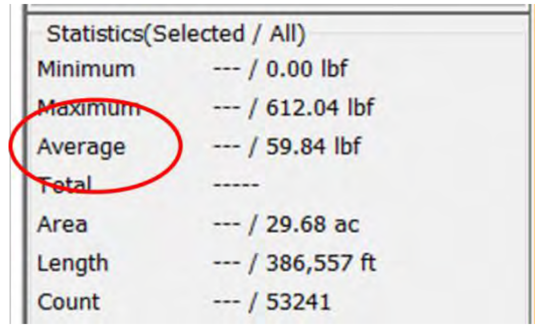


Figure 3. Average Pressure

26. Record the average force for Row 1 in Table 3.
27. Repeat Steps 22–26 for each row.
28. Change the attribute to *Seed Count*.
29. Select **Edit Legend**.
30. Change the *Ranges* to **3**.
    - Enter 190–527 for the green range.
    - Enter 147.5–190 for the yellow range.
    - Enter 0.00–147.50 for the red range.
31. Sketch the field boundary in Table 3 on the student observations sheet.
32. Use a pink highlighter to identify areas where the seed count was low.
33. Use a green highlighter to identify areas where the seed count was high
34. Answer the *Part Two Analysis Questions*.

Conclusion

1. Why would a technician review GIS data before troubleshooting equipment?

2. How can a technician use GIS data to identify the cause of equipment failure?

3. What components must be working when using GIS data to identify the cause and correct equipment failure?

Name____

Activity 3.3.2 Student Observations Sheet

Table 1. ***Planter Row Components***

Table 2. ***Field Information***

Percent Doubles	
Percent Good	
Percent Skips	
Row 5 Doubles Percentage	
Row 5 Good Percentage	
Row 5 Skips Percentage	

Table 3. ***Planter Information***

Row Number	**Singulation (Acres)**		**Avg. Pressure (lbf)**	**Seed Count Map**
	98.00–100.00%	**0.00–98.0%**		
Field				
Row 1				
Row 2				
Row 3				
Row 4				
Row 5				
Row 6				
Row 7				
Row 8				
Row 9				
Row 10				
Row 11				
Row 12				

Part Two Analysis Questions

Q1 How many rows does the planter seed at one time?

Q2 What does the data in Tables 2 and 3 indicate about row 5 of the planter?

Q3 Which row is the most efficient? Why?

Q4 Which row is the least efficient? Why?

Q5 Which row(s) may be planting at the wrong seed depth? Why?

Q6 What features on the base map indicate possible causes for the range in the seed count?

Name____

CASE

Lesson 3.3 Check for Understanding

1. How are drones used to collect data from a farm field?

2. How can agricultural equipment use remote sensing and machine learning to increase crop productivity?

3. Which of the following GPS and sensor systems will provide the most accurate information to a technician?
   a) A GPS receiver on the tractor.
   b) A GPS receiver on the tractor with a single sensor on a planter.
   c) A GPS receiver on the tractor with a single sensor on each planter row.
   d) A GPS receiver on the tractor with multiple sensors on each planter row.

4. Why is seed singulation quality important when planting a field?

5. How is GIS used to identify and solve mechanical problems on a planter?

CASE

Lesson 3.3 Check for Understanding Answer Key

1. How are drones used to collect data from a farm field?

   Drone use cameras to collect and store images about specific locations in a field.

2. How can agricultural equipment use remote sensing and machine learning to increase crop productivity?

   Agricultural equipment can learn how to apply fertilizers, seeds, and water to a field by analyzing data collected from remote sensors.

3. Which of the following GPS and sensor systems will provide the most accurate information to a technician?

   a) A GPS receiver on the tractor.
   b) A GPS receiver on the tractor with a single sensor on a planter.
   c) A GPS receiver on the tractor with a single sensor on each planter row.
   d) A GPS receiver on the tractor with multiple sensors on each planter row.

4. Why is seed singulation quality important when planting a field?

   Seed singulation quality is related to the number of seeds planted and the location of each seed. The location and number of seeds have a direct impact on crop production.

5. How is GIS used to identify and solve mechanical problems on a planter?

   GIS maps can display sensor data for each row in a planter. Then a technician can use the data to identify the cause of mechanical problems.

CASE

Lesson 4.1 Electrical Systems

Preface

Agricultural equipment uses electrical circuits to power an extensive range of devices, including lights, fans, motors, and actuators. Components such as switches, diodes, and potentiometers control a device's electrical current. Equipment manufacturers arrange components and devices in series, parallel, or series-parallel circuits to change a system's resistance. All component and device resistance is added together in a series circuit, reducing the circuit's total amperage. The total resistance will always be lower than the least resistant component or device in a parallel circuit.

Engineers use diodes to control the flow of current in a circuit. Diodes allow current to flow in one direction within a circuit. Zener diodes regulate voltage within a system. Electrical systems use alternating current (AC) or direct current (DC). Tractors operate on a 12V DC system charged with an alternator that generates AC power. A bridge rectifier consisting of four diodes converts AC voltage to DC power used to charge the battery.

Technicians calibrate electrical systems to prevent high amperage from damaging components and devices. Operators can adjust the system using a rheostat or potentiometer within the circuit. A rheostat is a variable resistor that changes the amperage supplied to an electrical device. A potentiometer is a voltage divider used to change the voltage supplied to an electrical device. Both components function by using a wiper terminal that changes the resistance in a circuit.

Students construct and calculate resistance in series, parallel, and series-parallel circuits during this lesson. Next, students build circuits containing diodes. Then they will test a charging system in a tractor using a digital multimeter. To complete the lesson, students will vary the resistance in a circuit using rheostats and potentiometers to change amperage and voltage.

Concepts	**Performance Objectives**
Students will know and understand	*Students will learn concepts by doing*
1. Agricultural equipment uses series, parallel, and series-parallel circuits.	• Construct series, parallel, and series-parallel circuits. (Activity 4.1.1) • Calculate total resistance in series, parallel, and series-parallel circuits. (Activity 4.1.1)
2. Diodes protect electrical equipment by allowing power to flow in one direction.	• Test a diode using a digital multimeter. (Activity 4.1.2) • Construct circuits using silicon diodes. (Activity 4.1.2) • Construct circuits using Zener diodes. (Activity 4.1.3)
3. Electrical systems use alternating and direct current.	• Rectify AC voltage to power an LED. (Activity 4.1.3) • Troubleshoot a tractor's charging system using a digital multimeter. (Activity 4.1.4)
4. Rheostats and potentiometers vary the resistance in an electrical circuit.	• Model a rheostat using a graphite pencil. (Activity 4.1.5) • Use a potentiometer to change the voltage in a circuit. (Activity 4.1.5)

National AFNR Common Career Technical Core Standards Alignment

Career Ready Practices
1. Act as a responsible and contributing citizen and employee.
• CRP.01.01: Model personal responsibility in the workplace and community.
2. Apply appropriate academic and technical skills.
• CRP.02.02: Use strategic thinking to connect and apply technical concepts to solve problems in the workplace and community.

Power, Structural and Technical (AG-PST)
1. Apply physical science principles and engineering applications related to mechanical equipment, structures, and biological systems to solve problems and improve performance in AFNR power, structural, and technical systems.
• AG-PST 1.2: Use hand and power tools commonly required in power, structural, and technical systems
• AG-PST 1.3: Investigate solutions to AFNR power, structural, and technical systems.
3. Service and repair mechanical equipment and power systems used in AFNR power, structural and technical systems.
• AG-PST 3.6: Service electrical systems by troubleshooting from schematics.

Next Generation Science Standards Alignment

Disciplinary Core Ideas	
Physical Science	
PS1: Matter and Its Interactions	
PS1.A: Structure and Properties of Matter	• Each atom has a charged substructure consisting of a nucleus, which is made of protons and neutrons, surrounded by electrons.
PS3: Energy	
PS3.A: Definitions of Energy	• "Electrical energy" may mean energy stored in a battery or energy transmitted by electric currents.

Science and Engineering Practices	
Planning and Carrying Out Investigations	• Select appropriate tools to collect, record, analyze, and evaluate data.
Analyzing and Interpreting Data	• Analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in order to make valid and reliable scientific claims or determine an optimal design solution.

Crosscutting Concepts	
Cause and Effect: Mechanism and Prediction	Events have causes, sometimes simple, sometimes multifaceted. Deciphering causal relationships, and the mechanisms by which they are mediated, is a major activity of science and engineering.
	• Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. • Systems can be designed to cause a desired effect. • Changes in systems may have various causes that may not have equal effects.
Energy and Matter: Flows, Cycles, and Conservation	Tracking energy and matter flows, into, out of, and within systems helps one understand their system's behavior.
	• The total amount of energy and matter in closed systems is conserved. • Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system.

Understandings about the Nature of Science	
Scientific Knowledge is Based on Empirical Evidence	• Science knowledge is based on empirical evidence. • Science arguments are strengthened by multiple lines of evidence supporting a single explanation.

Common Core State Standards for High School Mathematics

Modeling standards are indicated by the star symbol (*) throughout other conceptual categories.

CCSS: Conceptual Category – Number and Quantity	
Quantities	*Reason quantitatively and use units to solve problems.

CCSS: Conceptual Category – Algebra	
Reasoning with Equations and Inequalities	Understand solving equations as a process of reasoning and explain the reasoning. Solve equations and inequalities in one variable. Solve systems of equations.

CCSS: Conceptual Category – Statistics and Probability	
Interpreting Categorical and Quantitative Data	*Summarize, represent, and interpret data on a single count or measurement variable.
Making Inferences and Justifying Conclusions	*Make inferences and justify conclusions from sample surveys, experiments, and observational studies.
Using Probability to Make Decisions	*Calculate expected values and use them to solve problems.

Common Core State Standards for English Language Arts

CCSS: English Language Arts Standards » Science & Technical Subjects » Grade 11-12	
Key Ideas and Details	• **RST.11-12.1 –** Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account.
Craft and Structure	• **RST.11-12.4 –** Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to grades 11-12 texts and topics.
Integration of Knowledge and Ideas	• **RST.11-12.9 –** Synthesize information from a range of sources (e.g., texts, experiments, simulations) into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible.
Range of Reading and Level of Text Complexity	• **RST.11-12.10 –** By the end of grade 12, read and comprehend science/technical texts in the grades 11-CCR text complexity band independently and proficiently.

CCSS: English Language Arts Standards » Writing » Grade 11-12	
Text Types and Purposes	**WHST.11-12.2 –** Write informative/explanatory texts, including the narration of historical events, scientific procedures/experiments, or technical processes. • **WHST.11-12.2.E** – Provide a concluding statement or section that follows from and supports the information or explanation provided (e.g., articulating implications or the significance of the topic).
Research to Build and Present Knowledge	• **WHST.11-12.9 –** Draw evidence from informational texts to support analysis, reflection, and research.
Range of Writing	• **WHST.11-12.10 –** Write routinely over extended time frames (time for reflection and revision) and shorter time frames (a single sitting or a day or two) for a range of discipline-specific tasks, purposes, and audiences.

Essential Questions

1. What are parallel, series, and series-parallel circuits?
2. How does resistance change in parallel, series, and series-parallel circuits?
3. What is the relationship between ohms and volts?
4. How are amps, volts, and ohms calculated?

5. How is current controled in a circuit?
6. How can a diode regulate voltage in a circuit?
7. How is alternating current changed into direct current?
8. How does a technician check for diode leakage in a charging system?
9. What increases the resistance to electricity in a circuit?
10. How can voltage in a circuit be changed?
11. How can amperage in a circuit be changed?

Key Terms

AC voltage test	**Alternating current (AC)**	**Alternator**
Ampere	**Anode**	**Bridge rectifier**
Cathode	**Current**	**Diode**
Direct current (DC)	**Forward bias**	**Opened**
Parallel circuit	**Potentiometer**	**Rectified**
Reverse bias	**Rheostat**	**Schematic**
Series circuit	**Series-parallel circuit**	**Serpentine belt**
Short	**Stator**	**Thermistor**
Zener diode		

Day-to-Day Plans
Time: 10 days

*Refer to the Teacher Resources section for specific information on teaching this lesson, in particular **Lesson 4.1 Teacher Notes**, **Lesson 4.1 Glossary**, **Lesson 4.1 Materials**, and other support documents.*

Day 1:

- Present **Concepts**, **Performance Objectives**, **Essential Questions**, and **Key Terms** to provide a lesson overview.
- Provide students **Presentation Notes** pages to be used throughout the presentation to record notes and reflections. Students add these pages to their *Agriscience Notebook*.
- Present LunchBox Session© **Basic Electrical Units** and **Series and Parallel Circuit Basics**.
- Students take notes using the *Presentation Notes* pages provided by the teacher.

Day 2:

- Provide students with a copy of **Activity 4.1.1 Types of Circuits**.
- Students work in groups to complete Part One of *Activity 4.1.1 Types of Circuits*.

Day 3:

- Students work in groups to complete Parts Two and Three of *Activity 4.1.1 Types of Circuits*.

Day 4 – 5:

- Present LunchBox Session© **Diodes**.
- Students take notes using the *Presentation Notes* pages provided by the teacher.
- Provide students with a copy of **Activity 4.1.2 Directional Flow**.
- Provide each group of students a copy of the **Ignition System Service Manual**.
- Students work in groups to complete *Activity 4.1.2 Directional Flow*.

Day 6:

- Provide students with a copy of **Activity 4.1.3 Charging System**.
- Students work in groups to complete *Activity 4.1.3 Charging System*.
- Present YouTube video **Electrical System Troubleshooting for a Farm Tractor**.
- Students take notes using the *Presentation Notes* pages provided by the teacher.

Day 7:

- Provide students with a copy of **Activity 4.1.4 Charging Analysis**.
- Provide students with equipment to test for Parts One and Two of *Activity 4.1.4 Charging Analysis*.
- Present to students the location of the alternator and bridge rectifier in each piece of equipment used.
- Students work in groups to complete Parts One and Two of *Activity 4.1.4 Charging Analysis*..

Day 8:

- Create a fault in the charging system of a tractor or lawnmower for students to diagnose.
- Students work in groups to complete Part Three of *Activity 4.1.4 Charging Analysis*.

Day 9:

- Present LunchBox Session© **Variable Resistors**.
- Students take notes using the *Presentation Notes* pages provided by the teacher.
- Provide students with a copy of **Activity 4.1.5 Variable Resistor**.

Day 10:

- Students work in groups to complete *Activity 4.1.5 Variable Resistor*.
- *Optional*: Provide failed potentiometers for students to test during Part Three of *Activity 4.1.5 Variable Resistor*.
- Distribute **Lesson 4.1 Check for Understanding**.
- Students complete *Lesson 4.1 Check for Understanding* and submit it for evaluation.
- Use **Lesson 4.1 Check for Understanding Key** to evaluate student assessments.

Instructional Resources

LunchBox Sessions©

Basic Electrical Units

Series and Parallel Circuit Basics

Diodes

Variable Resistors

Student Support Documents

Lesson 4.1 Glossary

Presentation Notes

Activity 4.1.1 Types of Circuits

Activity 4.1.2 Directional Flow

Activity 4.1.3 Charging System

Activity 4.1.4 Charging Analysis

Activity 4.1.5 Variable Resistor

Ignition System Service Manual

Teacher Resources

Lesson 4.1 Electrical Systems PDF

Lesson 4.1 Teacher Notes

Lesson 4.1 Materials

Lesson 4.1 Check for Understanding

Answer Keys and Assessment Rubrics

Lesson 4.1 Check for Understanding Answer Key

Reference Sources

All About Circuits. Potentiometer as a Voltage Divider. Retrieved from **https://www.allaboutcircuits.com/textbook/experiments/chpt-3/potentiometer-voltage-divider/**

BBB Industries (2014). *Electrical System Troubleshooting for a Farm Tractor*. Retrieved from **https://www.youtube.com/watch?v=7iWfePTCqn4**

Briggs and Stratton Customer Education (2014). *Electrical Training Manual*.

Burris, Matthew. Lifewire. What are Diodes and What Are They Used For? Retrieved from **https://www.lifewire.com/applications-of-diodes-818815**

Herren, R. V., & Donahue, R. L. (2000). *Delmar's agriscience dictionary with searchable CD-ROM*. Albany, NY: Delmar.

Mack, J. P., Daniels, J. A., DeHart, M. A., & Norman, A. *Diesel Engine Technology: Fundamentals, Service, Repair* (Ninth Edition ed.). Tinley Park, IL: The Goodheart-Wilcox Company, Inc.

Materials Research Laboratory. *Graphite Potentiometer*. Retrieved from **https://www.mrl.ucsb.edu/sites/default/files/mrl_docs/workshops/graphite_potentiometer.pdf**

FFA Connections

This lesson provides conceptual and procedural knowledge required for participation in the following FFA activities:

- Agricultural Proficiency
  - **Agricultural Mechanics Design and Fabrication – Entrepreneurship/Placement**
  - **Agricultural Mechanics Repair and Maintenance –Placement**
  - **Agricultural Mechanics Repair and Maintenance –Entrepreneurship**
  - **Agriscience Research – Integrated Systems**
- Agriscience Fair
  - **Power, Structural and Technical Systems**
- Career Development Events
  - **Agricultural Technology & Mechanical Systems**

- Educational Resources
    - **SAE Idea Cards-Power, Structural and Technical Systems**
    - **Power, Structural and Technical System Careers**
    - **Power, Structural and Technical Systems Career Focus Area Resources**
    - Power, Structural and Technical Careers **(Word)**

Skills and knowledge from this lesson support the development and implementation of service-learning projects that address electrical systems.

- **Service-Learning and Living to Serve Grants**
    - Service-learning projects focused on diagnosing electrical system issues in agricultural and other outdoor equipment.
    - Project ideas include hosting a spring tune-up or winterization event for local community members for lawnmowers and other equipment with electrical systems.
    - Living to Serve Grants provide funding to FFA chapters to support service-learning and community service projects.

For more information, visit the **National FFA Organization** website.

SAE for All

Foundational SAE

All students in an agricultural education program are expected to have a Foundational SAE. Students completing the APP and extensions listed below will meet the Foundational SAE qualification for the *Advanced(Grades 11-12) level*. Students should place all documented evidence in the *FFA/SAE* section of their *Agriscience Notebook* along with the *SAE for All Foundational Checksheet*.

- Employability Skills for College and Career Readiness
    - Activity 4.1.4 Charging Analysis

Immersion SAE

Students interested in this lesson's topics should explore the following related Immersion SAEs. An immersion SAE is optional and replaces the agricultural literacy component of the Foundational SAE.

- **Immersion SAE Learning Guides**

For more information on the guiding principles for implementing SAE programs, visit the **SAE for All: Evolving Essentials** site.

Critical Thinking and Application Extensions

Explanation

1. Students will research how electrical connections impede a circuit within a tractor or car's charging system.

Application

2. Students will test a potentiometer on agricultural equipment and determine if it meets OEM specifications.

Self-Knowledge

3. Students will use a digital multimeter to test the charging system in their vehicles.

CASE

Lesson 4.1 Teacher Notes

Lesson 4.1 Electrical Systems

In preparation for teaching this lesson, review Concepts, Performance Objectives, Essential Questions, and Key Terms, along with presentations. Also, review all activity, project, and problem directions, expectations, and work students will complete.

Students use a digital multimeter (DMM) to test electrical circuits throughout this lesson. First, they assemble series, parallel, and series-parallel circuits and calculate the resistance in each circuit. Then, students will test silicon diodes and Zener diodes in a circuit that controls the current flow. Next, students test the charging system in a tractor to test the alternator and bridge rectifier. Finally, students model using a rheostat and a potentiometer to change current and voltage within a circuit.

LunchBox Sessions©

Register for one **LunchBox Session©** account with rights for presenting to your class. LunchBox Sessions are short information sessions technicians can use to refresh themselves on fundamental mechanics.

Basic Electrical Units

This presentation reviews electrical concepts taught in *Agricultural Power and Technology (APT)*. Content includes electrical units and their relationship within Ohm's Law. Students learning this material without an APT background may need extra time reviewing **Ohm's Law Equations**.

Series and Parallel Circuit Basics

Use the presentation to review the properties of series and parallel circuits and how to measure the total resistance of the circuit.

Diodes

This presentation explains the physical properties of semiconductors and the function of a diode. The terms cathode, anode, forward-bias, and reverse-bias are discussed during this LunchBox Sesson©.

Variable Resistors

Use the presentation at the beginning of the lesson to preview potentiometers and rheostats.

Activities, Projects, and Problems

Activity 4.1.1 Types of Circuits

Students construct series, parallel, and series-parallel circuits on a Basic Electrical Training Board. Students measure resistance in each circuit. In a series circuit, resistance adds. In a parallel circuit, resistance divides. The formulas for calculating resistance in series, parallel, and series-parallel circuits are listed in Table 1.

Table 1. ***Formulas for Calculating Total Resistance***

Circuit	Formula
Series Circuit	$R_{total} = R_1 + R_2 + \dots R_n$

Parallel Circuit	$R_{total} = \dfrac{1}{\frac{1}{R_1}+\frac{1}{R_2}}$
Series-Parallel Circuit	$R_{total} = \left[\dfrac{1}{\frac{1}{R_1}+\frac{1}{R_2}}\right] + \left[\dfrac{1}{\frac{1}{R_3}+\frac{1}{R_4}}\right]$

Teacher Preparation

- Review the LunchBox Sessions© *Basic Electrical Units* and *Series and Parallel Circuits* before starting the activity.
- Charge the 12V batteries in the Basic Electrical Training Board using the provided battery chargers. Connect the black terminal last to the battery. The batteries are fully charged when the green light on the charger turns on.

Student Performance

Students assemble a circuit on the Basic Electrical Training Board using a series schematic in Part One and a parallel circuit schematic in Part Two. Next, students use a DMM to answer analysis questions. Then they construct a series-parallel circuit for Part Three and answer the corresponding analysis questions. Finally, in Part Four, they list possible causes and corrections of a fault in a parallel circuit.

Results and Evaluation

During this activity, students should understand the application of series, parallel, and series-parallel circuits. In a series circuit, the total resistance is summative. In parallel, total resistance divides. This concept is foundational to electrical properties in Units 4–5. Potential responses to analysis questions are available in Table 2. Table 3 includes example causes and corrections for Part Four.

Table 2. ***Analysis Questions and Potential Responses***

Part One Analysis Questions		
Q1	Is the amperage the same at each point in the series circuit?	*Amperage stays the same throughout each part of a series circuit.*
Q2	How are electrical loads and components dependent upon each other in a series circuit?	*If one component becomes open in a series circuit, the entire circuit loses power.*
Q3	Why is the calculated resistance different than the measured resistance?	*Calculated resistance did not include resistance in the switch and wires.*
Part Two Analysis Questions		
Q4	How do the amperage readings of the parallel circuit compare to the series circuit?	*The amperage is higher because the resistance is lower in the parallel circuit.*
Q5	Why are electrical loads and components NOT dependent upon each other in a parallel circuit?	*In a parallel circuit, if one component fails, the remaining branches remain closed and operational. There are multiple paths for electricity to follow.*
Part Three Analysis Questions		
Q6	How are the parallel branches of the series-parallel circuit different from each other?	*Answers could vary based upon the resistor used. The resistor supplied with the board is 3.1Ω.* *The first branch is brighter because it has less resistance.*
Q7	What is the total resistance of the system?	*The total resistance is calculated by adding the resistance of each parallel branch.* $Branch\ 1 = \dfrac{1}{\frac{1}{2.6}+\frac{1}{2.6}}$ $\quad Branch\ 2 = \dfrac{1}{\frac{1}{2.6}+\frac{1}{3.1}}$

		Branch 1 = 1.3Ω *Branch 2 = 1.4Ω* *1.3Ω + 1.4Ω = 2.7Ω*

Table 3. ***Part Four Potential Responses***

Problem	Fault	Causes	Corrections
You are a technician for a local dealership working on a circuit with two 120Ω resistors wired in parallel, as shown in Figure 7. While diagnosing the circuit with a DMM, you measured 120Ω of resistance for the entire circuit. List the fault of the circuit in your Logbook. Include potential causes and corrections.	*One of the branches opened, creating a series circuit. The circuit with two 120Ω resistors should have a total resistance of 60Ω.*	*Causes can include a blown resistor, open connection, cut wire, or corrosion.*	*Replace or repair components.*

Activity 4.1.2 Directional Flow

Students learn about the role of diodes in an electrical circuit. A DMM is used to check the diodes to see if they are good, opened, or shorted. A good diode will read 0.5V to 0.8V in forward bias and OL in reverse bias when using the diode testing function. A diode is a semiconductor with an anode and a cathode marked with a line or a ring. The anode side allows for current flow to the cathode side, called forward bias. However, a diode wired in reverse bias will not allow for current flow from the cathode side to the anode side. Students set up circuits to demonstrate the properties of a diode in forward and reverse bias. Next, students will use a Zener diode that allows for current flow at breakpoints to regulate voltage or flow.

Teacher Preparation

- Review the LunchBox Sessions© *Diodes* before starting the activity.
- Check a local agricultural equipment dealer for any blown diodes to incorporate for Part One.
- Mark the silicon and Zener diodes to help students use the correct diode for Parts Two and Three.

Student Performance

Part One

Students will use a DMM with a diode testing function to test diodes to see if they are good, opened, or shorted.

- A good silicon diode will read 0.5V to 0.8V in forward bias and OL in reverse bias.
- An opened diode will read OL in both forward and reverse bias.
- A shorted diode will read 0V – 0.4V in both directions.
- Print copies of the **Ignition System Service Manual** for each group.

Part Two

Students assemble the circuit shown in Figure 1. While testing, the light should turn on while the diode is in forward bias and off when in reverse bias.

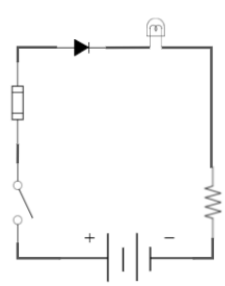


Figure1. Silicon Diode Circuit

Part Three

Students will use the *Ignition System Service Manual* to determine faults for two customer complaints. Students will record the complaint, cause, and correction in their *Logbook*.

Results and Evaluation

During this activity, students should understand the function and application of diodes. OEMs use diodes to control the directional flow of electricity in a circuit. Students scaffold learning with diodes in *Activity 4.1.3 Charging System*. Potential responses to analysis questions are available in Table 4. Answers to Part Four are listed in Table 5.

Table 4. ***Analysis Questions and Potential Responses***

Q1	How do you know if a diode is good, opened, or shorted?	*Answers will vary.* *A good silicon diode will read 0.5V to 0.8V in forward bias and OL in reverse bias.* *An opened diode will read OL in both forward and reverse bias.* *A shorted diode will read 0V – 0.4V in both directions.*
Q2	What would a technician do with an opened or shorted diode in a circuit?	*Technicians should replace the diode with the correct diode. Before replacing the diode, a technician will review the Five Whys to determine how and why the diode failed.*
Q3	How did changing from forward bias to reverse bias affect the bulb?	*In forward bias, the circuit is open, and the bulb should light up. In reverse bias, the circuit is closed, and the bulb should be off.*

Table 5. ***Part Four Responses***

Complaint	Cause	Correction
Complaint 1 A customer brought in a lawnmower that would not run. The engine fails the spark test, but the armature gap, magneto, spark plug, and timing are all functional.	*Two closed diodes in the wiring harness*	*Replace the wiring harness or repair the diodes. Check for shorts that cause the diodes to blow.*
Complaint 2 A customer has a lawnmower that will not turn off when the customer turns the ignition to the off position. However, the ignition switch and all connections are functional.	*Two open diodes in the wiring harness*	*Replace the wiring harness or repair the diodes. Check for shorts that cause the diodes to blow.*

Activity 4.1.3 Charging System

Students observe AC and DC currents by rectifying a small AC motor that powers an LED bulb. Next, students assemble and observe a circuit with a Zener diode as a voltage regulator.

Teacher Preparation

Part One
Prepare the AC mini-hand motor to connect to the bridge rectifier on the KidWind Power Output Board. Breadboard jumper wires typically come in ribbons. Separate two of the cables for each group of four students.

Part Two
Source Zener diodes rated 2V through Amazon.

Student Performance

Part One
Students will test the AC mini-hand motor attached to an LED bulb. Students crank the motor to see if the bulb stays lit or blinks. Students will observe a blinking light under AC power. Next, a bridge rectifier is used to rectify the input voltage to DC power to keep the bulb lit while turning the motor. Do not use a drill to turn the mini-hand motor. While it will generate more electricity, it may overload the diodes in the bridge rectifier.

Part Two
Students assemble a circuit with a Zener diode, as shown in Figure 2. The Zener diode regulates the voltage available to the DMM. They turn the motor and read the maximum voltage produced. Then, students remove the Zener diode and turn the motor again, reading the maximum voltage produced.

Figure 7. Zener Diode Schematic

Results and Evaluation
During Part One, students should observe the LED light blinking before connecting to the bridge rectifier. The bridge rectifier converts the AC current to DC, allowing the LED to stay light when turning the motor. Alternators produce AC current. This current must be rectified before charging the DC battery.

During Part Two, students should note a level production around 2V when using the Zener diode. The diode protects the load (DMM) from receiving a charge over 2V. A 12V system is equipped with a 14V Zener diode protecting the battery from being overcharged.

Potential responses to analysis questions are available in Table 6.

Table 6. *Analysis Questions and Potential Responses*

Q1	Was the AC voltage from the mini-hand motor rectified? How do you know?	*Yes.* *Students might note a brighter light or a more consistent light. This is because the rectified voltage keeps a more consistent current source to the LED. A non-rectified input current would result in a weak, blinking LED.*
Q2	How did the Zener diode impact the voltage available to the load (DMM)?	*Answers may vary. The Zener diode regulated the voltage, ensuring no more than 2V of electricity was available to the DMM.*
Q3	How can a Zener diode protect a load, such as a battery in a charging system?	*Zener diodes regulate voltage. In a charging system, the battery should not charge above 14V. The Zener diode protects the battery from overcharging.*

Activity 4.1.4 Charging Analysis
Students work in groups to test the charging system within a tractor.

Teacher Preparation
Review the YouTube video **Electrical System Troubleshooting for a Farm Tractor**.

Parts One–Two
The teacher should find equipment to test. A smaller tractor will work best, but any tractor with easy assess to the alternator and 12V battery will work. Riding lawn mowers will work for this activity as well. If using a riding lawn mower, note that the alternator is different. Lawnmowers use a stator underneath the flywheel to generate current. Practice the test procedure before students attempt it,.

Part Three

Prepare a tractor or lawnmower for testing the charging system. Students will test a tractor with the following customer complaint:

- Customer complaint: The tractor will work fine after starting, but the battery continues to die. The customer replaced the battery one month ago.

The tractor chosen for testing does not need a failed alternator to demonstrate this activity's concept and skill objectives. Examples of preparations are listed in Table 7.

Table 7. ***Part Four Preparation***

Simulated Failure	Tools/Materials	Procedure
Alternator cable	• Rachet • Socket • Electrical tape	Disconnect the negative battery cable from the battery. Remove the red cable from the back of the alternator. Next, wrap electrical tape around the connector. Reattach the connection and reconnect the battery cable.
Field connection	• Rachet • Socket • Electrical tape	Disconnect the negative battery cable from the battery. Loosen the field connector from the backside of the alternator. Place electrical tape inside the field circuit connection on the back of the alternator. Lightly place the field connection back into the alternator. Replace the negative battery cable.
Failed alternator	• Rachet • Socket • Failed alternator (from a local dealership)	Disconnect the negative battery cable from the battery. Disconnect the cables from the alternator. Remove the working alternator and replace it with the failed alternator. Reconnect the alternator cables before reconnecting the battery.

Student Performance

Parts One–Two

Students test an alternator on a tractor using a DMM. The Procedure outlines tests to do while the tractor engine is off, the key switch is on, or while the tractor is idling. Students collect the readings using a DMM and answer the analysis questions.

Part Three

Students repeat the Procedures outlined in Parts Two and Three to troubleshoot a tractor with a charging system failure. Students use the diagnostic process to find the cause and recommend repairs. Students record the complaint, cause, key parts, correction, and confirmation in their *Logbook*.

Results and Evaluation

Students should complete the lab diagnostic skills associated with testing the charging system. Often, the charging system is not always impeded by the alternator but by connections in the circuit, such as a field circuit. Potential responses to analysis questions are available in Table 8.

Table 8. ***Analysis Questions and Potential Responses***

Q1	When the tractor was *turned off*, did the battery voltage meet the criteria of the 12-volt system?	*Answers will vary.* *A battery should be slightly over 12V.*
Q2	Why is battery voltage routed to the alternator if the alternator charges the battery?	*Routing battery voltage back through the alternator allows for a complete circuit.*

Q3	When the tractor was *turned off*, did the tractor meet the criteria of the 12-volt system?	*Answers will vary.* *The voltage coming to and from the alternator while the tractor is in the off position should be consistent with the battery voltage.*
Q4	When the tractor was *idle*, did the battery voltage meet the criteria of the 12-volt system?	*Answers will vary.* *A battery should be slightly over 14V but less than 15V.*
Q5	Should the alternator be replaced? Why or why not?	*Answers will vary.* *The alternator is not charging the system if the battery voltage is less than 14V while the tractor is on.*
Q6	Is the bridge rectifier working correctly? Why or why not?	*Answers will vary.* *The presence of 100 mV (0.1 V) or more at the battery indicates a diode problem.*

Activity 4.1.5 Variable Resistor

Rheostats and potentiometers change the resistance in an electrical circuit. A rheostat is a two-terminal variable resistor used to change the amperage in a circuit. A potentiometer is a three-terminal variable resistor used to change the voltage in a circuit. Students learn how to use these parts in a circuit during this activity.

Teacher Preparation

1. Review the LunchBox Sessions© *Variable Resistors* before starting the activity.
2. Obtain 6B graphite pencils that conduct electricity. These pencils are available in the craft aisle of your local retailer.
3. Test potentiometers before distribution to students.
    - Place a DMM leads on the outside terminals and read resistance. Turn the knob. As the knob turns, the resistance should not change.
    - Place the DMM leads on one outside terminal and the wiper and read resistance. Turn the knob. The resistance should change as the knob turns.
    - Optional: Save any faulty potentiometers for students to test in Part Three.

Student Performance

Part One

Students fill in a model variable resistor using a graphite pencil. Next, students will use the DMM to test resistance across the model and then calculate for amperage change in a hypothetical circuit. The model demonstrates a rheostat's properties that vary resistance to control amperage in a circuit.

Part Two

Students construct a circuit using a potentiometer. Then, they use a DMM to measure the voltage and current within the circuit. As the knob turns, the voltage to the wiper is reduced, and the amperage stays the same.

Part Three

Students write a procedure to test a potentiometer using a DMM. Next, students demonstrate the procedure to the teacher. They record the procedure in their *Logbook*.

Results and Evaluation

Potential responses to analysis questions are available in Table 9.

Table 9. *Analysis Questions and Potential Responses*

Q1	What is the role between resistance and amperage in a rheostat?	*Resistance is changed in a rheostat to regulate amperage in a circuit.*
Q2	What is consistent in a rheostat?	*In a rheostat, the voltage in the circuit is consistent.*
Q3	Where are the wires connected to a potentiometer when wiring as a rheostat?	*The output connects to the wiper, and the battery power connects to one of the terminals. Only two of the three terminals are wired.*
Q4	What electrical unit is consistent within a circuit when using a potentiometer?	*The amperage in a circuit is consistent when varying the resistance in a circuit with a potentiometer.*
Q5	Why is a potentiometer known as a voltage divider?	*As the wiper moves across the potentiometer, the voltage decreases. The output voltage is a fraction of the incoming input voltage.*

Assessment

Lesson 4.1 Check for Understanding

Lesson 4.1 Check for Understanding is included for you to use as an assessment tool for this lesson. Use **Lesson 4.1 Check for Understanding Answer Key** for evaluation purposes.

Name____

Activity 4.1.1 Types of Circuits

Purpose

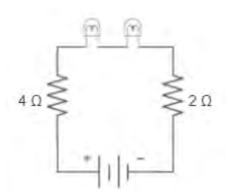
Agricultural equipment primarily uses a 12-volt electrical system. A battery powers the electrical systems in equipment with an engine. An alternator recharges the battery while the engine is running. Electrical current in the mobile system moves from the battery to the circuit loads, such as lights or the starting motor, and back to the source. Technicians troubleshoot the electrical system by applying Ohm's Law to electrical circuits. The three components of Ohm's Law are voltage, the resistance measured in Ohm's (Ω), and electrical current (amperes). Figure 1 details the relationship between volts, amps, and Ohms.

$$\text{volts} = \text{ohms} \times \text{amps}$$

$$12V = 2\Omega \times 6 \text{ amps}$$

Figure 1. Ohm's Law

Agricultural equipment has three types of electrical circuits. These circuits are series, parallel, and series-parallel circuits. The main difference between these circuits is the route electrons flow through the circuit. Figure 2 shows a series circuit with one path for current to flow. If a component within the circuit fails, the entire circuit will be open. The total resistance for the circuit is the sum of all resistors in the circuit. The total resistance in Figure 2 is 6Ω.



$$R_{total} = R_1 + R_2 + \ldots R_n$$

$$R_{total} = 4\Omega + 2\Omega$$

$$R_{total} = 6\Omega$$

Figure 2. Series Circuit

Parallel circuits provide multiple paths for current to flow. Each path works independently of the other. If one branch of the circuit becomes open, other branches will continue to operate. In a parallel circuit, current can flow through multiple resistors simultaneously and is calculated using the formula shown in Figure 3. Parallel circuits are popular in agricultural equipment because their total resistance will always be lower than the load with the lowest resistance. A series-parallel circuit contains a parallel circuit built into a series circuit.

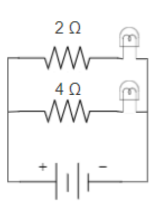
	$R_{total} = \dfrac{1}{\frac{1}{R_1} + \frac{1}{R_2}}$	$R_{total} = \dfrac{1}{\frac{1}{4} + \frac{1}{2}}$	$R_{total} = \dfrac{1}{{}^{3}/_{4}}$ $R_{total} = 1.33\Omega$

Figure 3. Parallel Circuit

Where are series and parallel circuits used in agricultural equipment? How can a technician troubleshoot a basic circuit?

Materials

Per group of four students:

- Basic Electrical Training Board
- Battery, 12V
- Digital multimeter (DMM)
- Fuse, 10A
- Resistor, 100Ω
- (15) Wire with alligator clips

Per student:

- Device with calculator
- Safety glasses
- Pen
- *Agriscience Notebook*

Procedure

Use the Basic Electric Training Board to wire a series, parallel, and series-parallel circuit. Then, analyze the circuit using a digital multimeter (DMM) and record the results on the student data page.

Part One – Series Circuit

1. Put on safety glasses and tie back long hair.
2. Use a DMM to find the resistance of *Bulb One* and *Bulb Two*. Record the resistance in Table 1 of *Activity 4.1.1 Student Data*.
3. Calculate the total resistance of *Bulb One* and *Bulb Two* if connected in series and record the calculated resistance in Table 1.
4. Wire the series circuit as shown in Figure 4 using a 10A fuse and five wires with alligator clips.

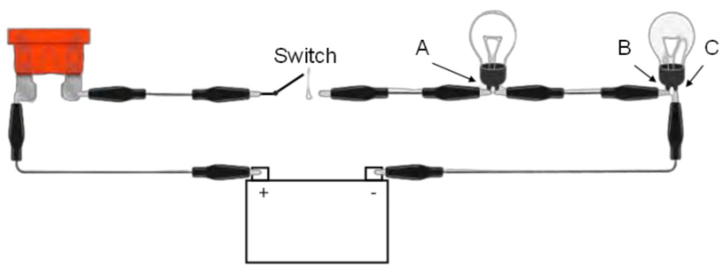


Figure 4. Series Schematic

5. Disconnect the leads from the battery.
6. With the switch to the on position, use the DMM to find the circuit's total measured resistance and record it in Table 1.
7. Turn the switch off.
8. Connect the leads to the battery.
9. Turn the switch to the on position.
10. Use the amp clamp to measure amperage (DC) at points *A*, *B*, and *C*. The screen of the DMM should face the positive side of the circuit. Record results in Table 1.
11. Record the brightness of the bulbs as bright or dim in Table 1.
12. Remove each bulb and observe how it affects the circuit. Record in Table 1.
13. Answer the *Part One Analysis Questions*.
14. Turn off the circuit.

Part Two – Parallel Circuit

1. Wire the parallel circuit shown in Figure 5 using a 10A fuse and six wires with alligator clips.

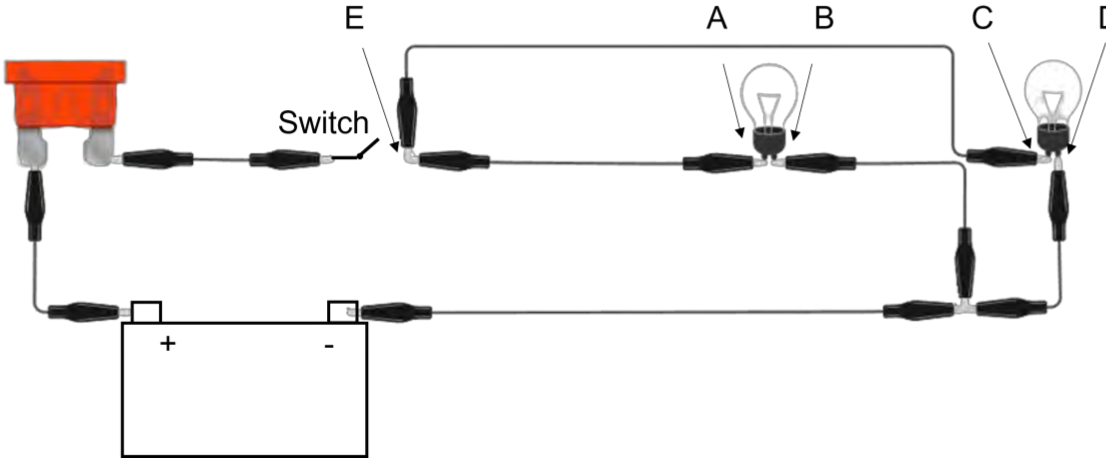


Figure 5. Parallel Schematic

2. Calculate the resistance using the formula in Figure 3 and record it in Table 2.
3. Turn on the switch.
4. Use the amp clamp to measure amperage (DC) at points *A*, *B*, *C*, *D*, and *E*. Record results in Table 2.
5. Record the brightness of the bulbs as *bright* or *dim* in Table 2.
6. Remove each bulb and observe how it affects the circuit. Record in Table 2.
7. Turn off the circuit.
8. Answer *Part Two Analysis Questions*.

Part Three – Series-Parallel Circuit

1. Wire a fuse, switch, battery, and two parallel circuits together in series on the electrical training board using these directions.
    - Wire Bulbs 1 and 2 parallel to each other, as shown in Figure 6.
    - Wire Bulb 3 and a resistor parallel to each other, as shown in Figure 6.
2. Turn on the switch.
3. Evaluate the circuit.
    - Observe the brightness of the two parallel branches.
    - Evaluate the electrical properties of each parallel branch with a DMM.
4. Answer the *Part Three Analysis Questions*.

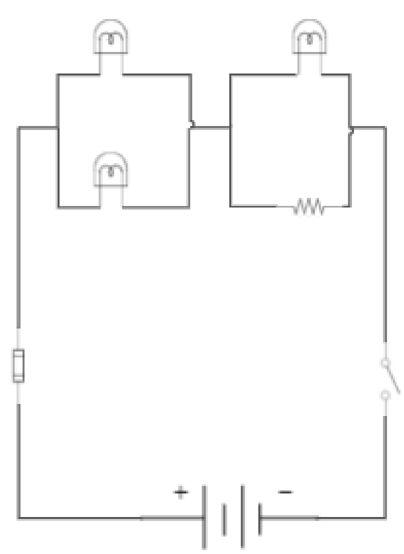


Figure 6. Series-Parallel Schematic

Part Four – Circuit Change

You are a technician for a local dealership working on a circuit with two 120Ω resistors wired in parallel, as shown in Figure 7. While diagnosing the circuit with a DMM, you measured 120Ω of resistance for the entire circuit. List the circuit's fault along with potential causes and corrections in Table 3.

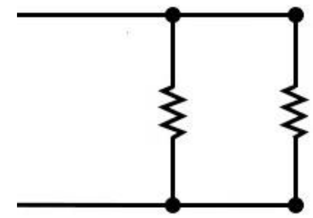


Figure 7. Circuit

Conclusion

1. What proprieties of a parallel circuit make them desirable in agricultural and power equipment?

2. What types of applications would a series-parallel circuit be desirable?

3. What are the differences between resistance in series and parallel circuits?

Name____

Activity 4.1.1 Student Data

Table 1. ***Series Circuit***

Resistance (Ω)	**Bulb 1**	**Bulb 2**	**Total Resistance**	
			Calculated	**Measured**
Amperage	**A**	**B**	**C**	

Circuit Description	**Bulb 1 Observations**	**Bulb 2 Observations**
Circuit On		
Bulb 1 Removed		
Bulb 2 Removed		

Part One Analysis Questions

Q1 Is the amperage the same at each point in the series circuit?

Q2 How are electrical loads and components dependent upon each other in a series circuit?

Q3 Why is the calculated resistance different than the measured resistance?

Table 2. ***Parallel Circuit***

Total Resistance (Ω)					
Amperage	**A**	**B**	**C**	**D**	**E**

Circuit Description	**Bulb 1 Observations**	**Bulb 2 Observations**
Circuit On		
Bulb 1 Removed		
Bulb 2 Removed		

Part Two Analysis Questions

Q4 How do the amperage readings of the parallel circuit compare to the series circuit?

Q5 Why are electrical loads and components NOT dependent upon each other in a parallel circuit?

Part Three Analysis Questions

Q6 How are the parallel branches of the series-parallel circuit different from each other?

Q7 What is the total resistance of the system?

Table 3. ***Part Four Circuit Change***

Fault	Causes	Corrections

Name____

Activity 4.1.2 Directional Flow

Purpose

When driving a car, the driver uses the steering wheel to control the car's direction and the gas pedal to control the speed. It would not be easy to control the car’s movement without these functions. Electrical circuits use diodes to restrict flow to one direction while resisting flow in the other direction. Diodes control the direction of current flow, rectify voltage, protect electrical components, or regulate voltage. Figure 1 shows the schematic symbol for a diode. The arrow points in the direction of the current flow.

A diode has both positive and negative semi-conducting material, allowing the device to work as an electrical check valve to restrict current. In this application, the diode acts as either a conductor or insulator, depending upon the direction of current flow. A diode has two terminals, an anode and a cathode. The anode is the positive side of the diode, and the cathode is the negative side. Current in a diode can only flow from the anode to the cathode or positive to negative. Cathodes have a line or ring. Figure 2 shows a diode marked with a grey ring on the cathode side.

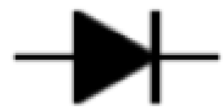


Figure 1. Diode Symbol

Figure 2. Diode Cathode Marking

A circuit can be designed with a diode in forward bias or reverse bias. Anodes connected to the positive side of the circuit allow current to flow in forward bias. A diode connected in reverse bias is wired with the cathode connected to the positive side of the circuit and will not allow current flow.

How would a technician check for a failed diode?

Materials

Per group of four students:

- Basic Electrical Training Board
- Battery, 12V
- Digital multimeter (DMM)
- Fuse, 10A
- *Ignition System Service Manual*
- LED bulb, 10mm
- Resistor, 100Ω
- Silicon diode, failed
- Silicon diode, new
- (6) Wire with alligator clips

Per student:

- Pen
- Safety glasses
- *Agriscience Notebook*
- *Logbook*

Procedure

As a group, test for directional continuity in diodes to determine functionality. Next, use the Basic Electrical Training Board to wire schematics using a silicon diode and a Zener diode.

Part One – Diode Test Analysis

Digital multimeters (DMM) produce a small voltage between the test leads while in *Diode Test* mode. For your safety and accurate reading, use the DMM to measure the potential voltage in the diode. Use a different diode if you detect voltage.

1. Put on safety glasses and tie back long hair.
2. Set up your digital multimeter (DMM) to *Diode Test* mode (⊣▶⊢).
3. Obtain a new silicon diode from your instructor.
4. Connect the black lead to the cathode side (marked) and the red lead to the anode to test forward bias.
5. Record the voltage reading in Table 1 of *Activity 4.1.2 Student Observations*.
6. Switch the leads to opposite sides of the diode to test in reverse bias.
7. Record the voltage reading in Table 1.
8. Determine if your diode is good, opened, or shorted. Place an X in Table 1 to indicate the diode functionality.
    - A good silicon diode will read 0.5V to 0.8V in forward bias and open (*OL*) in reverse bias.
    - An opened diode will read open (*OL*) in forward and reverse bias.
    - A shorted diode will read 0V – 0.4V in both directions.
9. Repeat Steps 4–8 with an LED.
10. Repeat Steps 4–8 with a failed diode.
11. Answer *Part One Analysis Questions*.

Part Two – Silicon Diode

1. Use the schematic in Figure 4 to assemble a circuit on the Basic Electrical Training Board using wires with alligator clips.
    - Place the diode in forward bias with the cathode marking on the bulb side of the circuit.
2. Turn the switch on, observe the light, and record your observations in Table 2.
3. Set up your DMM to read in DC volts. Place the red lead on the anode side of the diode and the black lead on the cathode side (marked). Record the voltage in Table 2.
4. Shut off the switch.
5. Switch the direction of the diode, placing it in reverse bias.
6. Repeat Steps 2–3 with the diode in reverse bias.
7. Answer the *Part Two Analysis Question*.

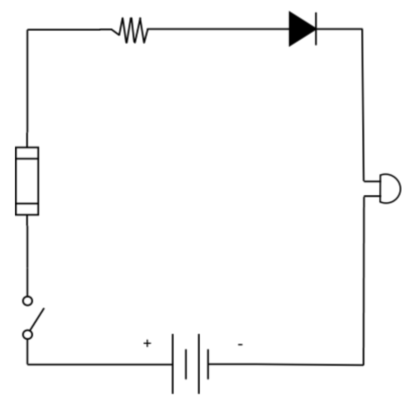


Figure 4. Silicon Diode Schematic

Part Three – Diode Situations

Review the two complaints on a V-Twin OHV engine. Use the *Ignition System Service Manual* to determine faults for each customer complaint. Next, record the complaint, cause, and correction in your *Logbook*. Finally, describe how the technician would use a DMM to confirm the diagnosis.

Complaint 1
A customer brought in a lawnmower that would not run. The engine fails the spark test, but the armature gap, magneto, spark plug, and timing are all functional.

Complaint 2
A customer has a lawnmower that will not turn off when the customer turns the ignition to the off position. However, the ignition switch and all connections are functional.

Conclusion

1. What is the difference between the anode and cathode ends of a diode?

2. What should a technician take into consideration when connecting LEDs to a circuit?

3. What is the function of the diode in an engine ignition circuit?

Name____

Activity 4.1.2 Student Observations

Table 1. ***Diode Test***

Diode	DMM Reading		Diode Functionality		
	Forward Bias	Reverse Bias	Good	Opened	Shorted
Silicon diode, new					
LED					
Silicon diode, failed					

Part One Analysis Questions

Q1 How do you know if a diode is good, opened, or shorted?

Q2 What would a technician do with an opened or shorted diode in a circuit?

Table 2. ***Silicon Diode***

Measurement	Forward Bias	Reverse Bias
Light bulb		
Voltage		

Part Two Analysis Question

Q3 How did changing from forward bias to reverse bias affect the bulb?

Name____

CASE

Activity 4.1.3 Charging System

Purpose

The battery powers the starting motor and all electrical elements in agricultural equipment. Most equipment has a 12V direct current (DC) system continually charged by an alternator producing alternating current (AC). The process of converting AC current to DC current, and ensuring the battery is not overcharged is controlled with diodes. Technicians must understand AC and DC properties and the function of diodes diagnose and repair issues within a charging system.

A 12V charging system includes a battery, an alternator, a Zener diode and a rectifier. The battery is a 12-volt, wet-cell battery producing DC voltage. When an engine is off, a battery should be 12-12.4V DC. While the engine operates, the alternator charges the battery. The alternator has to produce more voltage (force) than the battery for the battery to charge. The battery should operate at 14V DC while the engine is running. These base readings are part of a simple test to diagnose if the alternator is functional. Since the alternator produces AC, a bridge rectifier with four inner-connected diodes changes the current to DC. If the bridge rectifier fails, AC current leaks to the battery and can cause premature battery failure. Figure 1 shows a basic diagram of a 12V charging system.

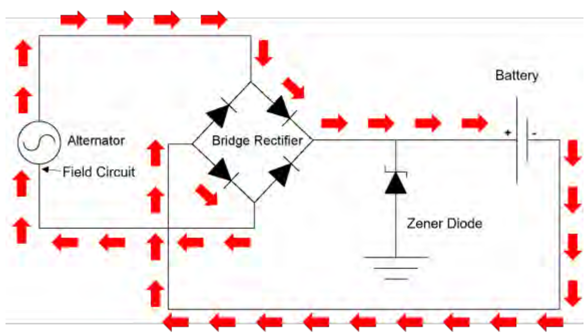


Figure 1. 12V Charging System

The alternator is a generating motor powered by a belt-drive system. As shown in Figure 2, the serpentine belt connects several system components. As the crankshaft pulley turns, the alternator turns. Inside the alternator is a rotor with oppositely poled magnets. AC voltage generates as the rotor turns inside a copper coil called a stator. Outdoor power equipment utilizing a 12V charging system, such as a riding lawn mower, uses a stator instead of a traditional alternator. The stator is a coil of wire placed underneath the engine flywheel. The flywheel contains a magnet producing alternating current as it rotates.

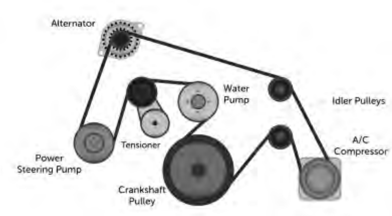


Figure 2. Serpentine Belt

Note the location of a Zener diode in Figure 1. A Zener diode controls the rate at which the charge is released to the battery to prevent overcharging. A Zener diode allows the current to flow backward when the voltage meets specific criteria. For example, a Zener diode with a breakdown voltage of 5V will not allow the current to flow until it has reached 5V. In a car, the charging system uses a Zener diode to regulate the battery's voltage to ensure it does not overcharge. Figure 3 shows the schematic symbol for a Zener diode.

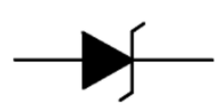


Figure 3. Zener Diode

How are diodes used in a charging system?

Materials

Per group of four students:

- AC mini-hand motor
- (2) Breadboard pin wire, male to female
- Digital multimeter (DMM)
- KidWind Output Power Board
- LED bulb, 10mm
- (4) Wire with alligator clips
- Zener diode, 2V rating

Per student:

- Pen
- Safety glasses
- *Agriscience Notebook*
- *Logbook*

Procedure

Work with your group to simulate converting AC power to DC power using a bridge rectifier. Next, wire schematics using a silicon diode and a Zener diode.

Part One – AC Simulation

1. Put on safety glasses and tie back long hair.
2. Connect the AC mini-hand motor to an LED, as shown in Figure 4.
    - The LED anode has a longer leg and connects to one of the outside pins.
    - The cathode has a shorter leg and attaches to the middle pin.
3. Crank the motor until the LED bulb lights up. If the LED does not light up, switch leads.
4. Record your observations of the *non-rectified* circuit in Table 1 of *Activity 4.1.3 Student Observations*.
5. Replace the LED with two male-to-male jumper wires, as shown in Figure 5.
6. Assemble a circuit to rectify the output voltage of the motor using the bridge rectifier shown in Figure 6.
    - Connect the jumper wire connected to the outside cable of the motor to the top AC connection using a wire with alligator clips.
    - Connect the jumper wire connected to the middle cable of the motor to the bottom AC connection using a wire with alligator clips.
    - Connect the LED light to the DC side of the bridge rectifier using wires with alligator clips.
7. Crank the motor until the LED bulb lights up.
    - If the LED does not light up, switch leads.
8. Record your observations of the *rectified* circuit in Table 1.
9. Draw a schematic in Table 2 of the rectified circuit.
    - Show the path from the source, through the bridge rectifier, to the load, and back to the source.
    - Use the wiring symbols provided in Table 2.
10. Answer the *Part One Analysis Question*.

Figure 4. Bridge Rectifier Connections

Figure 5. Male-to-Male Jumper Wires

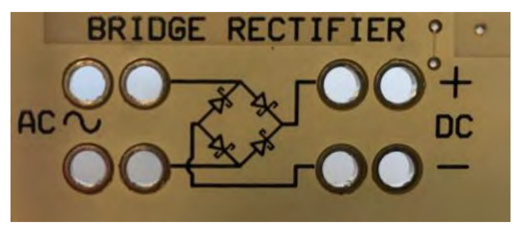


Figure 6. Bridge Rectifier Connections

Part Two – Zener Diode

1. Place a Zener diode parallel to the AC mini-hand motor and a DMM, as shown in Figure 7.
2. Turn the DMM to read AC voltage. Press MAX to read the maximum voltage.
3. Turn the motor clockwise with your hand. Record the maximum AC Voltage in Table 3.
    - Spin the motor as quickly as possible, attempting to generate the most electricity possible.
4. Clear the readings by turning off the DMM.
5. Remove the Zener diode from the circuit and reconnect the cables with alligator clips.
6. Repeat Steps 2–3 to observe the circuit without a Zener. Record DMM readings in Table 3 under the column *circuit without Zener.*
7. Answer the *Part Two Analysis Questions*.

Figure 7. Zener Diode Schematic

Conclusion

1. When is a Zener diode used in a circuit?

2. What potential errors could occur if a diode in a charging system fails?

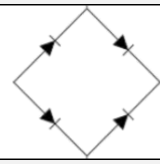
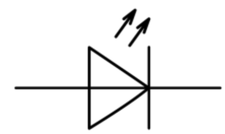
Name____

Activity 4.1.3 Student Observations

Table 1. ***LED Observations***

Circuit	Observations
Non-Rectified	
Rectified	

Table 2. ***Schematic***

Alternator	Bridge Rectifier	LED
		
Schematic		

Part One Analysis Question

Q1 Was the AC voltage from the mini-hand motor rectified? How do you know?

Table 3. ***Zener Diode***

Measurement	Circuit with Zener	Circuit without Zener
AC Voltage		

Part Two Analysis Questions

Q2 How did the Zener diode impact the voltage available to the load (DMM)?

Q3 How can a Zener diode protect a load, such as a battery in a charging system?

Name____ CASE

Activity 4.1.4 Charging Analysis

Purpose

The battery powers the starting motor and all electrical elements in agricultural equipment. Most equipment has a 12V direct current (DC) system continually charged by an alternator producing alternating current (AC). Technicians can apply knowledge of AC and DC properties to diagnose and repair issues within a charging system. Using a digital multimeter (DMM), technicians pinpoint potential issues at the alternator and battery.

Alternator Testing

- **DC battery voltage supplied to the field circuit** – The field circuit is a connection between the battery and the alternator. If this connection is corroded, the charging circuit is open and the alternator cannot charge the battery. The field circuit connection if Figure 1 is the small yellow cable connected the the alternator.
- **DC voltage coming out of the alternator –** With the engine off, a technician checks the DC voltage coming through the alternator. This verifies that current flows through the alternator without impedence.
- **AC amperage** – Lastly, with the engine in operation, the technican verifies alternator function. Is the alternator producing AC current?

Figure 1. Alternator

Battery Testing

- **DC battery voltage (engine off)** – Does the battery hold a good charge? When an engine is off, a battery should be 12-12.4V DC.
- **DC battery voltage (engine idle)** – Does the alternator produce enough electrical force to charge the battery? The alternator has to produce more voltage (force) than the battery for the battery to charge. The battery should operate at 14V DC while the engine is running. A charge over 14DC may indicate a failed Zener diode.
- **DC amperage** – Is bridge rectifier converting AC current to DC? A technican verifies the production of DC current coming into the battery.
- **AC voltage leak** – Is the bridge rectifier leaking AC current? The presence of 100 mV (0.1 V) AC or more at the battery indicates a diode problem. A technician measures AC voltage production at the battery while the engine is idling to verify the bridge rectifier.

How can a technician know if an alternator is working?

Materials

Per group of four students:

- Digital multimeter (DMM)
- Tractor

Per student:

- *Agriscience Notebook*
- Clipboard
- Ear protection
- *Logbook*
- Pen
- Safety glasses

Procedure

Work with your group to to test the charging system in a tractor with a digital multimeter (DMM).

Part One – Alternator Connections Test

Test the charging circuit at the alternator to diagnose poor connections using a DMM.

1. Put on safety glasses and tie back long hair.
2. Find the battery, alternator, and starter on the tractor.
3. Set up your DMM to collect readings in DC voltage.
4. Measure the battery's voltage while the tractor is off and record it in Table 1 in *Activity 4.1.4 Student Observations*.
5. Prepare the alternator for DMM testing.
    - Uncover the rubber boot on the alternator's positive cable, labeled as *A* in Figure 2.
    - Disconnect the field circuit from the alternator. The field circuit in Figure 2 is labeled *C*.

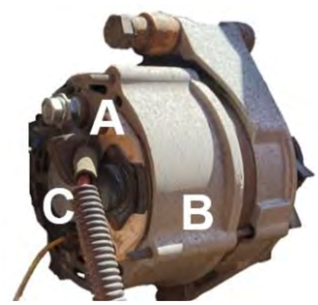


Figure 2. Alternator Connections

6. Test the cable carrying charge from the alternator to the battery.
    - Note: This cable carries the charging current from the alternator.
    - Turn the tractor's key switch to the *on* position without starting the tractor. Close the circuit from the battery to the alternator.
    - Connect the red lead of the DMM to *A* and the black terminal to the metal frame, *B*.
    - Record the voltage in Table 1.
7. Test the field circuit connection completing the circuit to the alternator.
    - Figure 2 shows how to position the DMM leads, with the red lead in the field circuit labeled *C* and the black lead to the ground *B*.
    - Close the circuit to from the battery to the alternator by turning the key to the *on* position, without starting the tractor.
    - The DMM displays the voltage at the field circuit. Record the voltage in Table 1.
8. Return the tractor's key switch to the off position.
9. Reconnect the field circuit to the alternator.
10. Answer *Part One Analysis Questions*.

Part Two – Alternator Charge Test

Test the charging capacity of the alternator using a DMM.

1. Put on ear protection.
2. Start the tractor and let the engine idle.
    - If running the tractor inside, open shop doors to ventilate the shop.
3. Measure the voltage produced by the alternator.
    - Measure the battery's voltage while the tractor is idled and record it in Table 2.

4. Measure the AC current produced by the alternator.
    - Set up the DMM to measure in AC amps.
    - Place the amp clamp around the cable coming out of the alternator and before the bridge rectifier (See the cable labeled *A* in Figure 2). Record the AC current in Table 2.
5. Measure the DC current charging the battery.
    - Set up the DMM to measure in DC amps.
    - Place the amp clamp around the negative battery cable.
6. Record the DC current in Table 2.
7. Quantify AC voltage leakage from the bridge rectifier.
    - Set up the DMM to measure in AC volts.
    - Measure AC voltage at the battery terminals.
    - The presence of 100 mV (0.1 V) or more in the battery indicates a diode problem in the bridge rectifier.
8. Record the AC voltage in Table 2.
9. Turn off the tractor.
10. Answer *Part Two Analysis Questions*.

Part Three – Charging System Diagnostics

Inspect the charging system of a tractor using the testing procedures in Parts One and Two. Follow the diagnostic process to find the cause and recommend repairs. Record the complaint, cause, key parts, correction, and confirmation in your *Logbook*.

Customer Complaint
The tractor will work fine after starting, but the battery continues to die. The customer replaced the battery one month ago.

Conclusion

1. Why is DC used to power electrical components in a 12V system?

2. How does a tractor convert AC-generated current into DC?

3. How does an alternator produce electricity?

Name____

Activity 4.1.4 Student Observations

Table 1. ***Alternator Connections***

Measurements	Tractor Engine	Expected Readings	DMM Reading
DC battery voltage	Off	12 – 12.4V	
DC voltage into alternator	Engine Off/Key in On Position	12 – 12.4V	
DC voltage out of the alternator	Engine Off/Key in On Position	12 – 12.4V	

Part One Analysis Questions

Q1 When the tractor was *turned off*, did the battery voltage meet the criteria of the 12-volt system?

Q2 Why is battery voltage routed to the alternator if the alternator charges the battery?

Q3 When the tractor was *turned off*, did the tractor meet the criteria of the 12-volt system?

Table 2. ***Charging Circuit***

Measurements	Tractor Engine	Expected Readings	DMM Reading
DC battery voltage	Idle	14V DC	
AC amperage from alternator	Idle	Varies, but should be present	
DC amperage to the battery	Idle	Varies, but should be present	
AC voltage leak	Idle	<0.1V AC	

Part Two Analysis Questions

Q4 When the tractor was *idle*, did the battery voltage meet the criteria of the 12-volt system?

Q5 Should the alternator be replaced? Why or why not?

Q6 Is the bridge rectifier working correctly? Why or why not?

Name____

CASE

Activity 4.1.5 Variable Resistor

Purpose

Your favorite song comes on the car radio, and you turn up the music. Have you ever thought about how the volume dial on the radio works? The knob varies the resistance in the circuit to change the voltage delivered to the speakers. By increasing the resistance, the volume lowers. Potentiometers, rheostats, and thermistors use resistance to control electrical components.

Potentiometers control the current supplied to outputs by varying resistance. Potentiometers have three terminals. One terminal connects to the power source, a second to an output, and a third to the ground. Figure 1 shows a rotary potentiometer that uses a knob to move a wiper. As the wiper moves closer to the power source, the output terminal's resistance decreases, increasing amperage.

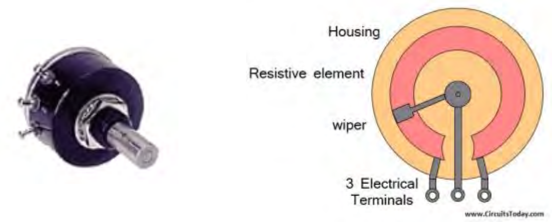


Figure 1. Rotary Potentiometer

GPS systems use potentiometers to signal the position of steering systems on agricultural equipment. Autosteer-capable equipment requires a precise angle of the tires while under operation. Figure 2 shows a potentiometer rotated by a linkage rod. The potentiometer output is used as an analog signal to determine position. The Autosteer program will use the signal to turn the wheels to the correct angle using electrohydraulic steering.

Figure 2. Potentiometer for Wheel Angle

Thermistors change resistance in reaction to a change in temperature. For example, a refrigerator uses a thermistor to control the cooling cycles as the temperature changes. Diesel engines utilize a thermistor to control an engine coolant temperature sensor. The sensor measures coolant temperatures to control fuel delivery, cooling fan operation, and temperature gauge readings.

Rheostats are variable resistors that control the current within a circuit. Since rheostats only have two terminals, the voltage coming out of a rheostat is consistent, while the current changes. Machines commonly have three-terminal potentiometers that function like rheostats. In this design, the input voltage applied to the first terminal output connects to the wiper. As a result, the third terminal will remain open.

How can a potentiometer be used to vary the voltage in electrical circuits? How can a technician identify a failed potentiometer?

Materials

Per pair of students:

- Battery case, D size
- Battery, D size
- Digital multimeter with an amp clamp
- Electrical tape
- Graphite pencil, 6B
- Potentiometer, 10KΩ
- (5) Wire with alligator clips

Per student:

- *Agriscience Notebook*
- *Logbook*
- Pen
- Safety glasses

Procedure

Work with a partner to model a variable resistor in Part One. Next, wire a circuit with a potentiometer and test the circuit with a digital multimeter.

Part One – Modeling a Rheostat

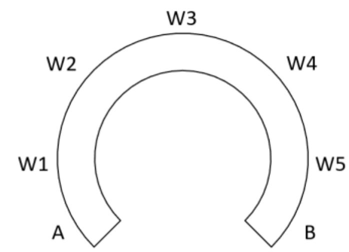


Figure 3. Model Rheostat

1. Put on safety glasses and tie back long hair.
2. Fill in the horse-shoe-shaped portion of the model rheostat shown in Figure 3 with a 6B graphite pencil.
    - Do not leave any white space.
3. Set up a DMM to measure resistance.
4. Simulate using the rheostat as a variable resistor with the black lead as the wiper.
    - Place the DMM's red and black leads inside the filled-in portion of the variable resistor closest to A. The leads should not touch.
    - Record the resistance in Ohms in Table 1 on *Activity 4.1.5 Student Observation*.
5. Move the black lead across the model variable resistor, recording the resistance for each location.
6. Calculate the current passing through the model rheostat and record it in Table 1.
    - The constant voltage in the circuit is 12V.
    - Use Ohms Law (volts = resistance x amperage).
        - o Amperage = 12V/resistance
7. Answer *Part One Analysis Questions*.

Part Two – Test a Potentiometer

1. Assemble the circuit shown in Figure 4 using wires with alligator clips.
    - The potentiometer's left terminal (A) attaches to the positive battery post.
    - The potentiometer's right terminal (C) connects to the negative battery post in a parallel circuit.
    - The wiper terminal (B) connects to the negative battery post in a parallel circuit.
    - Insulate all alligator clips connected to the potentiometer using electrical tape.

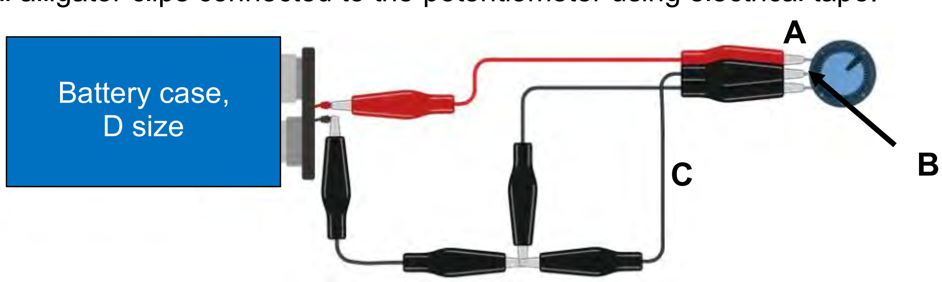


Figure 4. Potentiometer Assembly

2. Collect voltage readings within the circuit.
    - Turn the potentiometer counterclockwise dial to the left terminal.
    - Set up the digital multimeter to collect DC Volts.
    - Place the red lead of the DMM to the terminal marked *A* in Figure 4.
    - Place the black lead to the wiper terminal marked *B* in Figure 4.
    - Record the voltage in Table 2.
3. Collect amperage readings within the circuit.

- Turn the dial on the DMM to collect DC Amps.
- Place the DMM amp clamp over the cable marked *C* in Figure 4. The face of the DMM should be facing the potentiometer.
- Record amperage in Table 2.

4. Repeat Steps 2–3 while positioning the potentiometer knob in the middle and full right-turn (clockwise).

Part Three – Technician Procedure

Technicians use digital multimeters in the field to test potentiometers. Create a step-by-step procedure for testing a potentiometer to determine if it is good, opened, or shorted. Record the procedure in your *Logbook*. Next, use a potentiometer and a digital multimeter to demonstrate the process to your teacher.

Conclusion

1. How can a potentiometer be wired like a rheostat?

2. In what applications should a variable resistor be used to adjust amperage?

3. In what applications should a variable resistor be used to adjust voltage?

Name____

Activity 4.1.4 Student Observations

Table 1. ***Rheostat Data***

Red Lead	Wiper-Black Lead	Resistance	Amperage
A	A		
A	W1		
A	W2		
A	W3		
A	W4		
A	W5		
A	B		

Part One Analysis Questions

Q1 What is the role between resistance and amperage in a rheostat?

Q2 What is consistent in a rheostat?

Q3 Where are the wires connected to a potentiometer when wiring as a rheostat?

Table 2. ***Potentiometer Data***

Potentiometer Knob Setting	DC Voltage	Amperage
Left-Side		
Middle		
Right-Side		

Part Two Analysis Questions

Q4 What electrical unit is consistent within a circuit when using a potentiometer?

Q5 Why is a potentiometer known as a voltage divider?

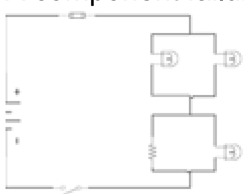
Name____

Lesson 4.1 Check for Understanding

1. Match the circuit property to its corresponding electrical circuit.

a. Parallel circuit
b. Series circuit
c. Series-parallel circuit

______ One path for current flow
______ Total resistance is always less than the lowest resistor
______ Current through each resistor is the same
______ A component failure will not open any portions of the circuit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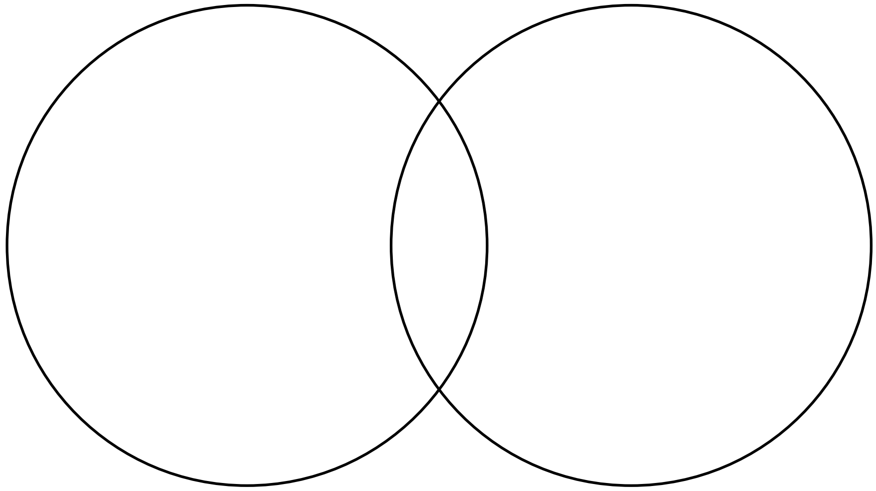
2. Draw an electrical circuit with a diode in forward bias.

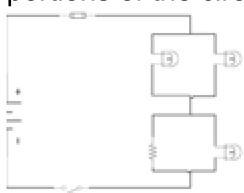
3. A technician suspects that the bridge rectifier in the charging system is leaking AC current. Write a procedure to determine if the alternator and bridge rectifier are functional.

4. Compare the function of rheostats and potentiometers using a Venn diagram.



Lesson 4.1 Check for Understanding Key

1. Match the circuit property to its corresponding electrical circuit.

B	One path for current flow	A.	Parallel circuit
A	Total resistance is always less than the lowest resistor	B.	Series circuit
B	Current through each resistor is the same	C.	Series-parallel circuit
A	A component failure will not open any portions of the circuit		
C			

2. Draw an electrical circuit with a diode in forward bias.

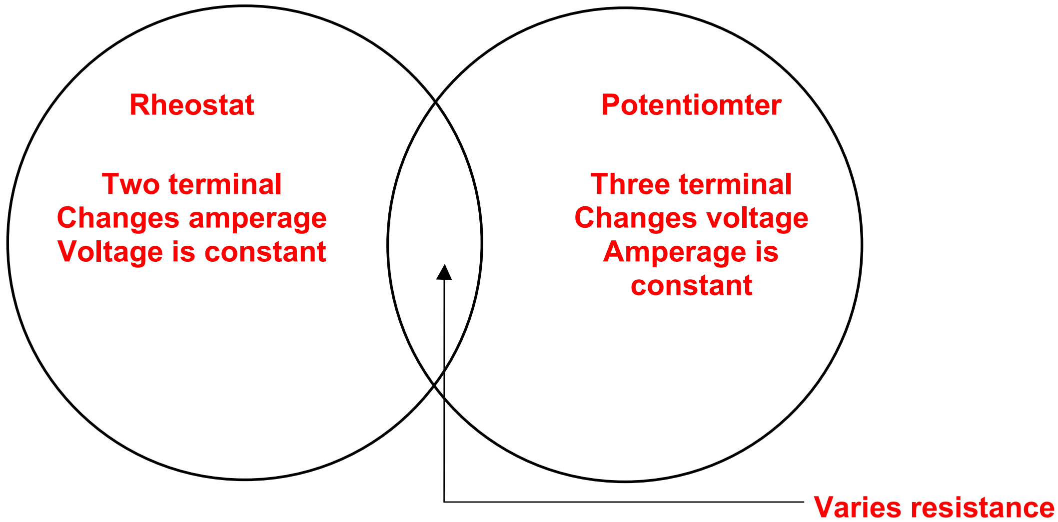
Answers will vary.
The circuit should include the diode with the anode on the positive side of the circuit.

3. A technician suspects that the bridge rectifier in the charging system is leaking AC current. Write a procedure to determine if the alternator and bridge rectifier are functional.

Answers will vary. Example as follows.

1) **Check the AC voltage at the battery while the engine is off and running to check the rectifier.**
2) **Check DC voltage at the battery while the engine is off.**
3) **Check DC voltage at the battery while the engine is on.**
4) **Check DC voltage coming into and out of the alternator while the engine is off.**

4. Compare the function of rheostats and potentiometers using a Venn diagram.



CASE

Lesson 4.2 Electrical Controls

Preface

Technicians use schematics to identify electrical components, the size of cables, and the sequence of a circuit. A technician refers to a schematic when testing a circuit for continuity. Agricultural and power equipment use electrical components to control lights, motors, and engines. One of the most commonly used devices to control a circuit is a relay. A relay can open or close a circuit when an internal electromagnet energizes. The relay function allows a lower-amperage circuit to control a higher-amperage circuit. Engineers also use relays to control directional flow within a circuit, giving an operator control over motor direction.

A solenoid works similarly to a relay. An electric coil uses electromagnetism to move a plunger when a solenoid is activated. Solenoids have multiple functions in equipment. For example, a fuel solenoid opens a fuel line during operation and closes it when the engine is off. Irrigation systems use solenoids to turn open and close plumbing to nozzles. A starter solenoid is used as a relay to activate a starter without drawing a higher amperage draw through the key switch. Safety switches are commonplace in agricultural equipment. These switches allow PTO operation during designed sequences and, in some equipment, permit the engine only to operate while the driver is seated.

Another type of electrical control is a sensor. A sensor is a device responding to physical stimuli with a quantified result. A transducer uses the sensor's response to send numerical data as electrical current to a computer. The computer will read this data as either millivoltage (mV) or Hertz (Hz).

Students will use an electrical schematic to describe a cranking circuit in this lesson. Next, students create a circuit and control panel to control motor speed and direction. Then, students will construct an ignition circuit and use a schematic to troubleshoot it. Next, students will operate a circuit using normally open and normally closed relays. Finally, students will construct and troubleshoot a transducer.

Concepts	**Performance Objectives**
Students will know and understand	*Students will learn concepts by doing*
1. Technicians read schematics when designing, constructing, and troubleshooting electrical circuits.	• Describe a cranking system using an electrical schematic. (Activity 4.2.1)
2. Electrical systems control how engine systems operate and function.	• Test the continuity of an ignition key switch. (Activity 4.2.2) • Assemble a shutdown circuit using a wiring schematic. (Project 4.2.3)
3. Agricultural equipment uses relays to control high amperage circuits that power specific components.	• Identify common terminals used on relays. (Activity 4.2.4) • Assemble a circuit using a relay. (Activity 4.2.4)
4. Electrical systems use resistors, diodes, potentiometers, relays, and solenoids to control equipment components.	• Design and construct a circuit to control motor speed and direction. (Project 4.2.5)
5. Technicians manage and troubleshoot controller systems used in precision agriculture.	• Construct and troubleshoot a transducer. (Project 4.2.6)

National AFNR Common Career Technical Core Standards Alignment

Career Ready Practices
1. Act as a responsible and contributing citizen and employee.
• CRP.01.01: Model personal responsibility in the workplace and community.
2. Apply appropriate academic and technical skills.
• CRP.02.02: Use strategic thinking to connect and apply technical concepts to solve problems in the workplace and community.
Environmental Service Systems Pathway (AG-ENV)
1. Use analytical procedures and instruments to manage environmental service systems.
• AG-ENV 1.3: Calibrate and service field equipment and instruments according to manufacturer's specifications.
Power, Structural and Technical (AG-PST)
1. Apply physical science principles and engineering applications related to mechanical equipment, structures, and biological systems to solve problems and improve performance in AFNR power, structural, and technical systems.
• AG-PST 1.2: Use hand and power tools commonly required in power, structural, and technical systems
• AG-PST 1.3: Investigate solutions to AFNR power, structural, and technical systems.
• AG-PST 1.4: Design or modify equipment, structures, or biological systems to improve performance of an AFNR enterprise or business unit.
5. Use control, monitoring, geospatial and other technologies in AFNR power, structural and technical systems.
• AG-PST 5.1: Execute procedures and techniques for monitoring and controlling electrical systems using basic principles of electricity.
• AG-PST 5.2 Design control systems by referencing electrical drawings.
• AG-PST 5.3 Use geospatial technologies in AFNR applications.

Next Generation Science Standards Alignment

Disciplinary Core Ideas	
Physical Science	
PS1: Matter and Its Interactions	
PS1.A: Structure and Properties of Matter	• Each atom has a charged substructure consisting of a nucleus, which is made of protons and neutrons, surrounded by electrons.
PS3: Energy	
PS3.A: Definitions of Energy	• "Electrical energy" may mean energy stored in a battery or energy transmitted by electric currents.

Science and Engineering Practices	
Planning and Carrying Out Investigations	• Select appropriate tools to collect, record, analyze, and evaluate data.
Analyzing and Interpreting Data	• Analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in order to make valid and reliable scientific claims or determine an optimal design solution.

Crosscutting Concepts	
Cause and Effect: Mechanism and Prediction	Events have causes, sometimes simple, sometimes multifaceted. Deciphering causal relationships, and the mechanisms by which they are mediated, is a major activity of science and engineering.
	• Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. • Systems can be designed to cause a desired effect. • Changes in systems may have various causes that may not have equal effects.

Energy and Matter: Flows, Cycles, and Conservation	Tracking energy and matter flows, into, out of, and within systems helps one understand their system's behavior.
	• The total amount of energy and matter in closed systems is conserved. • Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system.

Understandings about the Nature of Science	
Scientific Knowledge is Based on Empirical Evidence	• Science knowledge is based on empirical evidence. • Science arguments are strengthened by multiple lines of evidence supporting a single explanation.

Common Core State Standards for High School Mathematics

Modeling standards are indicated by the star symbol (*) throughout other conceptual categories.

CCSS: Conceptual Category – Number and Quantity	
Quantities	*Reason quantitatively and use units to solve problems.

CCSS: Conceptual Category – Algebra	
Reasoning with Equations and Inequalities	Understand solving equations as a process of reasoning and explain the reasoning. Solve equations and inequalities in one variable. Solve systems of equations.

CCSS: Conceptual Category – Statistics and Probability	
Interpreting Categorical and Quantitative Data	*Summarize, represent, and interpret data on a single count or measurement variable.
Making Inferences and Justifying Conclusions	*Make inferences and justify conclusions from sample surveys, experiments, and observational studies.
Using Probability to Make Decisions	*Calculate expected values and use them to solve problems.

Common Core State Standards for English Language Arts

CCSS: English Language Arts Standards » Science & Technical Subjects » Grade 11-12	
Key Ideas and Details	• **RST.11-12.1 –** Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account.
Craft and Structure	• **RST.11-12.4 –** Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to grades 11-12 texts and topics.
Integration of Knowledge and Ideas	• **RST.11-12.9 –** Synthesize information from a range of sources (e.g., texts, experiments, simulations) into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible.
Range of Reading and Level of Text Complexity	• **RST.11-12.10 –** By the end of grade 12, read and comprehend science/technical texts in the grades 11-CCR text complexity band independently and proficiently.

CCSS: English Language Arts Standards » Writing » Grade 11-12	
Text Types and Purposes	**WHST.11-12.2 –** Write informative/explanatory texts, including the narration of historical events, scientific procedures/experiments, or technical processes. • **WHST.11-12.2.E** – Provide a concluding statement or section that follows from and supports the information or explanation provided (e.g., articulating implications or the significance of the topic).
Research to Build and Present Knowledge	• **WHST.11-12.9 –** Draw evidence from informational texts to support analysis, reflection, and research.
Range of Writing	• **WHST.11-12.10 –** Write routinely over extended time frames (time for reflection and revision) and shorter time frames (a single sitting or a day or two) for a range of discipline-specific tasks, purposes, and audiences.

Essential Questions

1. What is the purpose of a relay?
2. How does a relay work?
3. How can technicians use a digital multimeter to diagnose faulty relays?
4. How are relays, potentiometers, switches, and diodes used as electrical controls?
5. What is the role of a solenoid in the starting circuit?
6. How does a technician diagnose electrical circuit failure?
7. How are safety switches used in agricultural equipment?
8. Why are safety switches built into the circuitry of tractors or harvesting equipment?
9. How does a transducer send a signal?

Key Terms

Analog	**Control panel**	**Digital**
Electromagnet	**Fuel solenoid**	**Fuse**
High-side	**Ignition**	**Indicator light**
Key switch	**Load**	**Low-side**
Magneto	**Normally closed (N.C.)**	**Normally open (N.O.)**
Relay	**Sensor**	**Shutdown circuit**
Solenoid	**Source**	**Starter**
Starter solenoid	**Starting circuit**	**Transducer**

Day-to-Day Plans
Time: 11 days

Refer to the Teacher Resources section for specific information on teaching this lesson, in particular ***Lesson 4.2 Teacher Notes****,* ***Lesson 4.2 Glossary****,* ***Lesson 4.2 Materials****, and other support documents.*

Day 1:

- Present **Concepts**, **Performance Objectives**, **Essential Questions**, and **Key Terms** to provide a lesson overview.
- Provide students **Presentation Notes** pages to be used throughout the video to record notes and reflections. Students add these pages to their *Agriscience Notebook*.
- Present LunchBox Session© **Interpreting Electrical Schematics**.
- Students will take notes using the *Presentation Notes* pages provided by the teacher.
- Provide students with a copy of **Activity 4.2.1 Schematic Inspection**.
- Provide student groups with copies of the **Cranking Circuit** and the **John Deere Service Manual**.
- Students will work in groups to complete *4.2.1 Schematic Inspection*.

Day 2:

- Provide students with **Presentation Notes**.
- Present LunchBox Session© **Starting and Charging Systems**.
- Students will take notes using the *Presentation Notes* pages.

- Provide students with a copy of **Activity 4.2.2 Starting Circuit**.
- Students work in groups of four to complete Parts One and Two of *Activity 4.2.2 Starting Circuit*.

Day 3:

- Students work in groups of four to complete Part Three of *Activity 4.2.2 Starting Circuit*.

Day 4 – 5:

- Provide students with a copy of **Activity 4.2.3 Shutdown Circuit** and **Ignition/Shutdown Schematic**.
- Students work in groups of four to complete *Activity 4.2.3 Shutdown Circuit* to assemble an ignition/shutdown circuit.

Day 6:

- Provide students with **Presentation Notes**.
- Present LunchBox Session© **Relays**.
- Students will take notes using the *Presentation Notes* pages.
- Provide students with a copy of **Activity 4.2.4 Relays**.
- Students work in groups of four to complete *Activity 4.2.4 Relays*.

Day 7:

- Provide students with a copy of **Project 4.2.5 Directional Control** and the **Project 4.2.5 Evaluation Rubric**.
- Students will work in groups of four to complete *Activity 4.2.5 Directional Control*.
- Evaluate student groups using the *Project 4.2.5 Evaluation Rubric.*

Day 8:

- Provide students with **Presentation Notes**.
- Present LunchBox Session© **Sensors, Transducers, & Transmitters**.
- Students will take notes using the *Presentation Notes* pages.
- Provide students with a copy of **Project 4.2.6 Sensing Data** and the **Project 4.2.6 Evaluation Rubric**.
- Students work in groups of four to complete Part One of *Project 4.2.6 Sensing Data.*

Day 9:

- Students will work in groups of four to complete Part Two of *Project 4.2.6 Sensing Data.*
- Assign each student group a **Project 4.2.6 Transducer Cards**.
- Students will develop their presentation for Part Three of *Project 4.2.6 Sensing Data.*

Day 10:

- Students will present their presentation for Part Three of *Project 4.2.6 Sensing Data.*
- Evaluate student groups using the *Project 4.2.6 Evaluation Rubric*.

Day 11:

- Distribute **Lesson 4.2 Check for Understanding**.
- Students will complete *Lesson 4.2 Check for Understanding* and submit it for evaluation.
- Use **Lesson 4.2 Check for Understanding Key** to evaluate student assessments.

Instructional Resources

LunchBox Sessions©

Starting and Charging Systems

Relays

Sensors, Transducers, & Transmitters

Student Support Documents

- Lesson 4.2 Glossary
- Presentation Notes
- Activity 4.2.1 Schematic Inspection
- Activity 4.2.2 Starting Circuit
- Activity 4.2.3 Shutdown Circuit
- Activity 4.2.4 Relays
- Project 4.2.5 Directional Control
- Project 4.2.6 Sensing Data
- Cranking Circuit Schematic
- John Deere Gator Service Manual
- Ignition/Shutdown Schematic
- Project 4.2.6 Transducer Cards

Teacher Resources

- Lesson 4.2 Electrical Controls PDF
- Lesson 4.2 Teacher Notes
- Lesson 4.2 Materials
- Lesson 4.2 Check for Understanding

Answer Keys and Assessment Rubrics

- Lesson 4.2 Check for Understanding Answer Key
- Project 4.2.5 Evaluation Rubric
- Project 4.2.6 Evaluation Rubric

Reference Sources

Briggs and Stratton Customer Education (2014). *Electrical Training Manual*.

Herren, R. V., & Donahue, R. L. (2000). *Delmar's agriscience dictionary with searchable CD-ROM*. Albany, NY: Delmar.

Lunchbox Sessions (2021). Interpreting Electrical Schematics. **https://www.lunchboxsessions.com/explore/electrical/interpreting-electrical-schematics**.

Lunchbox Sessions (2021). Relays. **https://www.lunchboxsessions.com/explore/electrical/relays**.

Lunchbox Sessions (2021). Sensor Basics. **https://www.lunchboxsessions.com/explore/electrical/sensor-basics**.

Lunchbox Sessions (2021). Starting and Charging Systems. **https://www.lunchboxsessions.com/explore/electrical/starting-charging-systems**.

Mack, J. P., Daniels, J. A., DeHart, M. A., & Norman, A. *Diesel Engine Technology: Fundamentals, Service, Repair* (Ninth Edition ed.). Tinley Park, IL: The Goodheart-Wilcox Company, Inc.

FFA Connections

This lesson provides conceptual and procedural knowledge required for participation in the following FFA activities:

- Agricultural Proficiency
  - **Agricultural Mechanics Repair and Maintenance –Placement**
  - **Agricultural Mechanics Repair and Maintenance –Entrepreneurship**
  - **Agriscience Research – Integrated Systems**
- Agriscience Fair
  - **Power, Structural and Technical Systems**
- Career Development Events
  - **Agricultural Technology & Mechanical Systems**
- Educational Resources
  - **SAE Idea Cards-Power, Structural and Technical Systems**
  - **Power, Structural and Technical System Careers**
  - **Power, Structural and Technical Systems Career Focus Area Resources**
  - Power, Structural and Technical Careers **(Word)**

Skills and knowledge from this lesson support the development and implementation of service-learning projects that address electrical components.

- **Service-Learning and Living to Serve Grants**
  - Service-learning projects focused on diagnosing electrical component issues in agricultural and other outdoor equipment.
  - Project ideas include hosting a spring tune-up or winterization event for local community members for lawnmowers and other equipment with electrical components.
  - Living to Serve Grants provide funding to FFA chapters to support service-learning and community service projects.

For more information, visit the **National FFA Organization** website.

SAE for All

Immersion SAE

Students interested in this lesson's topics should explore the following related Immersion SAEs. An immersion SAE is optional and replaces the agricultural literacy component of the Foundational SAE.

- **Immersion SAE Learning Guides**

For more information on the guiding principles for implementing SAE programs, visit the **SAE for All: Evolving Essentials** site.

Critical Thinking and Application Extensions

Explanation

1. Students will research how transducers are used in agriculture and identify the location of transducers on an implement.
2. Students will use tools to disassemble a failed starting solenoid to diagnose faults.

Application

3. Students will build a scrap solenoid using copper wire, a magnet, a battery, and a metal pin.

Lesson 4.2 Teacher Notes

Lesson 4.2 Electrical Controls

In preparation for teaching this lesson, review Concepts, Performance Objectives, Essential Questions, and Key Terms, along with presentations. Also, review all activity, project, and problem directions, expectations, and work students will complete.

During *Lesson 4.2 Electrical Controls*, students will assemble, test, and troubleshoot circuits using electrical controls common to agriculture and power equipment. Students start this lesson by learning how to read a schematic and describe a cranking circuit. Next, students will build a cranking circuit. Then, students will operate and troubleshoot an ignition/shutdown circuit. Students will learn about relays and their use within electrical circuits to control motors. Finally, students will build and troubleshoot a transducer.

LunchBox Sessions©

Register for one **LunchBox Session©** account with rights for presenting to your class. LunchBox Sessions© are short information sessions technicians can use to refresh themselves on fundamental mechanics.

Interpreting Electrical Schematics

This presentation reviews the basic rules of guidelines that OEMs use when developing schematics. Information includes connected cables, disconnected cables, display of component state, and jump tags on multiple-page schematics.

Starting and Charging Systems

Use this session to discuss starting and charging systems in power equipment. Students will explore the roles of the

Relays

Relays are explained during this session using animations and cutaway models. Students will learn about the inner workings of relays and review schematics that describe their function.

Sensors, Transducers, & Transmitters

During this presentation, students learn the difference between sensors, transducers, and transmitters. Students will learn how a transducer communicates data to a computer.

Activities, Projects, and Problems

Activity 4.2.1 Schematic Inspection

Students explore how technicians use electrical schematics developed by OEMs. First, students use a cranking circuit schematic to describe how a cranking circuit works. Next, students will use a John Deere Gator Service Manual to reference information about a John Deere Gator.

Teacher Preparation

- Print a copy of the **Cranking Circuit** and the **John Deere Gator Service Manual** for each student group.
- Provide a Basic Electrical Training Board for each group to reference. Students will not assemble a circuit during this activity.

Student Performance

Part One

Students use the *Cranking Circuit* to list the components, part numbers, and possible malfunctions of cranking circuit components. Students will highlight the path of the cranking circuit and then draw a simplified schematic.

Part Two

Students use the *John Deere Gator Service Manual* to define two parts and answer analysis questions.

Results and Evaluation

Table 1 contains information about the cranking circuit components. Potential responses to questions about cranking circuit components are in Table 2.

Table 1. ***Cranking Circuit Components***

Component	Part Number	Malfunction
Solenoid	**1685290**	**Failed connection** **Faulted coil**
Battery	**1685215**	**Corroded terminals** **Low battery voltage**
Ignition switch	**1716061**	**Loose connection** **Short**
Circuit breaker (fuse)	**1665238**	**Blown breaker** **Wrong sized fused**
Starter	N/A	**Poor connection** **Faulted starter**

Table 2. ***Analysis Questions and Potential Responses***

Q1	A customer brings in a Gator that is slow to sound the reverse alarm when backing up. What are some possible faults within the circuit?	*Answers will vary. Students may not list all the faults possible due to their exposure at this point in the unit.* *Corroded terminals on any component* *Low battery voltage* *The reverse switch is sticking* *Short in circuit* *Reverse switch failed* *Poor connection at the fuse*
Q2	Is the reverse switch open or closed on the schematic?	*The reverse switch is open.*
Q3	What three conditions must be met in the circuit for the starter solenoid to activate?	*The key switch is in the run position* *The parking brake is disengaged* *The foot throttle pedal is pressed down*
Q4	Which of the three conditions are most likely to have a fault? Why?	*Answers will vary. The foot pedal and park brake switches have more exposure to outside elements than the key switch and are more likely to have a faulted connection.*

Activity 4.2.2 Starting Circuit

Students learn about starting circuits in agricultural and power equipment and identify the key switch, starting solenoid, starter, and fuel solenoid roles throughout the activity.

Teacher Preparation

- Review **Lunchbox Session© Starting and Charging Systems**.
- Ensure that the 12V batteries are correctly charged. Use a DMM to test battery voltage. Charge any battery that is under 12.2V. Place the red clamp of the charger on the positive battery post and the black clamp on the negative post. Plug in the charger. When the light on the charger blinks green, unplug and disconnect the charger. Remove the black clamp first. Consult the **Battery Charger User Manual** for additional instructions.
- Obtain spare 10A fuses from a local auto parts store. During Part Two, students construct a circuit that blow their first fuse.

Student Performance

Part One

Students will use a digital multimeter to determine which paths are open during each position on the key switch. Students will record their responses on the student observations page. Table 3 includes a key for Part One.

Part Two

Next, students attempt to operate the starter by bypassing the starting solenoid and will blow a fuse in the process. A $^{7}/_{16}$" socket is needed to disconnect the positive cable from the starter, which students will replace with a wire with alligator clips. The fuse will blow as the amperage pull on the circuit is too high. If the fuse does not blow, replace the fuse with a 7.5A fuse. This component demonstrates the role of the starting solenoid. If the fuses do not blow, it is possible that a wire in the circuit becomes hot and opens.

Part Three

Students will construct the starting circuit with the starting solenoid and the fuel solenoid. The starter solenoid will activate the start when the key switch is in the start position. The fuel solenoid retracts when in the start and on positions.

Results and Evaluation

During this activity, students should master the application of solenoids in a circuit and how starting solenoids use low amperage to close a higher amperage circuit. Table 3 includes a key for the student observations page. Each “x” mark terminals have continuity with the battery and the ground in the *off*, *on,* and *start* positions of the key switch. Table 4 includes potential responses to analysis questions.

Table 3. *Ignition Key Switch*

Terminal	Electrical Component	Off Position		On Position		Start Position	
		Ground (G)	Battery (B)	Ground (G)	Battery (B)	Ground (G)	Battery (B)
S	Starter Solenoid						X
M	Magneto	X					
A	Alternator	X			X		
L	Fuel Solenoid	X			X		X

Table 4. ***Analysis Questions and Potential Responses***

Q1	What terminals are grounded when the switch is in the *off* position? Why?	*The fuel solenoid, magneto, and alternator are all grounded.* *The magneto is grounded in the off position, and the fuel solenoid closes off fuel in its resting position. This sequence turns off the engine.*
Q2	What roles do the fuel solenoid and the starter have in a charging system?	*The fuel solenoid opens up the fuel line. In carbureted engines, this would shut off fuel from the carburetor.* *The starter solenoid activates the starting motor using a lower-amperage circuit.*
Q3	Which cable will carry a higher current?	*The cables in the starting circuit are heavier gauged and will carry a higher current.*
Q4	Why does the starter use heavy gauged cables?	*The starter pulls are larger current and will need a heavier gauged cable to carry the current.*
Q5	How would a technician test the connection between the key switch and the starter?	*The technician should check for continuity between the key switch and the starting solenoid.*
Q6	What happens when the key switch is in the start position?	*The starter solenoid activates the starter, and the starter spins.*
Q7	What is the role of the fuse in the circuit?	*A fuse will burn out and open the circuit if the amperage draw is too high for the circuit.*
Q8	Did the fuse blow? Why or why not?	*Yes.* *The fuse blew to protect the battery. Without the solenoid, the high amperage draw went through the low side of the circuit. The cables on the low side of the circuit have lighter gauged cables that cannot carry the amperage draw. Without the fuse, the cables would increase heat and start an electrical fire.*
Q9	How will adding the solenoid into the starting circuit change the outcome?	*The starting solenoid will activate the starter when activated by the low-side of the circuit.*
Q10	How did the starter move when activated? Why?	*The starter rotates and moves outwards to engage the flywheel to start the combustion process.*
Q11	At what key switch positions is the fuel solenoid retracted? Why?	*Start and on.* *During these positions, the engine needs fuel to start and continue operation. In the off position, the fuel solenoid closes the fuel supply.*
Q12	What are the differences in voltage and amperage readings within the circuit during the *on* and *start* key switch positions?	*The amperage rating is higher in the start key switch position.*
Q13	What is the role of the starter solenoid in the starting circuit?	*The starting solenoid uses a low current to activate the starter drawing a high current. In this situation, the solenoid functions like a switch, as the starter motor draws more amperage than what the key switch can handle.*

Activity 4.2.3 Shutdown Circuit

During this activity, students wire the safety switches on the Basic Electrical Training Board. Then, students assemble portions of the shutdown circuit using a schematic to turn off a small engine.

Teacher Preparation

1. Print the **Ignition/Shutdown Schematic** for each student.
2. Prepare OHV engines with oil and gasoline.

Student Performance

Part One

Students will start an OHV engine and reflect on how the switch turned off the engine. Students will use a DMM to test for continuity between the ground, magneto, and oil sensor. In the on position, the switch will have continuity between the ground and oil sensor. In the off position, the switch will have continuity between the ground and magneto. Electricity takes the path of least resistance. By grounding the magneto, the voltage produced by the magneto and flywheel will not produce a spark, thus, turning the engine off.

Part Two

Students identify components of a simplified ignition shutdown circuit using the PTO, pedal, and seat switches.

Part Three

Students assemble the circuit from Part Two, as shown in Figure 1. Students will test for continuity of the pedal switch when the switch is in the up position. The orientation of the N.C. terminals is critical for proper operation. Students test for continuity between the ground and the magneto wire to determine when the engine will be interrupted and turned off. An engine will turn off when there is continuity between the magneto and the ground.

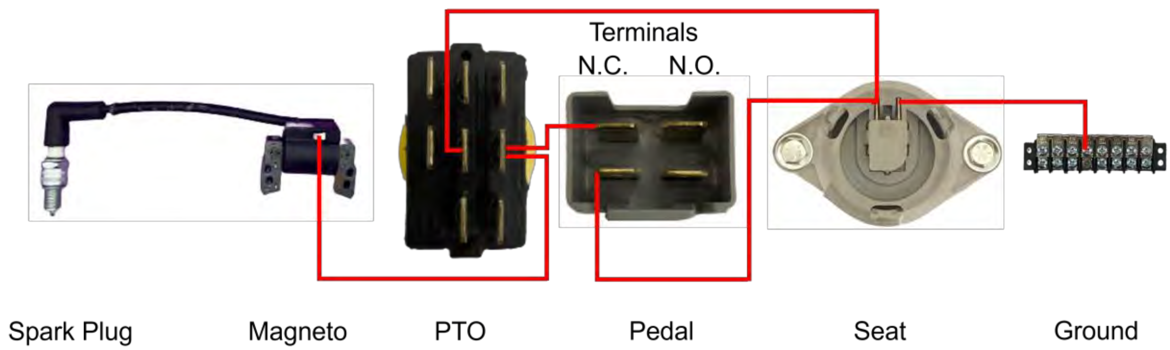


Figure 1. Circuit Schematic

Part Four

Students connect the circuit assembled during Part Three to an engine and test their shutdown circuit. They use the following guidelines for connecting the board to the engine.

- Disconnect the magneto wire from the on/off switch on the engine.
- Connect the magneto cable of your board to the magneto cable on the engine.
- Connect the ground cable on the board to any metal component on the engine.

Assist students if they have problems with their circuits. A DMM will be helpful to troubleshoot the circuit. Use the following examples of problems and the guiding questions to help students with common faults in the ignition/shutdown circuit.

- Improper ground: Is the ground cable connected to metal?
- Magneto cable: Is the magneto cable connected to the magneto?
- Short-circuit: Are any wires touching each other? Are the alligator clips at terminals making contact with each other?
- Faulty cable or alligator clip: Is there continuity between each cable?
- Misconnected wiring: Is the wiring assembled correctly?

Results and Evaluation

Answers for the student data page are in Table 5. Potential responses to analysis questions are listed in Table 6.

Table 5. ***Student Data Page***

Component	Part Number	Function
PTO Switch	**172287**	**Turns on the PTO while the engine is on**
Pedal Switch	**1723249**	**Allow for a safe start and operation**
Seat Switch	**1732005**	**Kill the engine when the driver leaves the seat while the PTO is operational.**

PTO Switch	Pedal Switch	Seat Switch	Continuity
On	Down	Operator in seat	**No**
Off	Up	Operator in seat	**No**
Off	Down	Operator off seat	**No**
On	Down	Operator off seat	**Yes**
Off	Up	Operator off seat	**Yes**

Table 6. ***Analysis Questions and Potential Responses***

Q1	Prediction: How did the switch turn off the engine?	*Answers will vary.*
Q2	Based on your DMM readings, how does the switch turn off the engine?	*The switch directs electricity from the magneto to the ground while it is in the off position.*
Q3	During which sequence could the operator step off the lawnmower with the engine running? Why?	*PTO switch is off, the pedal switch is down, and the operator is off the seat. Therefore, there is no continuity between the magneto and the ground in this sequence.*
Q4	Why would an OEM design a lawnmower to turn off when the PTO is on and the operator dismounts the tractor?	*This setting is a safety feature protecting the operator from the mower deck if the lawnmower rolls or if the driver gets their foot below the deck while dismounting.*

Activity 4.2.4 Relays

Students use a digital multimeter to check for continuity within relays to determine which relays are normally open and normally closed. Then, students use this knowledge to create a circuit using relays to meet the following criteria:

- Bulb One is on when the switch is in the on position and turns off when the switch is off.
- Bulb Two is off when the switch is in the on position and turns on when the switch is off.
- Use only one relay for this circuit.

Teacher Preparation

- Review the **Lunchbox Session© Relays** before starting the activity.
- Ensure that the 12V batteries are correctly charged. Use a DMM to test battery voltage. Charge any battery under 12.2V for the next day. Place the red clamp of the battery charger on the positive battery post and the black clamp on the negative post. Plug in the charger. When the light on the charger blinks green, unplug and disconnect the charger. The black clamp should be removed first. Consult the **Battery Charger User Manual** for additional instructions.

Student Performance

Part One

Students work with a partner to connect a relay to a 9V battery to determine how the electromagnet functions within the relay and answer analysis questions. Next, students use a digital multimeter to check for continuity to determine if the relay is SPST or SPDT.

Part Two
Students work in a group of four to design a circuit controlling lights on the Basic Electrical Training Board from EETC. The circuit should meet the following criteria.

- Bulb One is on when the switch is in the on position and turns off when the switch is off.
- Bulb Two is off when the switch is in the on position and turns on when the switch is off.
- Use only one relay for this circuit.

Results and Evaluation
Potential answers to analysis questions are listed in Table 7.

Table 7. *Analysis Questions and Potential Responses*

Q1	What did the relay do when powered at pins 85 and 86?	*The electromagnet in the relay switched between terminals. Students may note a clicking or thud sound. Students might also note the movement*
Q2	What is the function of the electromagnet in a relay?	*The electromagnet acts as a switch. It opens and closes connections from Pin 30 to other terminals (87, 87a).*
Q3	How does the relay change the function of the circuit as it lost and re-gained power?	*The circuit is open when the relay is off and closed when activated.*
Q4	Which side of the circuit is the low-side of the circuit?	*The low side is the side connected to pins 85 and 86.*
Q5	Which side of the circuit is the high-side of the circuit?	*The high side is the branch with the LED.*
Q6	How did the circuit with the *SPDT* relay function differently from the circuit with the *SPST* relay?	*The circuit is closed when the relay is off and open with the relay is open.*
Q7	Which relay did you use for this schematic? Why?	*Normally closed relay.* *Pin 87a and 87 will always be closed to one of the terminals. The N.C. relay allows the operator to switch the relay between the pins.*
Q8	Why are relays also used to control a low-amperage circuit?	*Answers will vary. The primary function of relays in low amperage situations is to switch or shorten wires to the voltage source.*

Project 4.2.5 Directional Control

Using a control panel, students use relays, potentiometers, and diodes to control a motor. The diodes in this situation are LEDs (light-emitting diodes) that can function as indicator lights. The motor should be able to change speed and direction.

Teacher Preparation

1. Gather tools and supplies for students to construct the control panels. Examples include scissors and poster board.
2. Ensure that the motors change rotation when switching wires connected to the positive and negative battery terminal connections. Brushless motors have three terminals and require a more complex circuit to reverse the motor than this project demands.
3. Provide students with enough cables with alligator clips to complete the schematic. Each group will need 20 cables, and the Basic Electrical Training Board comes with 15. Additional cables are available through Lab-Aids or online stores.

Student Performance
Part One
Figure 2 shows the circuit that students will build in Part One. Students will construct the circuit and test the switch to change motor direction before answering analysis questions.

Part Two
Students add the following items to the circuit.

- Potentiometer to control the speed
- LEDs to indicate the direction the motor is turning.

Students draw a schematic in their Logbook to include these features. Next, students construct a control panel that includes the switch, potentiometer, and indicator lights.

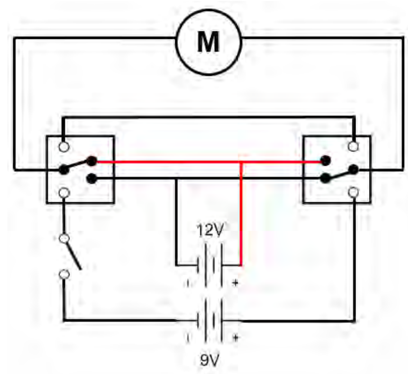


Figure 2. Base Circuit

Results and Evaluation
Evaluate students using the **Project 4.2.5 Evaluation Rubric**. Table 8 contains potential responses to analysis questions.

Table 8. *Analysis Questions and Potential Responses*

Q1	Why are two relays needed to control the current flow on the high-side of the circuit?	*The relays control the direction of motor flow. Two relays are needed, so there is always a closed path for voltage flow.*
Q2	How can LEDs be used as indicator lights to signal the motor's direction?	*When wired in parallel to each branch, the LED can indicate when voltage flows through that branch of the circuit.* *A LED wired in series will close the circuit in one direction.*
Q3	What electrical component can control motor speed while keeping voltage consistent?	*A rheostat maintains a constant voltage. A potentiometer can be wired as a rheostat if only two terminals are used, one being the wiper.*

Project 4.2.6 Sensing Data

Students build a transducer using a flow meter, breadboard pins, cables with alligator clamps, and a 9V battery. Students will then create faults with the transducer and write a procedure to repair the circuit.

Teacher Preparation

1. Purchase a flow rate transducer.
2. Separate three male-to-male breadboard jumper wires from the ribbon cables before distributing them to student groups.
3. Print off the **Project 4.2.6 Evaluation Rubric** for each group.
4. Print off **Project 4.2.6 Transducer Cards** and cut apart the cards.
5. Separate the students into groups of four. During Part Four, assign each group a transducer card. Each transducer card includes a fault and instructions for simulating the fault. Students will simulate the faults and present a procedure for diagnosing the fault.

Student Performance
Part One
Students use the SEEED product page listed below to access the flow rate meter information.

- **https://media.digikey.com/pdf/Data%20Sheets/Seeed%20Technology/314150001_Web.pdf**

Part Two

Students assemble a transducer using the schematic in Figure 3. Next, students pour water through the flow rate meter with the arrow pointing down. The DMM will display readings in Hz as the students pour the water. Next, students calibrate the transducer using known readings in Hz versus a calculated flow rate. Students calculate the flow rate by dividing the volume collected (ml) by the time (sec) it took to pour the water. Using this information, students create a calibration chart.

Figure 3. Transducer Wiring Schematic

Part Three

Students receive a transducer card with a common fault for the instructor. Next, students simulate the fault and repeat the Procedure for Part Two to test and calibrate the flow meter. These readings will not be consistent with the chart students produced in Part Two. The student groups will develop a procedure for diagnosing this error using a DMM. Students present their assigned fault and how the fault influenced their readings between Parts Two and Three. Students also demonstrate how to diagnose the error using a DMM.

Results and Evaluation

Evaluate student presentations using the *Project 4.2.5 Evaluation Rubric*. Potential answers to analysis questions are included in Table 9.

Table 9. *Analysis Questions and Potential Responses*

Q1	What is the purpose of the electrical tape in the circuit?	*The electrical tape prevents short circuits within contact points within the circuit. The tape also insulates the connections from water to prevent corrosion.*
Q2	What would cause a low flow rate reading on a sprayer?	*Answers will vary and may include:* *Plugged flowrate transducer* *Plugged or kinked line* *Shorted sensor wire* *Low power to the transducer* *High battery voltage* *Switched ground and voltage reading* *Knicked or opened cable* *Corroded terminals*

Assessment

Lesson 4.2 Check for Understanding

Lesson 4.2 Check for Understanding is included for you to use as an assessment tool for this lesson. Use **Lesson 4.2 Check for Understanding Answer Key** for evaluation purposes.

Name____

CASE

Activity 4.2.1 Schematic Inspection

Purpose

Have you ever used a map to route a path to a location? Maps are great tools for visually characterizing landscapes, roads, and byways when planning a trip. Technicians use schematics as a map to trace the path of electrical current from the source, through a fuse, to the load, and back to the source within agricultural equipment. Schematics include sources, loads, and fuses. A source is a power supply, such as a 12V battery. The load is a component consuming power. Fuses protect branches of a circuit from a high amperage surge. Original equipment manufacturers (OEMs) draw schematics as a visual representation of the electrical circuits of their equipment to aid technicians in troubleshooting and to conduct warranty repairs on equipment

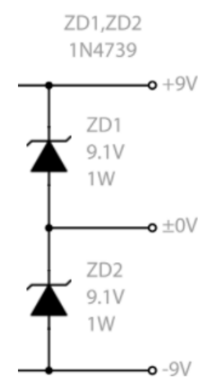


Figure 1. Schematic

Schematics have guidelines that all OEMs follow to maintain consistency. Schematic symbols show electrical components in their de-energized state. OEMs will include information with symbols. For example, Figure 1 shows a circuit branch that uses two Zener diodes. The schematic details the diode's part number (1N4739). Electrical values are listed to help the technician troubleshoot the circuit. Some schematics will also include a component index to reference the technician to other pages or tables within the service manual.

OEMs draw schematics to display the path electricity takes through a circuit, not the circuit's physical layout. As technicians follow the schematic, sometimes lines cross over, as shown in Figure 2. Lines that show a dot illustrate electrical connections. Lines without a dot or an illustrated loop are not connected.

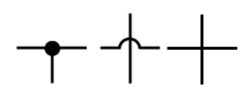


Figure 2. Cables

Larger circuits sometimes require multiple pages in a service manual to capture. Jump tags serve as notes for where lines connect across page breaks. Figure 3 shows a schematic with jump tags referencing different pages. The technician would look for jump tags with the corresponding numbers within this schematic to continue following the circuit. Some OEMs use more complex codes within their jump tags that communicate which page the schematic continues. For example, the tag SH10-C1 jumps to sheet 10, row C, and column one.

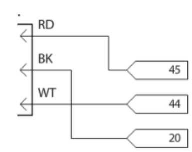


Figure 3. Jump Tags

Technicians find general information in a service manual, such as battery specifications. OEMs display information such as specifications of electrical equipment or wiring diameters in tables within the service manual. Technicians should use a service manual's table of contents to find information needed during a diagnosis. Using these guidelines, technicians can reference schematics for information to diagnose problems and isolate the cause.

Materials

Per group of four students:

- Basic Electrical Training Board
- *Cranking Circuit Schematic*
- *John Deere Gator Service Manual*
- Markers, assorted colors

Per student:

- *Agriscience Notebook*
- Pen

Procedure

Use the *Cranking Circuit Schematic* to locate circuit information and sketch a simplified schematic. Next, use the *John Deere Gator Service Manual* to answer analysis questions.

Part One – Cranking Circuit

1. Review the *Cranking Circuit Schematic* and circle the following components.
    - Solenoid
    - Battery
    - Ignition switch
    - Circuit breaker (fuse)
    - Starter
2. Record the part number for each component in Table 1 of *Activity 4.2.1 Student Data*.
3. Sketch the component's schematic symbol in Table 1.
4. Use the specified markers to trace the path electricity takes in the cranking circuit.
    - Red – Highlight the path from the positive battery post to the solenoid, circuit breaker, and battery terminal on the ignition switch.
    - Gray – Highlight the path from the solenoid to the starter.
    - Gray – Highlight the path from the solenoid back to the ground.
    - Gray – Highlight the path from the starter to the ground.
    - Blue – Highlight the path of the fuel shut off solenoid terminal on the ignition switch to the fuel shutoff solenoid.
5. Locate the components listed in Table 1 on the Basic Electrical Training Board that make up the cranking circuit that starts the engine.
6. Sketch what the component physically looks like in Figure 4.
7. List a potential cause for each component to malfunction in Table 1.
8. Sketch a simplified schematic of the cranking circuit in Table 2. Include the *Sketch Criteria*.

Sketch Criteria

- Components listed in Table 1
- Label each component
- Sketch how the components connect
- Use dots to show connections (See Figure 2)
- Use loops to show cables to cross, but do not connect (See Figure 2)

Part Two – Trace the Path

Review electrical schematics using the *John Deere Gator Service Manual*. Trace the paths of electrical current and answer the analysis questions.

H1 Reserve Alarm

1. Review the *Table of Contents* in the *John Deere Gator Service Manual*.
2. Locate the *H1 Reverse Alarm* on page 80 of the service manual. Circle the alarm.
3. Highlight the path current takes to power the reverse alarm using the following criteria:
    - Use one color to highlight the path electricity follows from the source to the load (alarm).
    - Use a different color to highlight the path electricity takes from the load back to the source.
4. Answer the *H1 Reverse Alarm Analysis Questions*.

Ignition Circuit

5. Read *Ignition Circuit Operation* on page 94. Then, list the criteria of the ignition circuit for the Gator to start in your student data sheet.
6. Review the schematic for the ignition circuit on page 95.
7. Locate the *S3 Foot Throttle Switch* on page 95 of the service manual. Circle the throttle switch.
8. Highlight the path current takes through the foot throttle switch to the solenoid using the following criteria:
   - Use one color to highlight the path electricity follows from the source to load (starter solenoid).
   - Use a different color to highlight the path electricity takes from the load (starter solenoid) to the source.
9. Answer the *S3 Foot Throttle Switch Analysis Questions*.

Conclusion

1. What information is available on a schematic?

2. How do OEMs represent connections between schematics across multiple pages?

Name____

Activity 4.2.1 Student Data

Table 1. ***Cranking Circuit Components***

Component	Part Number	Symbol	Sketch	Malfunction
Solenoid				
Battery				
Ignition switch				
Circuit breaker (fuse)				
Starter	N/A			

Figure 4. Simplified Schematic

H1 Reverse Alarm Analysis Questions

Q1 A customer brings in a Gator that is slow to sound the reverse alarm when backing up. What are some possible faults within the circuit?

Q2 Is the reverse switch open or closed on the schematic?

Ignition Circuit Criteria

-
-
-

S3 Foot Throttle Switch Analysis Questions

Q3 What three conditions must be met in the circuit for the starter solenoid to activate?

Q4 Which of the three conditions are most likely to have a fault? Why?

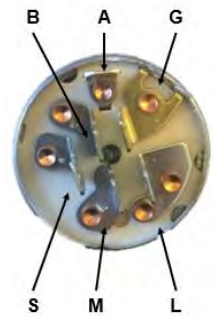
Name____

Activity 4.2.2 Starting Circuit

Purpose

Have you ever created a Rube Goldberg machine or witnessed one in action? Such machines are complex contraptions designed to achieve a simple task. Similarly, agriculture and power equipment have several parts that work in chain reactions to perform tasks such as driving, operating implements, or harvesting commodities. Engine systems require electrical controls to initiate and end these series of events.

A key switch serves as an electronic control with three main positions, off, on, and start. Some switches also have an accessory position. When the operator turns the key to each position, a series of circuits open and close. Figure 1 shows the terminals on the backside of a key switch and their application.



G	Ground
L	Fuel Solenoid
A	Alternator
B	Battery
M	Magneto
S	Starter Solenoid

Figure 1. Key Switch

Solenoids play a vital role in the starting circuit by converting electrical power into mechanical movement using an electromagnet. This mechanical movement serves two functions in agricultural equipment.

- The first function is to control fluid flow, such as a fuel solenoid. As the solenoid is activated, a pin moves back, opening the fuel line. Field sprayers and transmissions are other examples of agricultural applications that use solenoids to control fluid movement.
- The second application is to function as a switch. A starter solenoid uses a low amperage current to open a high current circuit to the starter motor. As current passes through the solenoid terminals, the electromagnet energizes and pushes the pin against the electrical connections along the top of the solenoid. Figure 2 shows a cutaway of a starting solenoid.

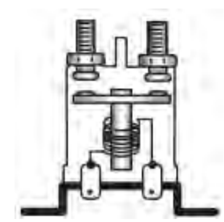


Figure 2. Starter Solenoid

The starting circuit includes electrical cables of various sizes with different connections. Technicians measure a cable's size by gauge. A larger diameter cable will have a lower gauge number and carry a higher current than a thinner diameter cable. For example, a 10-gauge cable is 2.59mm wide and is rated for 30 amps, while a 14-gauge cable is 1.63mm with a maximum current of 15 amps. Agricultural equipment have several connection points for ground cables to prevent an excess of cables going back to the battery terminals. The Basic Electrical Training Board includes ground terminal blocks and junction posts connected to a thermal circuit breaker, as shown in Figures 3 and 4. The ground terminal block connects multiple grounds back to the negative battery post. The starter solenoid connects to the positive junction post with a female connector.

Figure 3. Ground Terminal Block

Figure 4. Junction Posts

Electrical controls require protection from excess current. Fuses interrupt current flow if a high current that could cause an electrical fire is present in a circuit. A fuse consists of a metal strip that melts when the current flowing through the circuit is higher than the fuse's rating. The thermal circuit breaker in Figure 4 interrupts current flow between the junction posts. Technicians should diagnose why a fuse failed before replacing it with another.

What is the role of a solenoid in the starting circuit? How can a technician use knowledge of a key switch to diagnose equipment failure?

Materials

Per group of four students:

- Basic Electrical Training Board
- Battery, 12V
- Digital multimeter (DMM)
- (2) Fuse, 10A
- Key
- Masking tape
- Permanent marker
- (15) Wire with alligator clips

Per student:

- *Agriscience Notebook*
- Pen
- Safety glasses

Procedure

Use a digital multimeter (DMM) to determine how a key switch electronically controls equipment components. Next, assemble a starting circuit without a starting solenoid. Then, add the starting solenoid to the circuit and analyze the circuit functions using a DMM.

Part One – Ignition Terminals

1. Put on safety glasses and tie back long hair.
2. Insert the key into the key switch.
3. Turn the key to locate the *off*, *on*, and *start* switch positions.
4. Set up the DMM to test for continuity.
5. Turn the switch to the *off* position.
6. Test for continuity between the Ground (G) terminal block and other terminals in the key switch. Mark an "x" to indicate continuity for each connection in Table 1 of *Activity 4.2.2 Student Observations*.
7. Test for continuity between the key switches Battery (B) terminal and other terminals in the key switch. Record which terminals had continuity with the battery in Table 1.
8. Repeat Steps 6–7 with the switch in the *on* and *start* positions.
9. Answer *Part One Analysis Questions*.

Part Two – Starting Circuit without Solenoid

1. Compare the diameter of the wires on the starting circuit to the wires with alligator clips.
2. Use masking tape and a permanent marker to mark the ground terminal block and junction posts shown in Figures 3 and 4.
3. Place the key in the *off* position.
4. Connect the battery to the board using the battery cable with connectors shown in Figure 5.
5. Attach a wire with alligator clips to the positive junction post shown in Figure 4. Use this cable as your battery connection for the board.

Figure 5. Connecting to Battery

6. Construct the starting circuit using wires with alligator clips to bypass the starting solenoid, as shown in Figure 6. The starter grounds through the terminal block.
7. Turn the key switch to the *start* position for five seconds.
8. Turn the key to the *off* position.
9. Answer *Part Two Analysis Questions.*

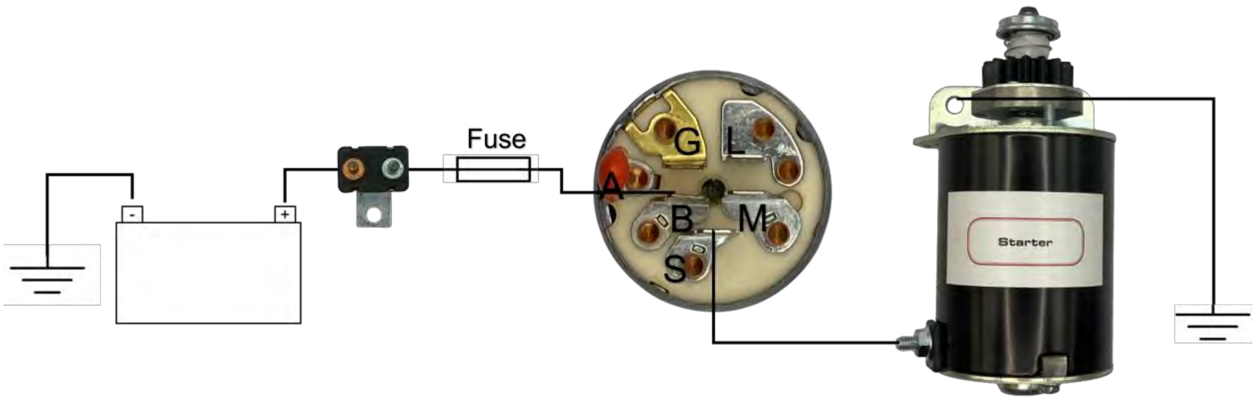


Figure 6. Starter Circuit without Solenoid

Part Three – Fuel and Starter Solenoids

1. Construct the starting circuit with the fuel and starting solenoids, as shown in Figure 7.

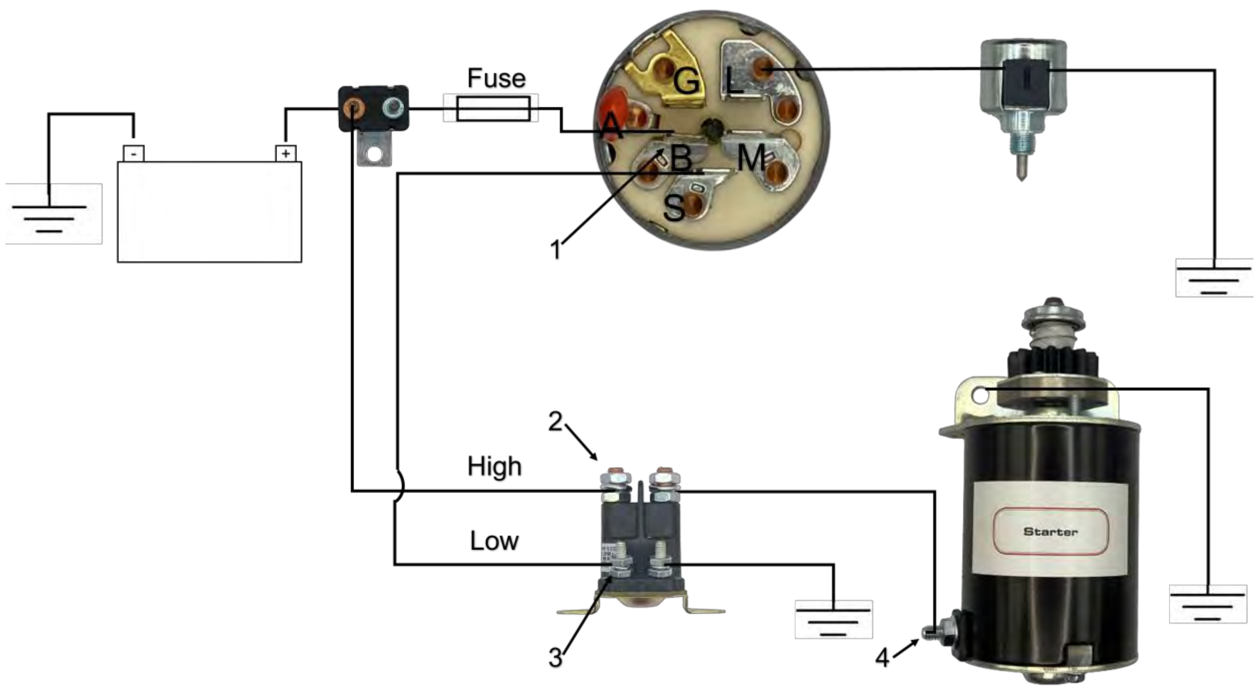


Figure 7. Starter Circuit with Fuel Solenoid

2. Turn the key switch to the *start* position for five seconds and let the switch rest in the *on* position.

3. Collect voltage measurements in the circuit using a DMM while the key switch is *on*. Record your results in Table 2.
    - Set up the DMM to collect readings in DC volts.
    - Place the black lead on the negative post of the battery.
    - Place the red lead at position 1, as shown in Figure 7.
    - Continue measurements by moving the red lead to positions 2-4.
4. Collect amperage 1 switch is *on.*
    - Set up the DMM to collect readings in DC amps.
    - Place the amp clamp over the positive cable coming into the top of the starter solenoid. Record your results in Table 2.
    - Move the amp clamp to the negative cable coming out the backside of the starter solenoid. Record your results in Table 2.
5. Collect voltage measurements in the circuit using a DMM while the key switch is in *start*. Record your results in Table 2.
    - Set up the DMM to collect readings in DC volts.
    - Place the black lead on the negative post of the battery.
    - Place the red lead at position 1, as shown in Figure 7.
    - Continue measurements by moving the red lead to positions 2-4.
6. Collect amperage readings in the circuit using a DMM while the key switch is in *start*.
    - Set up the DMM to collect readings in DC amps.
    - Place the amp clamp over the positive cable coming into the top of the starter solenoid. Record your results in Table 2.
    - Move the amp clamp to the negative cable coming out the backside of the starter solenoid. Record your results in Table 2.

Conclusion

1. A clicking sound is a sign of a faulty starter solenoid when trying to start an engine. Why did the solenoid fail?

2. What are the differences and similarities between a starter and a fuel solenoid?

Name____

Activity 4.2.2 Student Observations

Table 1. ***Ignition Key Switch***

Terminal	Electrical Component	Off Position		On Position		Start Position	
		Ground (G)	Battery (B)	Ground (G)	Battery (B)	Ground (G)	Battery (B)
S	Starter Solenoid						
M	Magneto						
A	Alternator						
L	Fuel Solenoid						

Part One Analysis Questions

Q1 What terminals are grounded when the switch is in the *off* position? Why?

Q2 What roles do the fuel solenoid and the starter solenoid have in a starting circuit?

Part Two Analysis Questions

Q3 Which cable will carry a higher current?

Q4 Why does the starter use heavy gauged cables?

Q5 How would a technician test the connection between the key switch and the starter?

Q6 What happens when the key switch is in the *start* position?

Q7 What is the role of the fuse in the circuit?

Q8 Did the fuse blow? Why or why not?

Q9 How will adding the solenoid into the starting circuit change the outcome?

Table 2. ***Voltage and Amperage Readings***

Reading		On	Start
Voltage	1 – Key Switch Battery Terminal		
	2 – Starter Solenoid High-Side		
	3 – Starter Solenoid Low-Side		
	4 – Starter Motor		
Amperage	Positive Cable		
	Negative Cable		

Part Three Analysis Questions

Q10 How did the starter move when activated? Why?

Q11 At what key switch positions is the fuel solenoid retracted? Why?

Q12 What are the differences in voltage and amperage readings within the circuit during the *on* and *start* key switch positions?

Q13 What is the role of the starter solenoid in the starting circuit?

Name____

CASE

Activity 4.2.3 Shutdown Circuit

Purpose

Have you ever operated a riding lawn mower and stepped off to pick up debris before mowing over it? Did the mower stop? If so, you have initiated the shutdown circuit. In *Activity 4.2.2 Starting Circuit*, you learned about the ignition switch and how it controls what portions of the circuit receive battery power or are grounded. The ignition shutdown circuit uses safety switches. While a safety switch is in the closed position, it interrupts the *on* and *start* key switch positions to ground the magneto or the starter, preventing engine operation.

The *Ignition/Shutdown Schematic* details the ignition and shutdown circuits on a New Regent™ riding lawnmower. The lawn tractor includes safety switches and a PTO switch that turns on the mower deck. The tractor must meet the following conditions for the engine to start.

- The operator must place their foot on the pedal for the starter to initiate.
- The PTO switch is pushed, and the clutch is disengaged.
- The operator must be seated for the engine to start and continue running.

The Basic Electrical Training Board includes the controls found in the *Ignition/Shutdown Schematic*. Technicians that work on a range of agricultural and power equipment will encounter different types of switches in an ignition shutdown circuit. Safety switches on agricultural equipment protect the operator and those close to the machine. How are safety switches installed in mobile equipment?

Materials

Per group of four students:

- Basic Electrical Training Board
- Battery, 12V
- (2) C-clamp
- Digital multimeter (DMM)
- Funnel
- Highlighter
- Magneto
- Oil, 30W
- Small engine, OHV
- Socket wrench, ¼″
- Socket, 8mm ¼″ drive
- Spark plug
- (12) Wire with alligator clips

Per student:

- *Agriscience Notebook*
- *Ignition/Shutdown Schematic*
- *Logbook*
- Safety glasses

Per class:

- Shop towels

Procedure

Use a DMM to determine how each switch turns off an OHV engine. Then use the *Ignition/Shutdown Schematic* to identify the components of a shutdown circuit. Next, construct a sample of the circuit and test for continuity using a DMM. Finally, construct a circuit that turns off an engine. Record all observations and answers to analysis questions in your *Logbook*.

Part One – Magneto Interrupt

1. Put on safety glasses and tie back long hair.

2. Acquire a small engine from your teacher.
3. Disconnect the spark plug wire from the spark plug.
4. Place the throttle lever in the **STOP** position.
5. Ensure the fuel valve to the left of the speed control panel is in the **OFF** position.
6. Remove the dipstick and wipe it with a clean shop towel.
7. Insert the dipstick. Do not turn or tighten.
8. Remove the dipstick and check the oil level. It should be at the top of the full indicator on the dipstick.
    - Add oil if needed, use a funnel and pour the oil slowly into the engine oil fill. Fill to the point of overflowing.
    - **Do not overfill by tipping the engine.**
9. Go to the running station and secure the engine to the table using two C-clamps.
    - Position the C-clamps next to the drain plugs on each side of the crankcase base.
10. Point the muffler to the air handling vent.
11. Wait for your teacher to check the engine setup.
12. Put on ear protection.
13. Turn the fuel valve in front of the gas tank to the **ON** position.
14. Set the choke on the carburetor to the **CHOKE** position.
15. Connect the spark plug wire to the spark plug and move the throttle lever to the **RUN** position.
16. Turn the switch to the **ON** position.
17. Ask your teacher for permission to start the engine.
18. Once you receive permission, gently and evenly pull on the rope starter. The engine should start with a few pulls of the rope starter.
19. Turn the switch to the **OFF** position.
20. Remove ear protection.
21. Use an 8mm socket to remove the two screws holding the speed control bracket.
22. Sketch the switch in your *Logbook*. Label the location of the ground, magneto, and oil sensor wires.
23. Use a DMM to measure continuity between the terminals on the switch, as shown in Figure 1. Record which wires have continuity while the switch is in the **ON** and **OFF** positions.
24. Answer *Part One Analysis Question* in *Activity 4.2.3 Student Data* page.

Figure 1. Switch

Part Two – Component Identification

1. Review the components included in Figure 2. List the switches in Table 1.

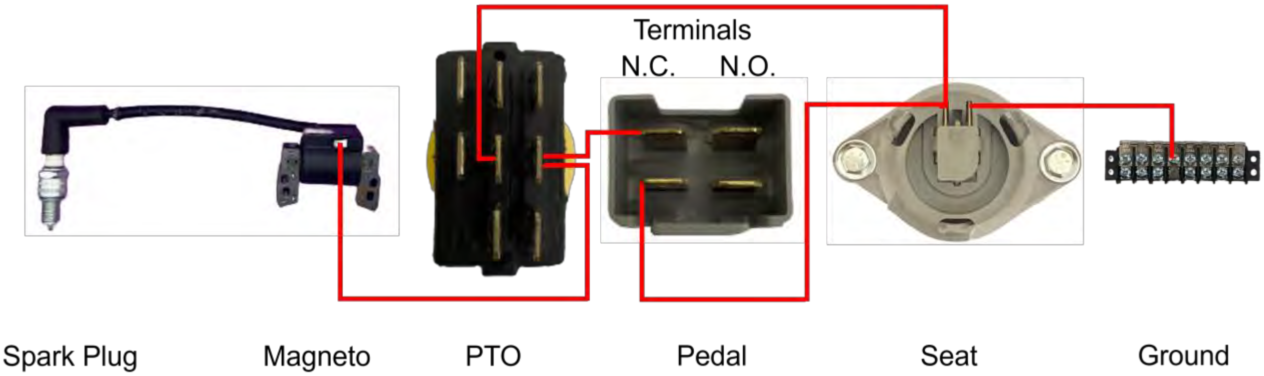


Figure 2. Ignition Interrupt

2. Highlight the wires in the *Ignition/Shutdown Schematic* represented in Figure 2.
3. Review the part numbers listed in the *Ignition/Shutdown Schematic*. List the part numbers for the components listed in Table 1.
4. Record the function of each switch in Table 1.

Part Three – Circuit Construction

Figure 3. Magneto/Spark Plug Connection

1. Attach a spark plug to the magneto, as shown in Figure 3.
2. Identify the normally closed terminals in the pedal switch.
    - Turn the dial of the DMM to continuity.
    - Use the DMM to identify the pedal switch terminals with continuity when normally closed.
    - Connect a cable to each N.C. terminal.
3. Assemble the circuit in Figure 2 using wires with alligator clips.
4. Set up the DMM to test for continuity in the circuit.
    - Connect the red lead to the end magento's armature, as shown in Figure 3.
    - Connect the black lead to the ground terminal on the Basic Electrical Training Board.
5. Position the switches as listed in each row of Table 2. Record in Table 2 if the magneto had continuity to the ground for the switch series.
    - Use the clear plastic brackets to hold the seat or pedal switch down.

Part Four – Engine Shutdown

1. Attach the circuit to your OHV engine with the guidelines listed below.
    - Disconnect the magneto wire from the on/off switch on the engine.
    - Disconnect the alligator clip from the magneto on your board.
    - Connect the magneto cable of your board to the magneto cable on the engine.
    - Connect the ground cable on the board to any metal component on the engine.
2. Set up your circuit by positioning the switches in the first combination listed in Table 2.
3. Start your engine manually.
    - Use a DMM to troubleshoot your circuit if it does not work as you predicted.

4. Record if the engine runs in Table 2.
5. Repeat Steps 2–4 for each switch combination listed in Table 2.
6. Answer *Part Four Analysis Questions*.

Conclusion

1. How are switches used to control electrical circuits?

2. How are switches used to increase operator safety?

Name____

Activity 4.2.3 Student Data

Part One Analysis Question

Q1 Based on your DMM readings, how does the switch turn off the engine?

Table 1. ***Shutdown Circuit Components***

Switch	Part Number	Function

Table 2. ***Grounding the Magneto***

PTO Switch	Pedal Switch	Seat Switch	Continuity	Engine Running
On	Down	Operator in seat	☐ Yes ☐ No	☐ Yes ☐ No
Off	Up	Operator in seat	☐ Yes ☐ No	☐ Yes ☐ No
Off	Down	Operator off seat	☐ Yes ☐ No	☐ Yes ☐ No
On	Down	Operator off seat	☐ Yes ☐ No	☐ Yes ☐ No
Off	Up	Operator off seat	☐ Yes ☐ No	☐ Yes ☐ No

Part Four Analysis Questions

Q2 How does a shutdown circuit stop engine operation?

Q3 During which sequence could the operator step off the lawnmower with the engine running? Why?

Q4 Why would an OEM design a lawnmower to turn off when the PTO is on and the operator dismounts the tractor?

Name____

Activity 4.2.4 Relays

Purpose

Have you ever opened a fuse box on a truck or tractor and wondered about the bigger box-like structure? As shown in Figure 1, the fuse box contains relays with various ratings. A relay is an electrical switch using a low electrical amperage to open and close a higher amperage circuit. For example, a tractor's heating and cooling systems use a blower motor to circulate warmed or cooled air. A relay activates the blower motor in the heating and cooling system. Sometimes, relays control lower amperage devices such as lights to shorten the wire consistently carrying battery voltage.

Figure 1. Fuse/Relay Box

Relays use electromagnets to open and close circuits. As the lower-amperage current, or low side of the circuit, passes through the relay, a coil of wire engages a switch that opens or closes the controlled circuit. The controlled circuit branch has a higher amperage and is on the high side.

Figure 2. Relay

All switches are identified by the number of poles and throws. A pole is the number of circuits the switch can control and the throw is the number of contact points. For example, a single pole single throw (SPST) switch contacts electricity from one circuit and opens or closes the circuit to one throw. A single pole double throw (SPDT) switch contacts electricity to two throws. When activated, the switch alternates the direction between each throw.

Electrical circuits connect to relay pins. Figure 2 shows the bottom side of a relay with five pins. Technicians read the pin numbers in schematics when identifying the poles and throws in a relay. Figures 3 and 4 contain relay schematics. Pins 85 and 86 connect to the low side of the circuit. The low side is a SPST switch that activates the relay. Pins 30, 87, and 87a make up SPDT high-side circuit.

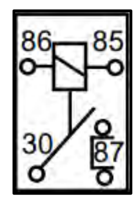


Figure 3. SPST Relay

High-side circuits in a relay can have pins with varying positions, Normally-Open (N.O.) or Normally-Closed (N.C.). Figure 3 shows a schematic for a SPST relay. Note that the pole extending from contact point 30 is not in contact with throw 87. Therefore, while the low side of the circuit is open, the high side will also be open. However, when the low side closes the relay's electromagnet, the high side circuit between pin 30 and both pins labeled 87 becomes closed.

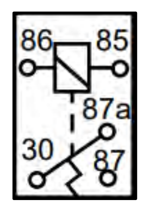


Figure 4. SPDT Relay

An N.C. pin has continuity with the pole, pin 30, until the electromagnet is activated. The relay in Figure 4 is two throws, a N.O. pin 87 and a N.C. pin 87a. When the relay is activated, the high side of the circuit pivots to be closed between pins 30 and 87. One high-side circuit will always be closed in an SPDT relay.

How do relays serve as electrical controls? How can technicians use a digital multimeter to diagnose SPST and SPDT relays?

Materials

Per group of four students:

- Basic Electrical Training Board
- Battery, 12V
- Battery, 9V
- Digital multimeter (DMM)
- Masking tape
- Permanent marker
- (2) Relay, SPDT
- (2) Relay, SPST
- (10) Wire with alligator clips

Per student:

- *Agriscience Notebook*
- *Logbook*
- Pen
- Safety glasses

Procedure

Observe the internal functions of a relay with a partner. Next, use a normally open and normally closed relay to control a circuit. Then, in a group, design a circuit that uses a relay to control lights on the Basic Electrical Training Board. Record all measurements and answers to analysis questions in your *Logbook*.

Part One – Relay Function

1. Pair up with a partner.
2. Put on safety glasses and tie back long hair.
3. Connect a 9V battery to one of the relays with two wires with alligator clips.
4. Connect the wires to pins 85 and 86, the low side circuit.
5. Answer the analysis questions in your *Logbook*.

   Q1 What did the relay do when powered at pins 85 and 86?
   Q2 What is the function of the electromagnet in a relay?
6. Disconnect the circuit.
7. Set up a DMM to check for continuity.
8. Determine the continuity for the relay having the same schematic as Figure 3 when in the normal position.
   - Place the red lead on pin 30 and the black lead on pin 87.
   - Record the continuity for each pin in your *Logbook*.
9. Determine the continuity for the relay having the same schematic as Figure 4 when in the normal position.
   - Place the red lead on pin 30 and the black lead on pin 87a.
   - Switch the black lead from pin 87a to pin 87.
   - Record the continuity for each pin in your *Logbook*.
10. Use the continuity data collected to label the relays as *SPST* and *SPDT* with masking tape and a permanent marker.

11. Assemble a circuit using the *SPST* relay, as shown in Figure 5.
    - Use two wires to connect the 9V battery wires to pins 85 and 86.
    - Use one cable to connect pin 30 to the 12V (-) terminal.
    - Connect the 12V (+) terminal to one terminal on Bulb One on the Basic Electrical Training Board.
    - Connect pin 87 to the second terminal on the light.
12. Disconnect and reconnect the cable from pin 85 and observe the circuit.
13. Repeat Steps 9–10 with the SPDT relay. Use the 87a pin.
14. Answer the analysis questions in your *Logbook*.

Q3 How does the relay change the function of the circuit as it lost and re-gained power?
Q4 Which side of the circuit is the low-side of the circuit?
Q5 Which side of the circuit is the high-side of the circuit?
Q6 How did the circuit with the *SPDT* relay function differently from the circuit with the *SPST* relay?

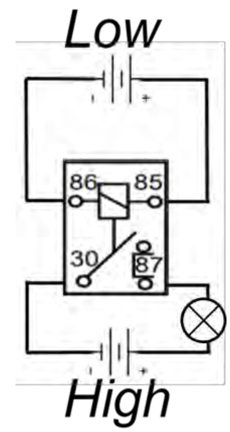


Figure 5. Circuit Schematic

Part Two – Relayed Switches

Work in a group of four to design a circuit using a relay to control two lights on the Basic Electrical Training Board. Draw the schematic for the circuit in your *Logbook*. After your teacher approves your schematic, construct the circuit on the board, test the circuit, and answer the analysis questions. The board must meet the following criteria:

- Bulb One is on when the switch is in the on position and turns off when the switch is off.
- Bulb Two is off when the switch is in the on position and turns on when the switch is off.
- Use only one relay for this circuit.

Then, answer the analysis questions in your *Logbook*.

Q7 Which relay did you use for this schematic? Why?
Q8 Why are relays also used to control a low-amperage circuit?

Conclusion

1. What would cause a relay to fail?

2. When would a technician use an SPDT relay instead of an SPST relay?

3. Why should a technician differentiate between normally open and normally closed pins?

Name____

CASE

Project 4.2.5 Directional Control

Purpose

Garage door openers use controls to open and close a garage door. The drive assembly of the opener includes a DC motor that connects to a metal sprocket. As the motor turns, the sprocket moves a chain to open and close the door. The opener supplies voltage to the motor in different directions to control the motor's rotational movement. What electrical components control a garage door opener?

Agricultural and power equipment use several *Standard Methods to Control Motors*, such as resistors, relays, potentiometers, switches, and diodes.
Standard Methods to Control Motors

- Turning a motor on/off
- Changing the direction of a motor
- Changing the speed of a motor
- Turning a motor off, or braking movement, with a safety switch

Figure 1 includes a drawing of a circuit controlling DC motor direction using two relays. The low side of the circuit comprises a switch. The motor will turn clockwise while the low-side of the circuit is open. When the switch is closed, both relays are activated, switching the direction of current flow on the circuit's high side. A change in current flow will also change the direction a motor turns.

Motors include a metal nameplate with a listed voltage rating. Technicians keep motors within ±10% of the nameplate voltage rating. An operator can control motor speed by changing the amperage in the circuit, not the voltage. Adjusting the current keeps the electrical pressure consistent within that branch of the circuit.

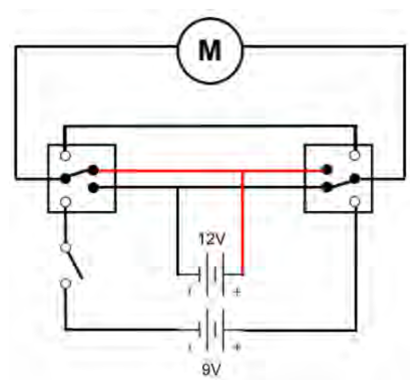


Figure 1. Motor Direction Control

How are relays, potentiometers, switches, and diodes used as electrical controls?

Materials

Per group of four students:

- Battery, 12V
- Battery, 9V
- Button switch, N.C., SPST
- DC motor, brushed, 12V
- (2) LED bulb, 10mm
- Potentiometer, 10KΩ
- (2) Relay, SPST
- Switch, SPST
- (20) Wire with alligator clips

Per student:

- *Agriscience Notebook*
- *Logbook*
- *Project 4.2.5 Evaluation Rubric*
- Safety glasses

Per class:

- Supplies and tools for control board construction

Procedure

Construct a circuit that uses a switch and relays to control the direction of a DC motor. Next, add a variable resistor to the circuit to control motor speed and LEDs to signal directional movement.

Part One – Base Circuit

1. Assemble the circuit shown in Figure 1 using wires with alligator clips. Test the circuit to ensure it functions as described in the *Purpose*. When completed, answer the analysis questions in your *Logbook*.

   Q1 Why are two relays needed to control the current flow on the high side of the circuit?
   Q2 How can LEDs be used as indicator lights to signal the motor's direction?
   Q3 What electrical component can control motor speed while keeping voltage consistent?

Part Two – Multiple-Controls

The circuit created in Part One has primary electronic control of a machine. Your group is tasked with adding branches to the base circuit to include a safety shutoff, vary the motor speed, and indicate the direction the motor is turning. First, draw a schematic of the complete circuit in your *Logbook* using electrical symbols. Next, create a control panel that houses all the electrical controls and indicator lights comprised within the circuit. Finally, label each control and indicator light.

Your teacher will use *Project 4.2.5 Evaluation Rubric* to assess the project. The schematic, circuit, and control panel criteria are listed below.

Schematic Criteria

- Recorded in *Logbook*
- Uses electrical symbols
- The reader can follow the path from the source to the load and back to the source

Circuit Criteria

- The motor reverses direction when the switch is closed.
- The potentiometer changes amperage, not voltage.
- The potentiometer changes motor speed in both directions.
- The button acts as a safety switch to interrupt the motor.
- The LEDs indicate motor direction.

Control Panel Criteria

- Designed to keep all electrical controls and indicators organized.
- Controllers and indicator lights are appropriately labeled.

Conclusion

1. How can a diode be used to ensure a consistent motor direction?

2. How do electrical systems use resistors, diodes, potentiometers, relays, and solenoids to control equipment components?

Name____

CASE

Project 4.2.5 Evaluation Rubric

Areas with Room for Improvement	Criteria	Areas that Meet or Exceed Expectations
	Schematic The schematic is recorded in the *Logbook* using correct electrical symbols. The reader can follow the path from the source to load and back throughout each branch.	
	Circuit • The motor reverses direction when the switch is closed. • The potentiometer changes amperage, not voltage. • The potentiometer changes motor speed in both directions. • The bumper switch acts as a safety switch to interrupt the motor. • The LEDs indicate motor direction.	
	Control Panel The panel keeps all electrical controls and indicators organized. Controllers and indicator lights are appropriately labeled.	

Name____

CASE

Project 4.2.6 Sensing Data

Purpose

How do industry and technological advancements impact the role of technicians? Technicians must continue to learn as OEMs produce new equipment —one example of technological advancements are global positioning systems (GPS). As you learned in *Unit 3 Precision Agriculture*, agricultural producers incorporate GPS technology to maximize productivity. Technicians manage and troubleshoot the electrical control systems used in precision agriculture.

Precision agriculture is dependent upon sensors transmitting signals to electrical components. A sensor reacts to a physical stimulus and produces a signal a computer can interpret. A transducer contains a sensor that transfers the sensor response as a small voltage output. The computer receiving the signal will read the DC millivoltage or the frequency of AC generated by the transducer. The frequency of AC is measured in Hertz (Hz). Through calibration, the output signal of the transducer corresponds to a calculated rate. Table 1 includes a list of sensors used in sprayers and their application.

Table 1. *Transducers*

Component	Application
Ultrasonic	Ultrasonic transducers use ultrasonic waves to measure the distance from devices. Sprayers use ultrasonic sensing to guide the equipment through a field and keep equipment within rows without damaging crops. Sprayer booms are also equipped with ultrasonic sensors to position the boom above the ground.
Flowmeter	Precision spraying requires a consistent and controlled rate of liquid application. Flow meters help regulate the pump to ensure precise application.
Pressure	The pressure within a sprayer impacts the flow rate and quality of the spray. Sprayer nozzles should apply a mist of small droplets with a slight overlap between nozzles. As the pressure in a sprayer boom decreases, the droplet size increases, and the width of the spray area decreases.

Transducers send analog or digital signals. Analog signals have a range of possibilities, including temperature. Digital signals have a narrow range of responses, such as a limit switch that can signal if the switch is open or closed. Technicians should consult the OEM service manual to determine if the transducer is analog or digital so they can complete a failure analysis.

Materials

Per group of four students:

- Battery, 9V
- (3) Breadboard pin wire, male to male
- Colored pencils, assorted
- Cup, 3 oz
- Device with a timer
- Device with internet access
- Digital multimeter (DMM)
- Electrical tape
- Flow meter
- *Project 4.2.6 Transducer Card* and materials
- Syringe, 60ml
- Water
- (4) Wire with alligator clips

Per student:

- *Agriscience Notebook*
- *Logbook*
- *Project 4.2.6 Evaluation Rubric*
- Safety glasses

Procedure

Use OEM information to define the parameters of a flow rate transducer. Next, work in a group to test a transducer with a digital multimeter (DMM) to create a calibration chart. Then create a fault in your transducer circuit and test it with a DMM. Finally, complete the project by presenting the results to your classmates.

Part One – Transducer Information

1. Use a device with internet access to locate information about the **Flow Rate Transducer (water flow)** (https://www.seeedstudio.com/G1-8-Water-Flow-Sensor-p-1346.html).
2. Complete Table 2 on the *Project 4.2.6 Student Data* page using information from the website.

Part Two – Transducer Function

1. Fill a 60ml syringe with water.
    - Fill a 3 oz cup with water.
    - Place the syringe in the cup and pull back on the plunger until 60ml of water is obtained.
2. Set up the transducer and 60ml syringe as shown in Figure 1.
    - The arrow on the transducer indicates the direction of water flow. Ensure the syringe is in line with the arrow.
3. Assemble a circuit with a flow rate transducer, three male-to-male pin wires, four wires with alligator clips, and a 9V battery. Figure 2 is a schematic of the circuit.

Figure 1. Sensor Set-Up

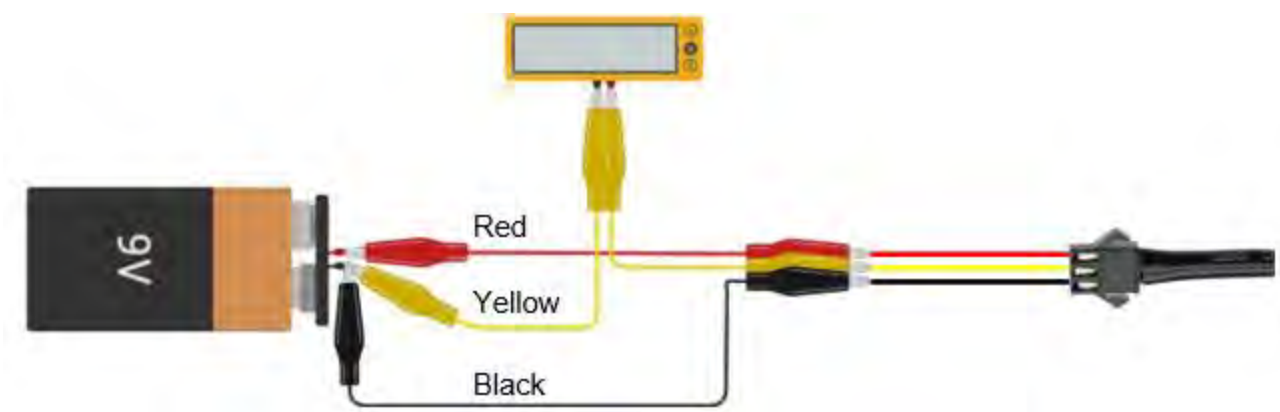


Figure 2. Wiring Schematic

4. Set up the DMM to collect readings in *Hz*.
    - Turn the dial to *Hz*.
    - Connect the red lead of the DMM to the alligator clip connected to the sensor wire.
    - Connect the black lead of the DMM to the battery's negative terminal.
5. Insulate all the electrical connections in the circuit using electrical tape to prevent shorts.
6. Record the DMM reading in Table 3 under *no flow*.
    - Your flow rate will be 0ml/sec.

7. Press the **MAX MIN** button on the DMM to collect the max reading
8. Place the cup of water under the output end of the flow rate transducer.
9. Collect data.
    - Use a timer to record the time in seconds needed for 60ml of water to flow through the transducer.
    - Slowly push down the syringe plunger while collecting water in the cup.
    - Observe the Hz readings on the DMM.
10. Record the volume of water, Max Hz and the time in Table 3 under *slow flow*.
11. Calculate the flow rate in ml/sec by dividing the volume by time. Record in Table 3.
12. Disconnect the empty syringe and repeat Steps 1–2.
13. Repeat Steps 7–11 with a faster flow.
14. Use the data from Table 3 to make a line graph. This line graph will serve as a calibration chart.
    - Plot the points showing the relationship between transducer readings and flow rate.
    - Connect the points to make a line.
15. Answer *Part Two Analysis Questions*.

Part Three – Transducer Diagnostics

Your teacher will assign your group a common transducer failure and materials. Simulate the failure and repeat Part Two to determine how the failure changes the transducer readings. Record the data from the faulted transducer in Table 4. Overlay the data from Table 4 on the calibration chart using a colored pencil.

Create a presentation about the transducer fault and your results including the *Presentation Criteria*. Your teacher will evaluate your presentation using the *Project 4.2.6 Evaluation Rubric*.

Presentation Criteria

- Description of the fault
- Influence of the transducer reading
- Method(s) to determine the fault using a DMM
- Demonstrate how to use the DMM to diagnose the fault

Conclusion

1. What materials or tools are needed when troubleshooting a transducer?

2. What is the difference between a sensor and a transducer?

Name____

Project 4.2.6 Student Data

Table 2. ***Flow Rate Transducer***

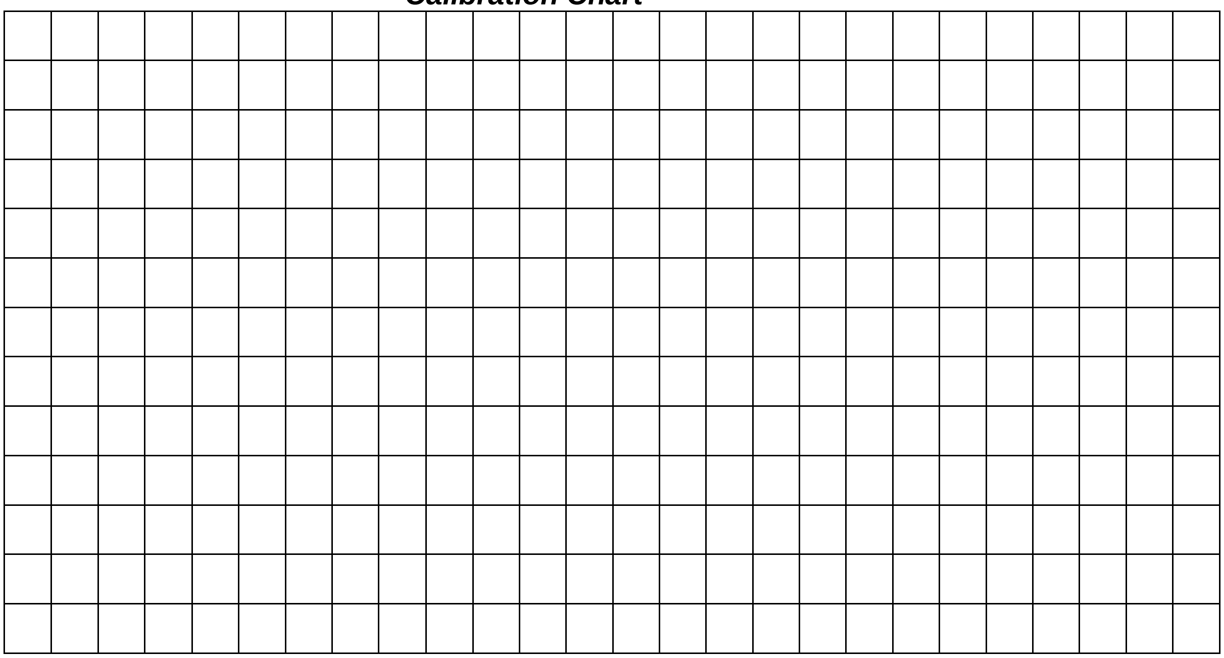
Specification	Data	Specification	Data
Working voltage		Load capacity	
Flow rate range		Water pressure	

Table 3. ***Flow Rate Transducer***

Test	Volume (ml)	Time (seconds)	Flow Rate (ml/sec)	Transducer Reading (Hz)
No flow	0ml	0 seconds	0 ml/sec	
Slow flow				
Fast flow				

Calibration Chart

Transducer Reading (Hz)



Rate ml/sec

Part Two Analysis Questions

Q1 What is the purpose of the electrical tape in the circuit?

Q2 What would cause a low flow rate reading on a sprayer?

Table 4. ***Flow Rate Fault***

Test	Volume (ml)	Time (seconds)	Flow Rate (ml/sec)	Transducer Reading (Hz)
No flow	0ml	0 seconds	0 ml/sec	
Slow flow				
Fast flow				

Name____

CASE

Project 4.2.6 Evaluation Rubric

Areas with Room for Improvement	Criteria	Areas that Meet or Exceed Expectations
	Description of the fault Students present the fault assigned to their group and demonstrate how they simulated the fault. The simulation is accurate.	
	Influence on Transducer Readings Students present how the fault altered the transducer readings. A chart showing the difference of readings from a normally operational transducer and the transducer with the faults is shown.	
	Method(s) to determine fault Students provide a series of steps or methods that a technician can use to diagnose the faults within the system.	
	Demonstration A demonstration with the DMM is conducted to show how the fault can be diagnosed using diagnostic tools.	

CASE

Project 4.2.6 Transducer Cards

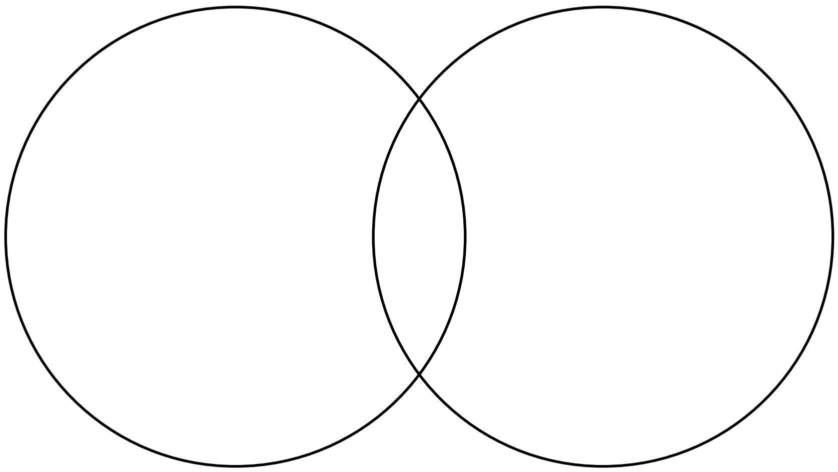
Fault	How to simulate	Materials
Shorted sensor wire	Short any two connections together by connecting the conductors of each cable. Then, tape the cables together to hold the short in place.	Electrical tape
Low battery voltage	Replace the battery with a lower voltage battery.	D Cell battery D Cell battery holder
High battery voltage	Connect two 9V batteries in series to power the sensor. The source voltage will be 18V.	Extra 9V battery Extra cable with alligator clip
Switched ground and voltage reading	Switch the ground wire and the voltage reading (middle) cable at the flowrate plug.	N/A
Plugged flowrate transducer	Plug the flowrate transducer to simulate a kink or foreign material in the system.	Duct tape
Knicked or open cable	Disconnect, cut or knick any cable.	Wire strippers
Corroded terminals	Simulate corrosion on battery terminals using electrical tape.	Electrical tape

Name____

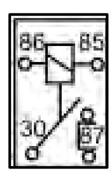
Lesson 4.2 Check for Understanding

1. List three components of an electrical schematic.

2. Compare the function of relays and solenoids using a Venn diagram.



3. Draw a schematic using a normally open relay and describe the function.

Schematic	
Function	

4. How do electrical systems use safety switches to shut down engine operation?

5. How does a transducer communicate sensor data?

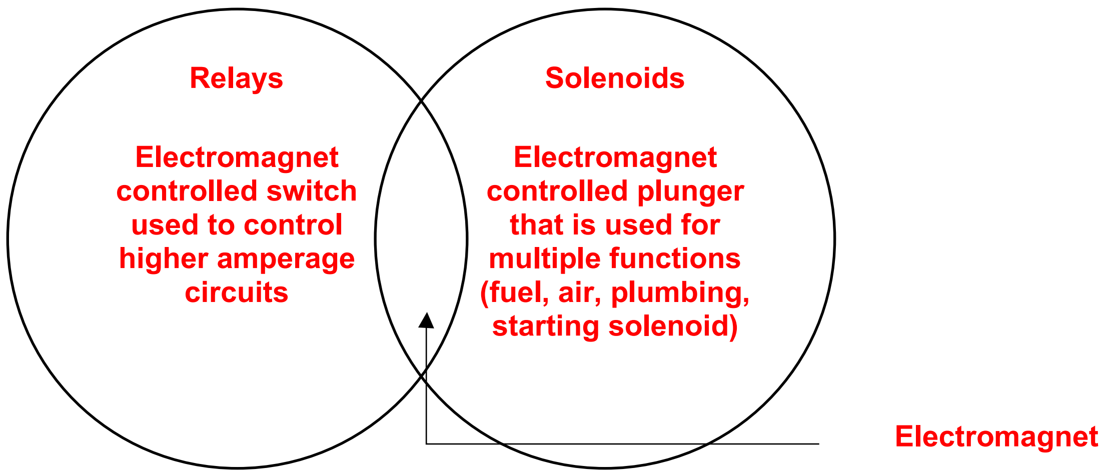
CASE

Lesson 4.2 Check for Understanding Answer Key

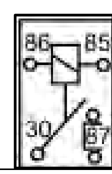
1. List three components of an electrical schematic.

Answers may include symbols, part numbers, electrical values, connections, cables, and jump tags.

2. Compare the function of relays and solenoids using a Venn diagram.



3. Draw a schematic using a normally open relay and describe the function.

Schematic	**Answers will vary. The circuit should include a high and low side. The low side of the circuit turns on a device. The high side powers a device.** 
Function	**Answers will vary. Student responses should describe the function of the circuit drawn.**

4. How do electrical systems use safety switches to shut down engine operation?

Students should explain how safety switches are designed to be open under normal operation. When a safety switch closes, it grounds the circuit to either the magneto (turning off the engine) or the starter solenoid (preventing the engine from starting).

5. How does a transducer communicate sensor data?

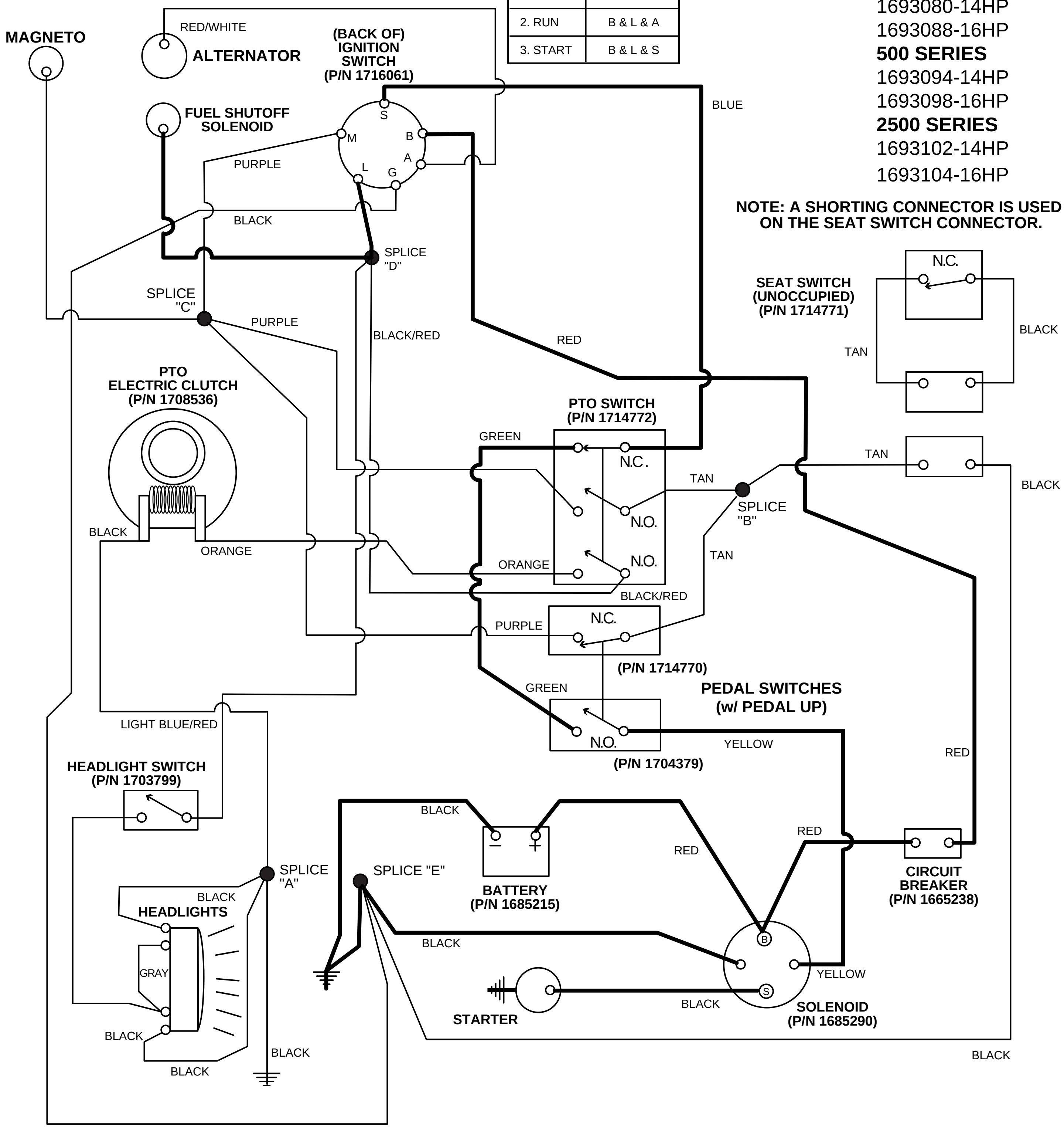
Transducers include a sensor. As the sensor responds to stimuli, the transducer sends an electronic signal that a computer can quantify.

CRANKING CIRCUIT

IGNITION SWITCH	
POSITION	CIRCUIT MAKE
1. OFF	G & M & A
2. RUN	B & L & A
3. START	B & L & S

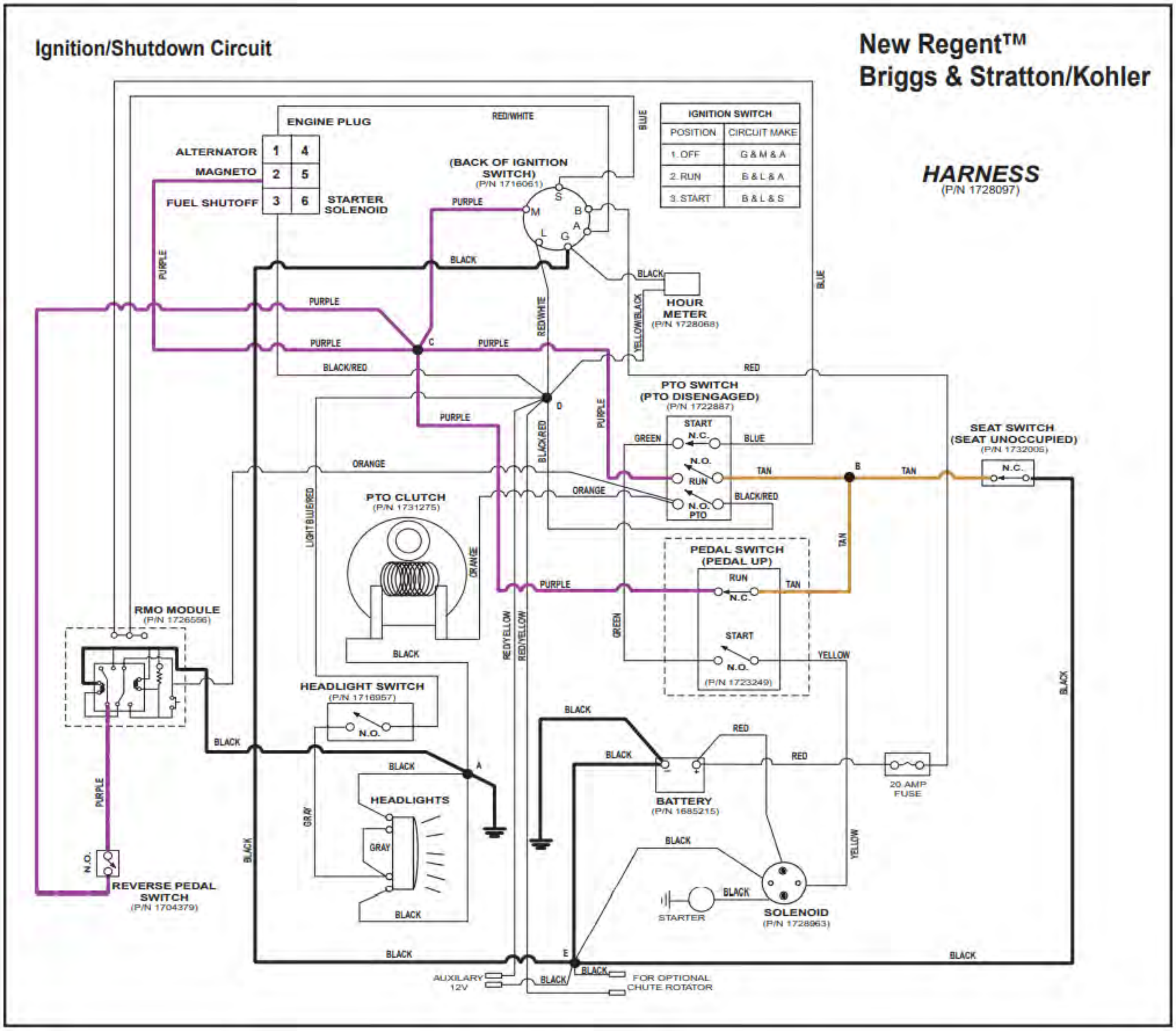
(HYDRO MODELS)
REGENT SERIES
1693080-14HP
1693088-16HP
500 SERIES
1693094-14HP
1693098-16HP
2500 SERIES
1693102-14HP
1693104-16HP

NOTE: A SHORTING CONNECTOR IS USED ON THE SEAT SWITCH CONNECTOR.



CASE

Ignition/Shutdown Schematic



Briggs and Stratton Customer Education (2014). *Electrical Training Manual*.

JOHN DEERE
WORLDWIDE COMMERCIAL & CONSUMER EQUIPMENT DIVISION

Gator Utility Vehicles
Turf Gator

TM1686 NOVEMBER 2003

TECHNICAL MANUAL

JOHN DEERE

North American Version
Litho in U.S.A.

Table of Contents

General Information

Operation and Diagnostics

The operation and diagnostics stories divide the electrical system into individual circuits by function. Each circuit is isolated from the main wiring schematic and only shows the components that are used in it. The story contains information on function, operating conditions, and theory of operation. The circuit schematics are drawn with the components in the operating position, with the power, or battery positive, into them across the top and the ground, or battery negative, across the bottom.

Diagnostic Information

The diagnostic procedures is used to test the complete circuit regardless of the problem or complaint. Select a symptom or system from the quick check or troubleshooting chart and follow the test procedures under that heading.

The diagnostic procedure lists:

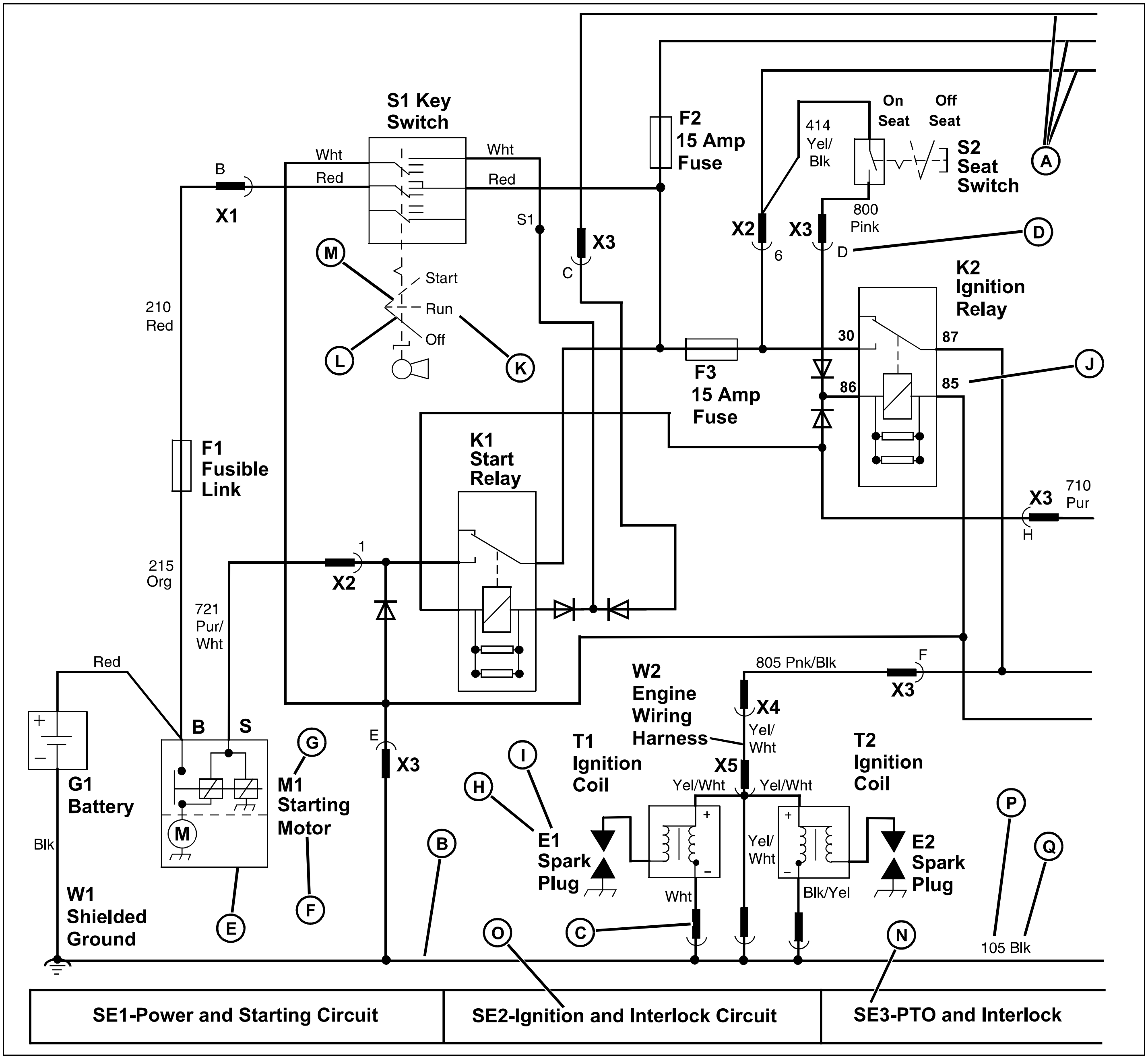
- Test conditions
- Test sequence
- Test location
- Normal reading
- Check or test to perform if reading is not normal

When performing the test or check, be sure to set your machine up to the test conditions listed and follow the sequence carefully. The middle “NORMAL” column gives the reading or condition that should be obtained when performing the test or check. If the results of the test or check are not normal, perform the test, check, or adjustment listed in the third “IF NOT NORMAL” column to repair the malfunction. The detailed tests or adjustments referred to in the “IF NOT NORMAL” column are located at the end of that group. The system diagram that accompanies each test procedure is drawn to resemble machine components. The key number on the art matches the number in the “TEST LOCATION” column and the leader line points to the exact point the test is to be made.

Wire Color Abbreviation Chart

Blk	**Black**
Blu	**Blue**
Brn	**Brown**
Grn	**Green**
Gry	**Gray**
Org	**Orange**
Pnk	**Pink**
Pur	**Purple**
Red	**Red**
Tan	**Tan**
Wht	**White**
Yel	**Yellow**
Blk/Wht	**Black/White**
Blu/Wht	**Blue/White**
Brn/Wht	**Brown/White**
Brn/Yel	**Brown/Yellow**
Dk Blu	**Dark Blue**
Dk Brn/Lt Grn	**Dark Brown/Light Green**
Dk Brn/Red	**Dark Brown/Red**
Dk Brn/Yel	**Dark Brown/Yellow**
Dk Grn	**Dark Green**
Lt Blue	**Light Blue**
Lt Grn	**Light Green**
Org/Wht	**Orange/White**
Pnk/Blk	**Pink/Black**
Pur/Wht	**Purple/White**
Red/Blk	**Red/Black**
Red/Wht.	**Red/White**
Wht/Blk	**White/Black**
Wht/Red.	**White/Red**
Yel/Blk	**Yellow/Black**
Yel/Red	**Yellow/Red**
Yel/Wht	**Yellow/White**

Reading Electrical Schematics



The schematic is made up of individual circuits laid out in a sequence of related functions. It is formatted with all power wires (A) across the top and all ground wires (B) across the bottom. Current flow is generally from top to bottom through each circuit and component. All components are shown in the off position. The diagram does not list connector (C) information unless needed to avoid confusion. If the connector is shown, the number next to it is the terminal pin location (D) in the connector.

Each component is shown by a symbol (E), its name (F), and an identification code (G). The identification code contains a device identifying letter (H) and number (I).

The identifying letter is always the same for a specific component, but the identifying numbers are numbered consecutively from upper left to lower right. The terminal designation (J) is placed directly outside the symbol next to the connecting wire path. Switch positions (K) are also placed directly outside the symbol. The solid line (L) shows the position the switch is currently in and dash lines (M) represent other switch positions.

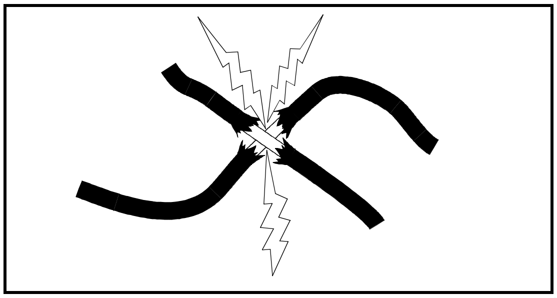
Each circuit is identified at the bottom of the drawing by a section number (N) and section name (O).

The circuit number (P) and wire color (Q) of the wires are shown directly next to the wire path.

The same component name and identification code are used consistently on all diagrams in this section. Components can be easily cross-referenced.

Common Circuit Tests

Shorted Circuit:



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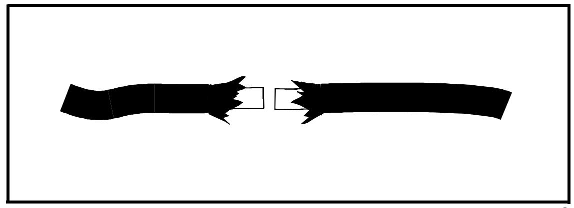
A shorted circuit may result in the wrong component operating (i.e. improper wire-to-wire contact). To test for a shorted or improperly wired circuit:

1. Turn component switch on.
2. Start at the controlling switch of the component that should not be operating.
3. Follow the circuit and disconnect wires at connectors until component stops operating.
4. Shorted or improper connections will be the last two wires disconnected.

High Resistance or Open Circuit:



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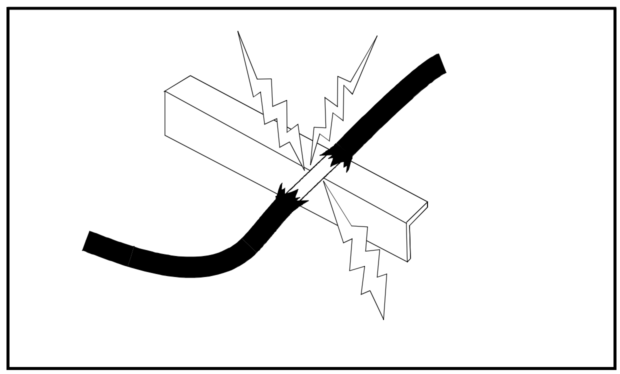
1. High resistance or open circuits usually result in slow, dim or no component operation (i.e. poor, corroded, or disconnected connections). Voltage at the component will be low when the component is in operation. To test for high resistance and open circuits:
2. Check all terminals and grounds of the circuit for corrosion.
3. If terminals are not corroded or loose, the problem is in the component or wiring.

Grounded Circuit:



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Grounded circuits usually result in no component operation or a blown fuse.

Conductors for 12 Volt Circuits

Standard Conductors For 12 Volt Circuits						
SAE Wire Size (Gauge)	20	18	16	14	12	10
Metric Wire Size (mm)	0.5	0.8	1.0	2.0	3.0	5.0
Typical Stranding	7 X 28	16 X 30	19 X 29	19 X 27	19 X 25	19 X 23
Minimum Conductor Area In Circular Mils	1072	1537	2336	3702	5833	9343

Specifications

Battery:

Voltage 12
BCI group U-1
CCA rating (Amps at 0° F) 340
Reserve capacity (minutes) 41
Specific gravity . . . . 1.225 or above
Electrolyte required fill (approximately) . . . . 1.9 L (2.0 qt)
Load test (minimum) . . . . 340 amps for 15 seconds

Ignition:

Primary coil resistance . . . . 0.67 - 1.10 ohms
Secondary (Plug wire and core) . . . . 6 - 10 ohms
Air gap . . . . 0.3 mm (0.012 in.)

Spark Plug:

Type . . . . NGK BPR5ES-10
Gap . . . . 0.8 mm (0.032 in.)
Torque . . . . 25 N•m (221 lb-in.)

Starting Motor/Generator:

Type . . . . Starter / Generator
Starter amp draw (on vehicle) . . . . 51 amps at 750 rpm
Starter no-load amp draw (free running) . . . . 6 amps (max.) at 2500 rpm
Generator regulated amperage/voltage . . . . Up to 43 amp at 14.5 ± 0.5 volts
Generator unregulated voltage . . . . 18 VAC

Lighting:

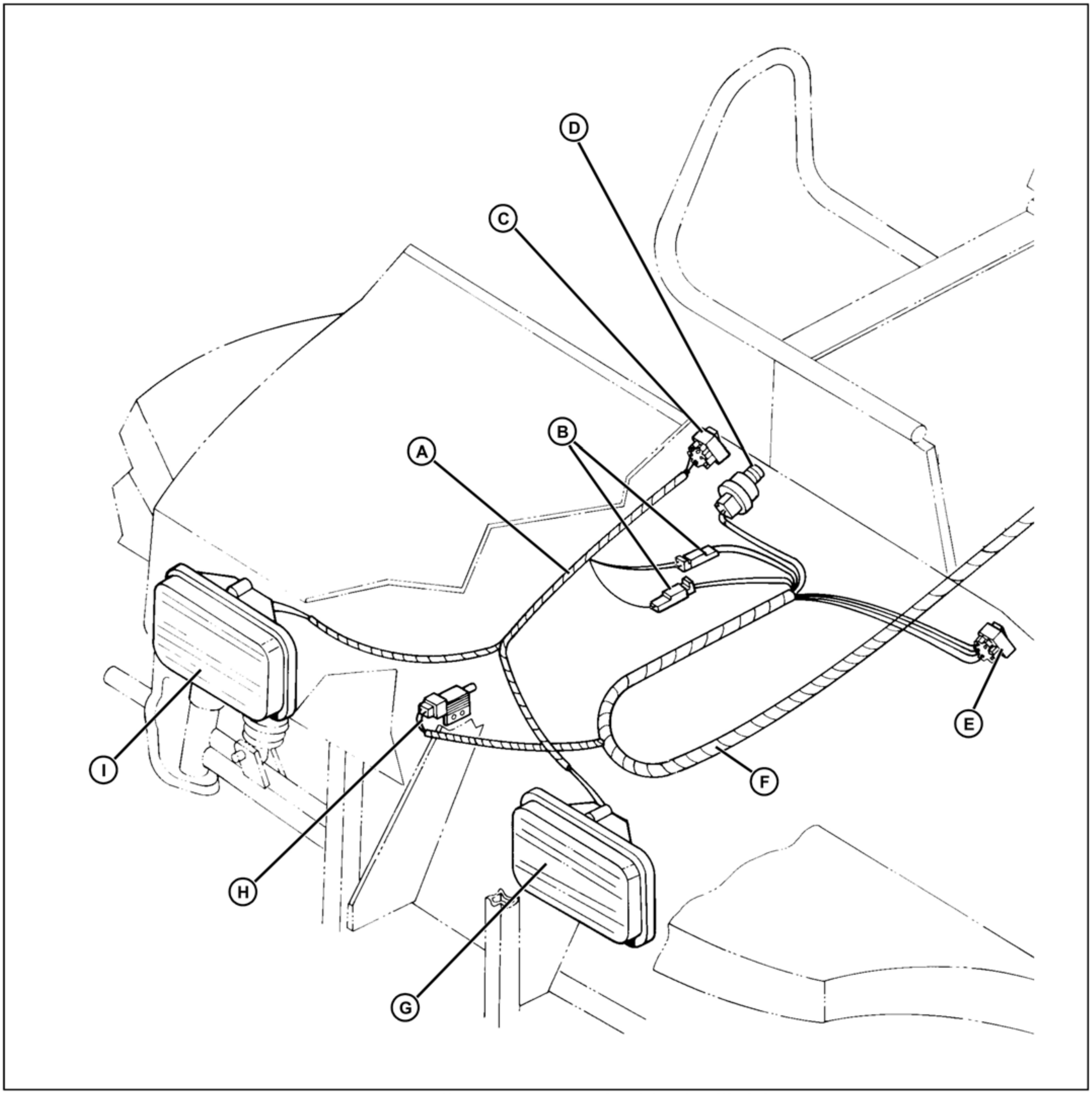
Headlights (halogen) . . . . 37.5 watts
Tail/Brake Lights . . . . 21 watts
Position Lights . . . . 10 watts
Front /Rear Turn Lights . . . . 21 watts

Neutral Start Switch:

Neutral (depressed) . . . . Continuity
In Gear (released) . . . . No Continuity

Component Location

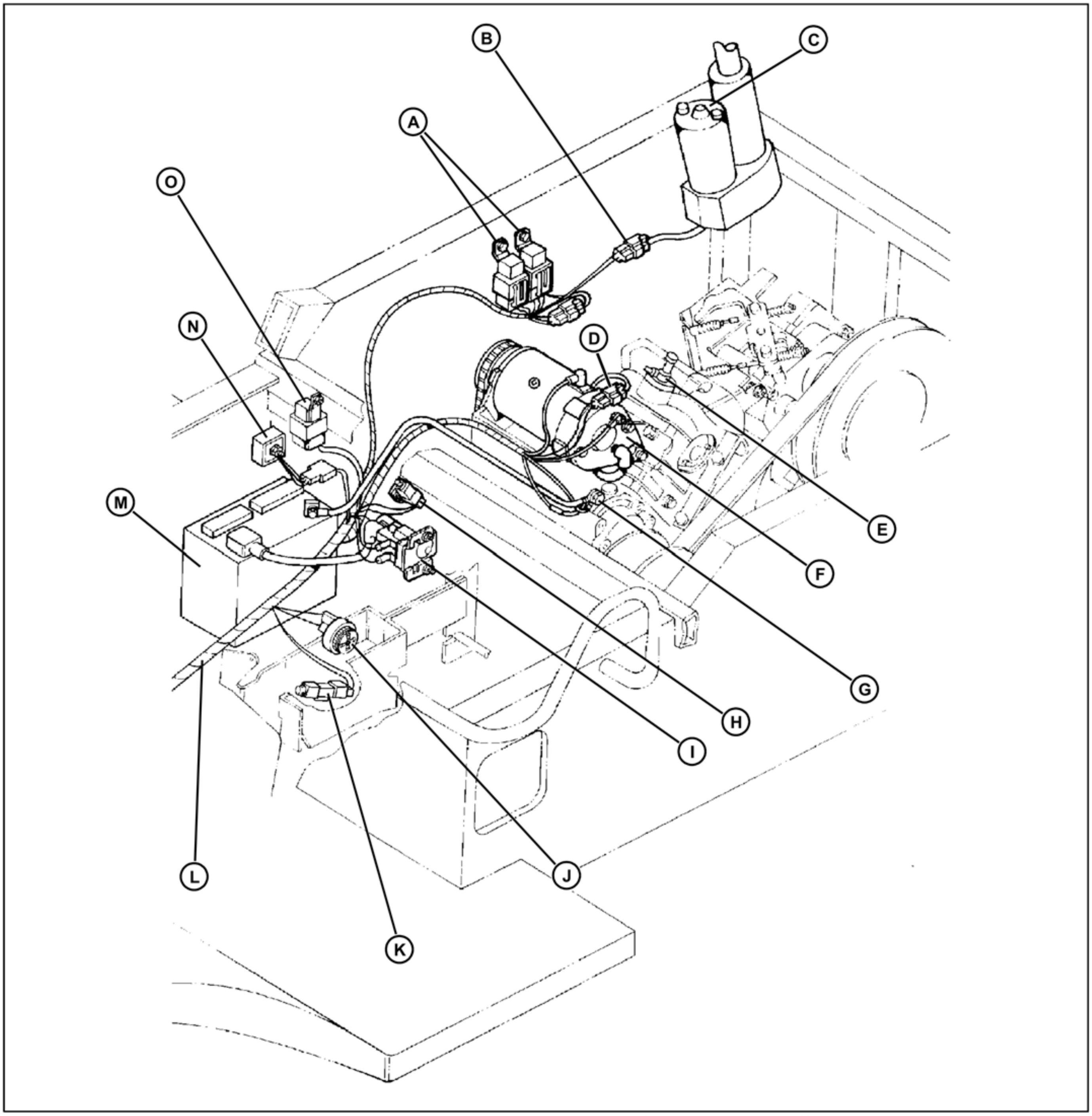
Electrical Components



M87610

A - W4 Standard Headlight Harness
B - X4 / X5
C - S5 Light Switch
D - S2 Key Switch
E - S6 Cargo Box Lift Switch (Optional)
F - W1 Main Wiring Harness
G - E2 Headlight
H - S3 Foot Throttle Switch
I - E2 Headlight

ELECTRICAL COMPONENT LOCATION



M87611

A - K1 and K2 Cargo Box Lift Relays (Optional)
B - W17 Cargo Box Lift Wiring Harness (Optional)
C - M2 Cargo Box Lift Motor (Optional)
D - X2
E - E1 Spark Plug
F - G2 Starting Motor/Generator
G - W1 Ground
H - S3 Park Brake Switch
I - K1 Starter Solenoid
J - H1 In Reverse Alarm
K - S1 Reverse Switch
L - W1 Main Wiring Harness
M - G1 Battery
N - N1 Voltage Regulator
O - K2 Magneto Run Relay

Schematics and Harnesses

Electrical Schematic and Wiring Harness Legend

Components:

E1 - Spark Plug (SE3, W1)

E2 - Right Headlight (SE5, W1; SE5, W4)

E3 - Left Headlight (SE5, W1; SE5, W4)

F1 - Fusible Link (SE1, W1)

G1 - Battery (SE1, W1)

G2 - Starting Motor/Generator (SE3, W1)

H1 - In Reverse Alarm (SE1, W1)

K1 - Starter Solenoid (SE1, W1)

K2 - Magneto Run Relay (SE1, W1)

N1 - Voltage Regulator (SE2, W1)

S1 - Reverse Switch (SE1, W1)

S2 - Key Switch (SE1, W1)

S3 - Foot Throttle Switch (SE1, W1)

S4 - Park Brake Switch (SE3, W1)

S5 - Light Switch (SE5, W1)

S6 - Cargo Box Lift Switch (SE6, W1)

T1 - Magneto Ignition Coil (SE3, W1)

W1 - Shielded Ground (SE1, W1)

Connectors:

X1 - W1 Main Wiring Harness to Hour Meter (Optional) (SE1, W1)

X2 - W1 Main Wiring Harness to G2 Starting Motor/ Generator (SE3, W1)

X3 - W1 Main Wiring Harness to W2 Engine Wiring Harness (SE3, W1)

X4 - W1 Main Wiring Harness to W3 Standard Headlight Wiring Harness (SE5, W1; SE5, W3)

X5 - W1 Main Wiring Harness to W3 Standard Headlight Wiring Harness (SE5, W1; SE5, W3)

X6 - W1 Main Wiring Harness to S6 Cargo Box Lift Switch (SE6, W1)

X7 - W1 Main Wiring Harness to W4 Cargo Box Lift Wiring Harness (SE6, W1)

X8 - W1 Main Wiring Harness to Auxiliary Power (Optional) (SE6, W1)

Electrical Section Wiring Harness Legend:

W1 - Main Wiring Harness

W2 - FE290D–AS15 Engine Wiring Harness

W3 - Standard Headlight Wiring Harness

W4 - Cargo Box Lift Wiring Harness

W5 - Light and Horn Wiring Harness

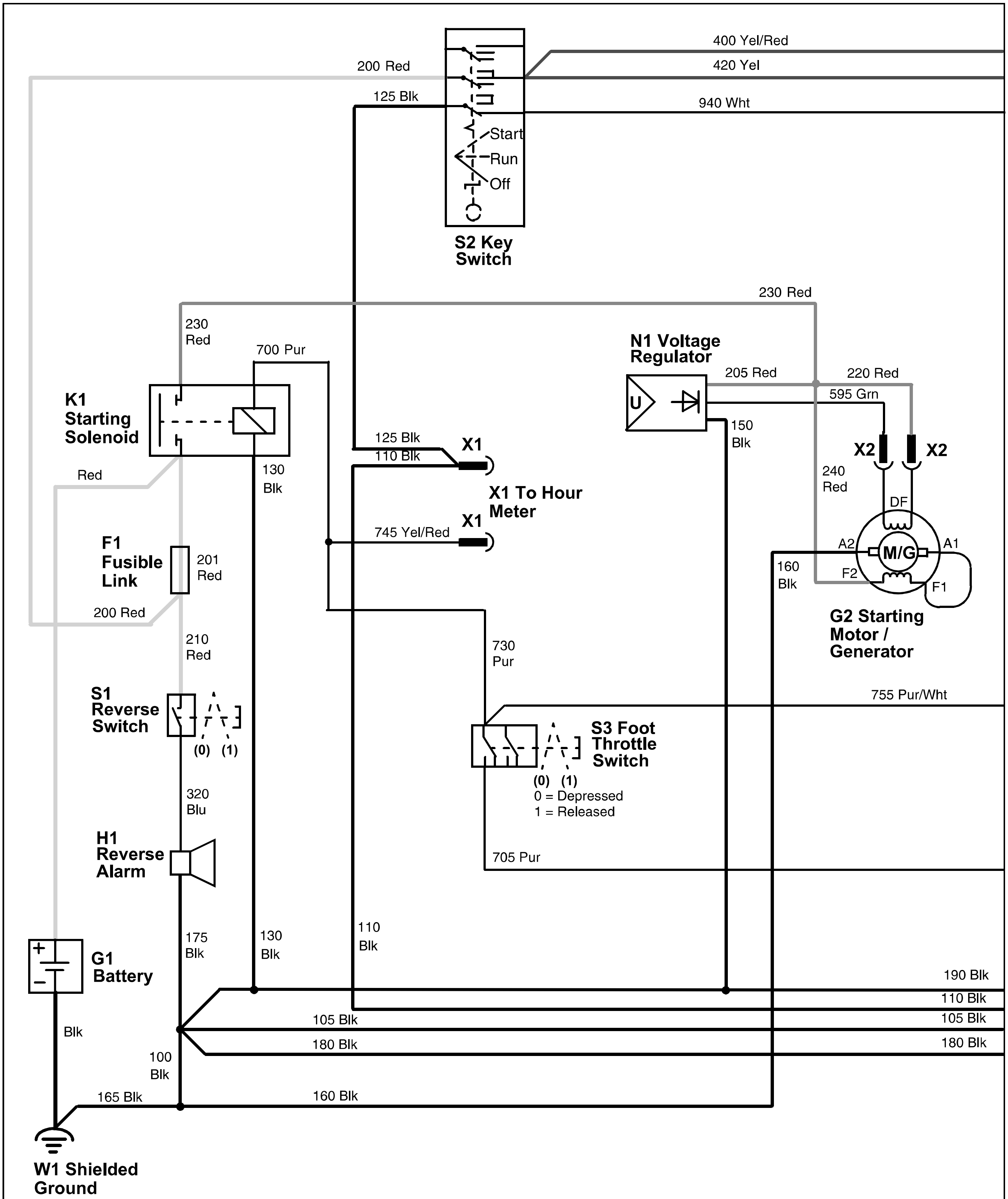
W6 - Rear Position/Brake/Turn Wiring Harness (Left)

W7 - Rear Position/Brake/Turn Wiring Harness (Right)

W8 - Front Position/Turn Wiring Harness (Left and Right)

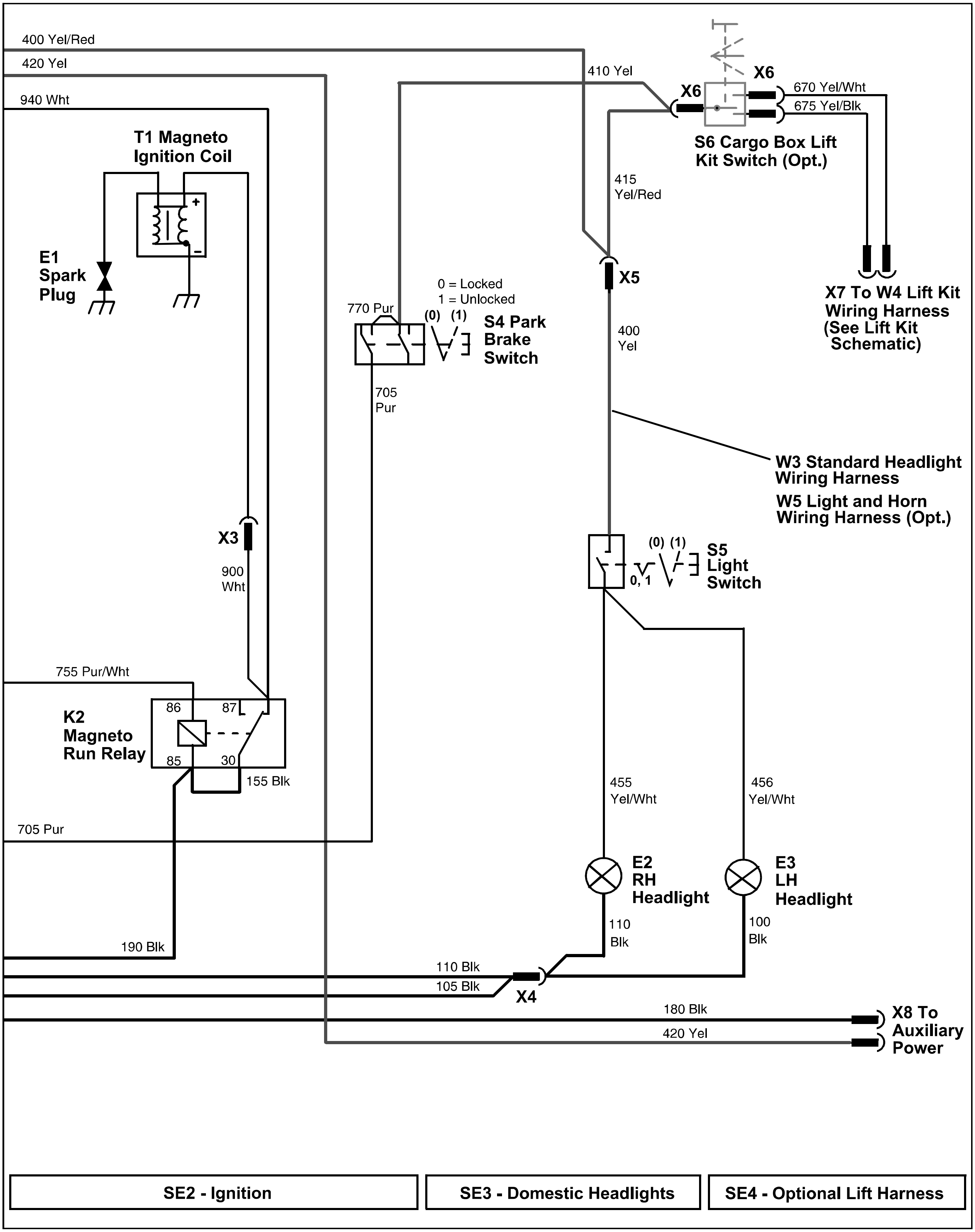
W9 - Headlight Adaptor Wiring Harness (Domestic Use Only)

W1 Main Electrical Schematic (1 of 2)

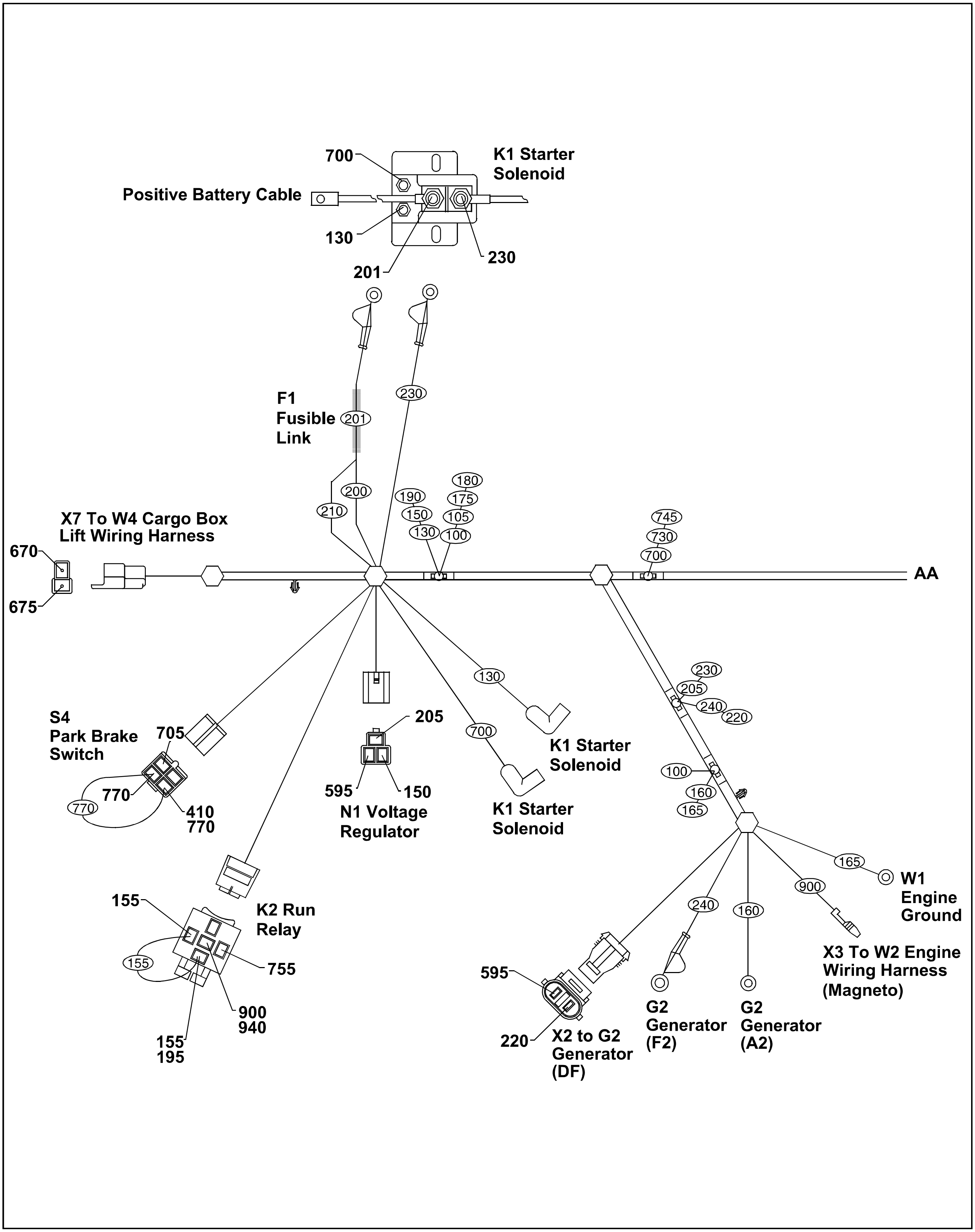


SE1 - Starting / Charging

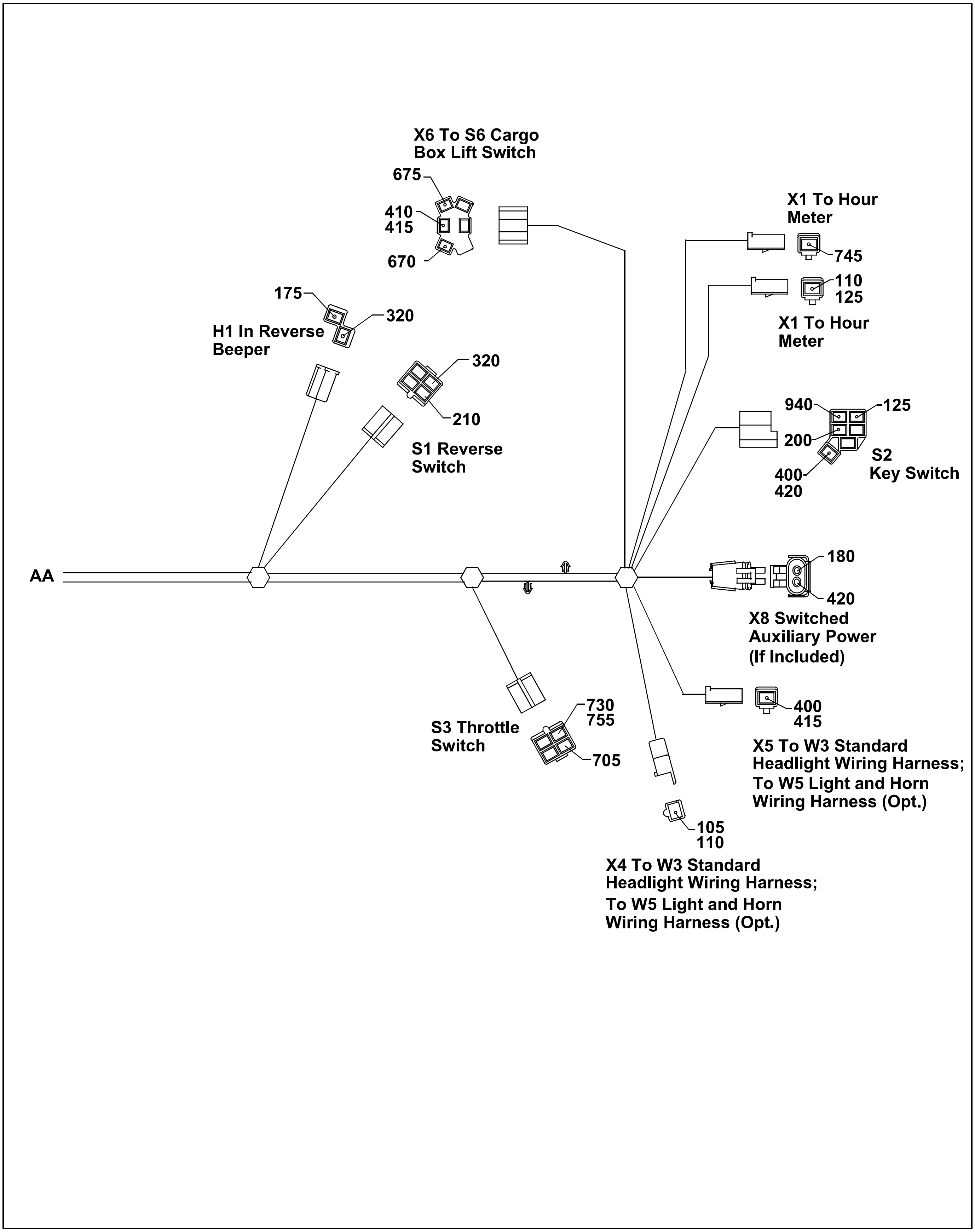
W1 Main Electrical Schematic (2 of 2)



W1 Main Wiring Harness (1 of 2)



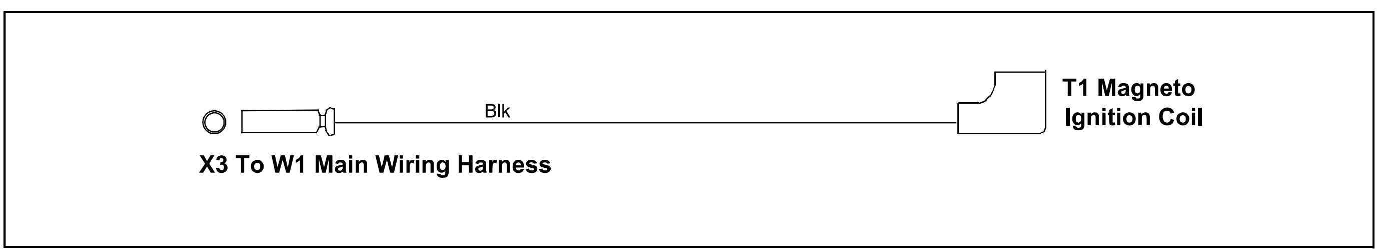
W1 Main Wiring Harness (2 of 2)



W1 Main Wiring Harness Wire Color Code

Size / No. / Color	Termination Points
5.0 100 Blk	160 and 165 Splice, 105, 130, 150, 175, 180 and 190 Splice
0.8 105 Blk	Solder 100, X4
0.8 110 Blk	X1, X4
0.8 125 Blk	S2, X1
0.8 130 Blk	K1, W1 Gnd
1.0 150 Blk	N1, 100 Blk
0.8 155 Blk	K2, K2 jumper
8.0 160 Blk	G2, 100 Blk
8.0 165 Blk	100 and 160 Splice, W1 Engine Gnd
0.8 175 Blk	H1, 100 Blk
2.0 180 Blk	X8, 100 Blk
0.8 190 Blk	K2, 100 Blk
0.8 195 Blk	K3, K2
2.0 200 Red	F1, S2
0.5 201 Fuse Link	K1, 200 and 210 Red
1.0 205 Red	230 Red, N1
0.8 210 Red	F1, S1
0.8 220 Red	230 Red, X2 (G2)
8.0 230 Red	K1, Splice 205, 220 and 240 Red
8.0 240 Red	230 Red, G2
0.8 320 Blu	S1, H1
1.0 400 Yel/Red	S2, X5
1.0 410 Yel	X6 (S6), S4
1.0 415 Yel/Red	X5, X6 (S6)
1.0 420 Yel	S2, X8
1.0 595 Grn	X2 (G2), N1
0.8 670 Yel/Wht	X6 (S6), X7
0.8 675 Yel/Blk	X6 (S6), X7
0.8 700 Pur	730/745 Pur, K1
1.0 705 Pur	S4, S3
0.8 730 Pur	700/745 Pur, S3
0.8 745 Yel/Red	700/730 Pur, X1
0.8 755 Pur/Wht	S3, K2
0.8 770 Pur	S4, S4 jumper
0.8 900 Wht	X3, K2
0.8 940 Wht	S2, K2

W2 Engine Wiring Harness



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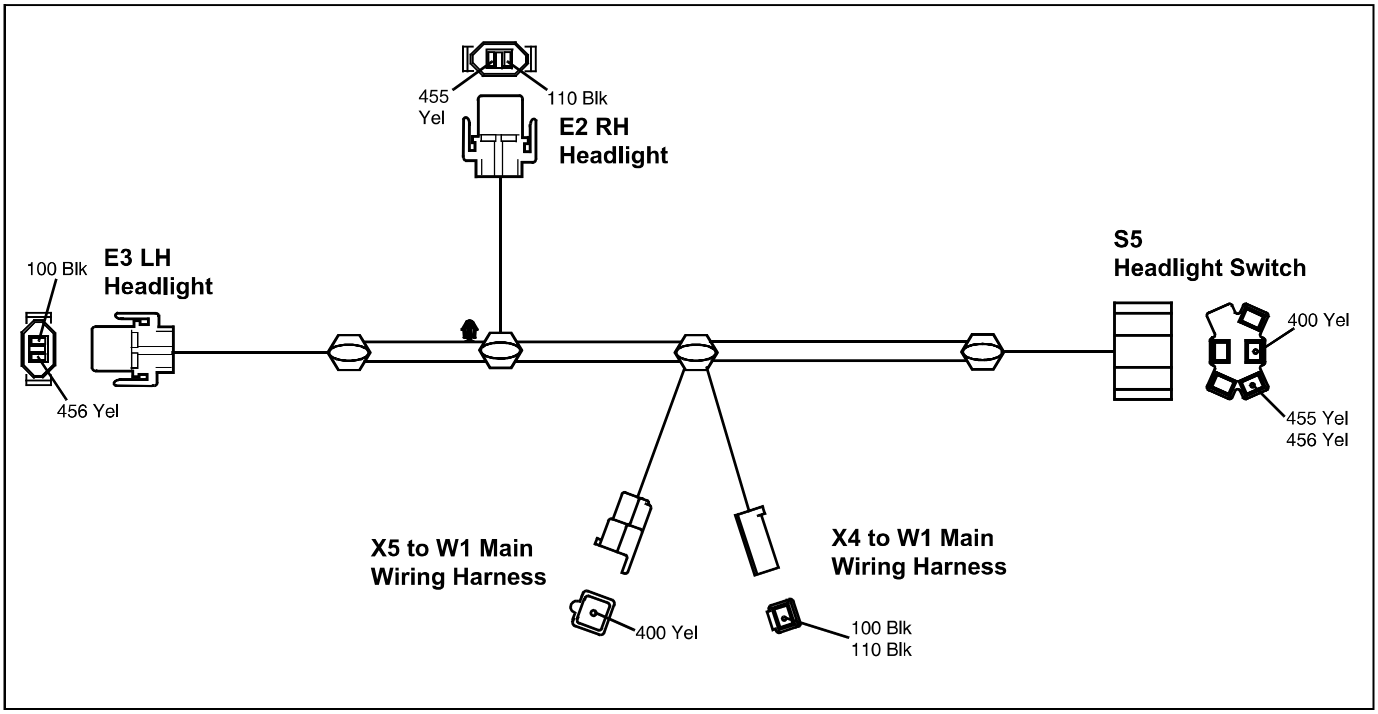
W3 Standard Headlight Wiring Harness



MIF

Operation and Diagnostics

Power Circuit Operation

Function:

Provides unswitched power to the primary components whenever the battery is connected.

Operating Conditions, Unswitched Circuits:

Voltage must be present at the following components with the key switch in the OFF position:

- Battery Positive Terminal
- In Reverse Switch
- “B” Terminal of Key Switch

The positive battery cable connects the battery to the starter solenoid. The starter solenoid bolt is used as a tie point for the rest of the electrical system.

The battery cables and the starter solenoid tie point connections must be good for the vehicle electrical system to work properly.

The ground cable connection is equally important as the positive cable. Proper starting operation depends on these cables and connections to carry the high current for its operation.

The connection between the starter solenoid and key switch is fused by a fusible link. This is a short piece of wire that is designed to fail if current load is too high or a short occurs. It protects the wiring harness from damage.

Switched Power:

Voltage must be present at the following components with the key switch in the RUN position, and the park brake ON:

- “A” and “S1” Terminals of Key Switch
- Light Switch
- Cargo Box Lift Switch Connector
- Park Brake Switch
- Auxiliary Power Connector

These circuits are controlled by the key switch and are protected by the fusible link.

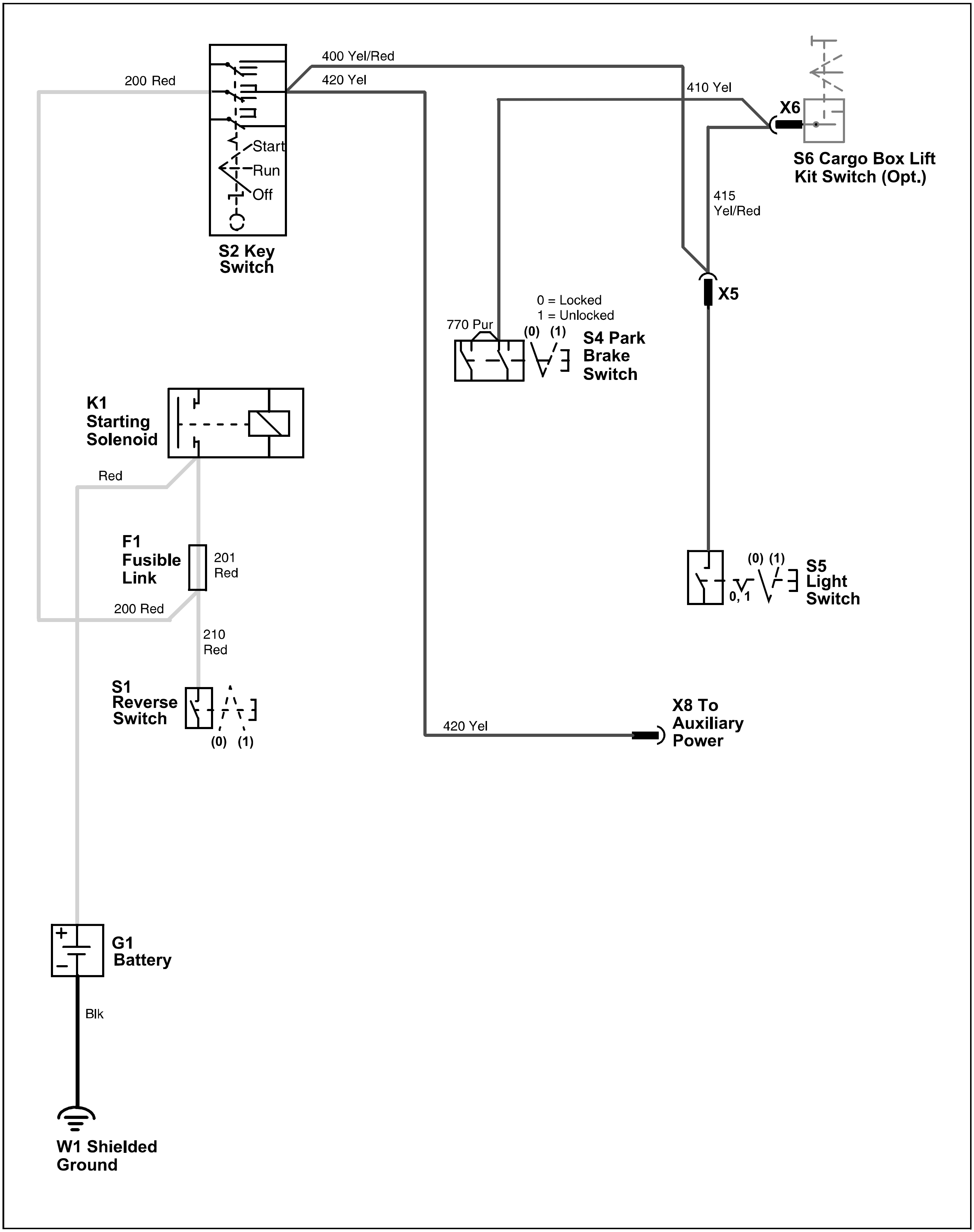
Voltage should be present at the foot throttle switch with the park brake OFF.

Lighting and Lift Power Circuits:

See the appropriate schematics and diagnostic procedure for these circuits.

The positive wires for these kits are also connected to the starting motor/generator bolt. These leads also contain fusible links to protect the wiring harnesses.

Power Circuit Schematic



Power Circuit Diagnosis

Power Circuit Unswitched Power

Test Conditions:

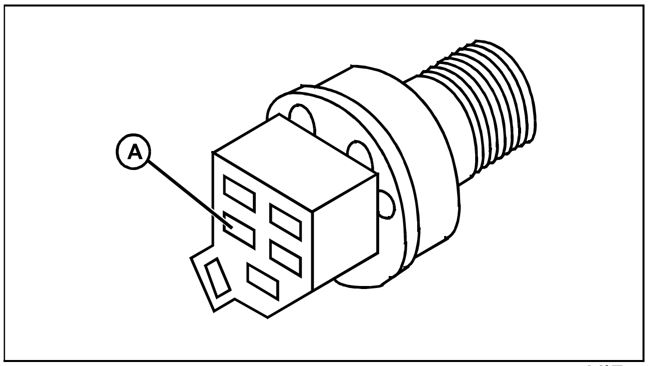
- Key switch in OFF position

System: Power Circuit Unswitched Power

(1) Is voltage at the G1 battery positive post between 11.8 - 13.2 VDC?

Yes - Go to next step.

No - Test the battery. Go to next step.

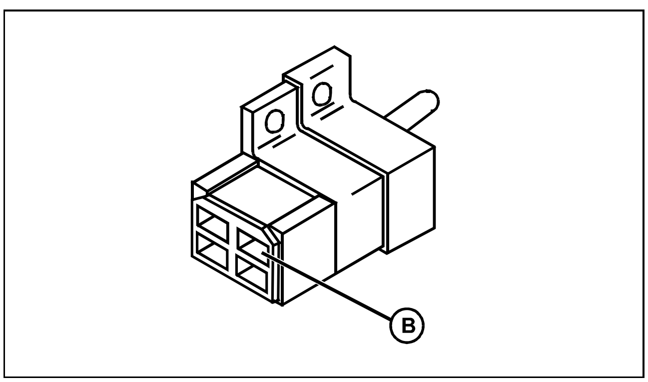


MIF

(2) Is battery voltage present at S2 key switch - 200 Red wire (A)?

Yes - Go to next step.

No - Test F1 fusible link. Check 200 Red wire connections. Go to next step.



MIF

(3) Is battery voltage present at S1 reverse switch - 210 Red wire (B)?

Yes - Test complete.

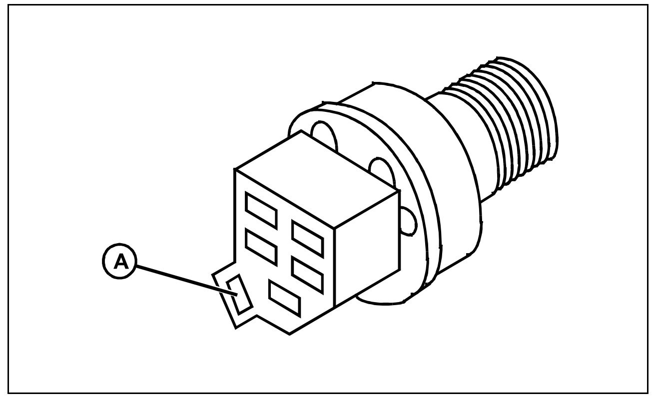
No - Test F1 fusible link. Check 210 Red wire connections.

Power Circuit Switched Power

Test Conditions:

- Key switch in run position
- Park Brake locked

System: Power Circuit Switched Power

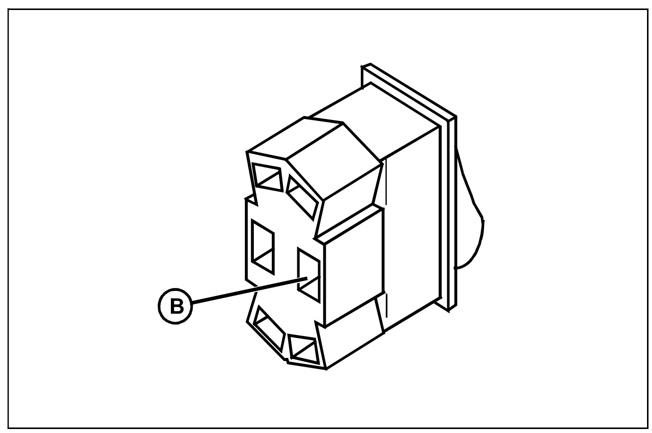


MIF

(1) Is battery voltage present at S2 key switch - 400 Yel/Red and 420 Yel wires (A)?

Yes - Go to next step.

No - Replace key switch. Go to next step.



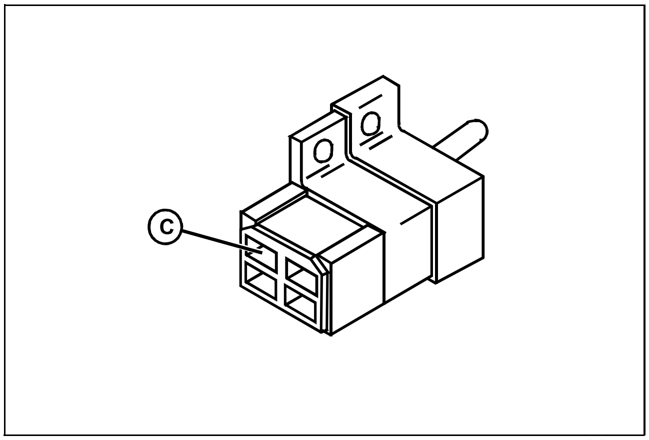
MIF

(2) Is battery voltage present at S5 light switch - 400 Yel wire (B)?

Yes - Go to next step.

No - Check 400 Yel/Red and 400 Yel wires and connections. If ok, replace key switch. Go to next step.

System: Power Circuit Switched Power



MIF

(3) Is battery voltage present at S4 park brake switch - 410 Yel wire (C)?

Yes - Test complete.

No - Check 400, 415 Yel/Red and 410 Yel wires and connections. If ok, replace key switch. Test complete.

Cranking Circuit Operation

Function:

To energize the starter solenoid and engage the starting motor/generator which cranks the engine.

Operating Conditions:

To crank the engine using the foot throttle the key switch must be in the run position, the park brake must be unlocked and the foot throttle must be depressed closing the contacts in the foot throttle switch.

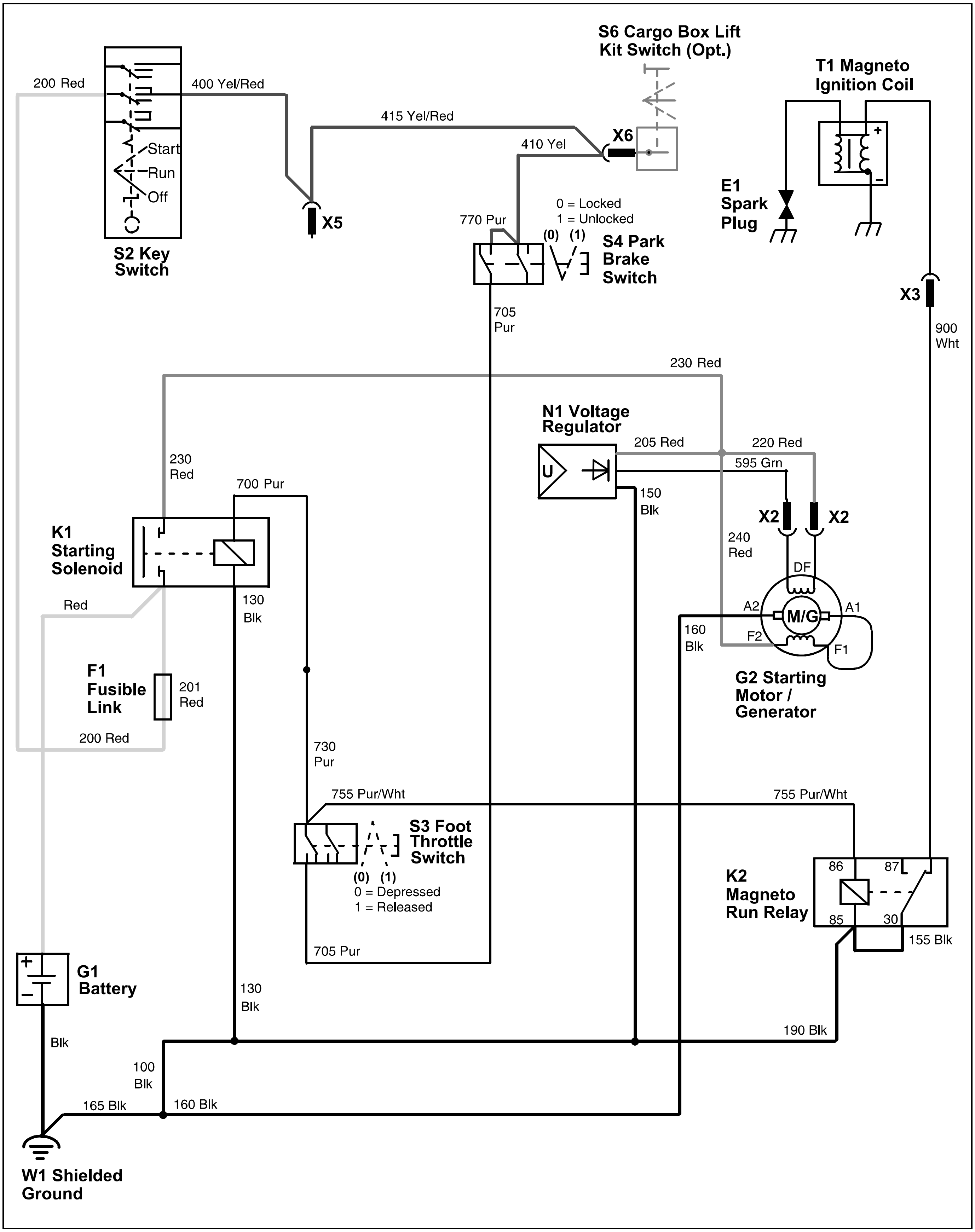
Foot Throttle Switch Theory of Operation:

Current flows from the battery through F1 fusible link to the key switch. With key switch in the run position current flows through the key switch, through 400 Yel/Red, 415 Yel/Red and 410 Yel/Red wires to the park brake switch. With the park brake unlocked, current flows through the park brake switch and 705 Pur wire to the foot throttle switch.

When the foot throttle is depressed, the switch closes and current flows through the switch contacts, and 730 Pur and 700 Pur wires to the starter solenoid coil.

With the starter solenoid coil energized, high current from the battery flows through the solenoid contacts, and 230 Red and 240 Red wires to the starting motor/generator causing it to turn and crank the engine.

Cranking Circuit Schematic



MIF

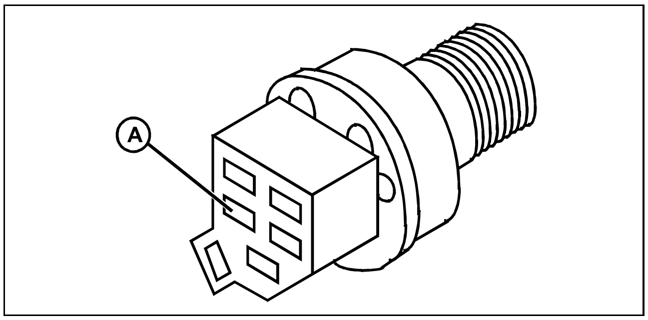
Cranking Circuit Diagnosis

Cranking Circuit Unswitched Power

Test Conditions:

- Key switch in off position
- Park brake locked
- Spark plug disconnected
- Transmission in neutral

System: Cranking Circuit Unswitched Power

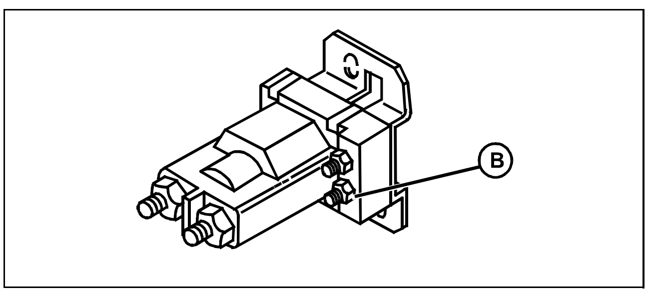


MIF

(1) Is battery voltage present at S2 key switch - 200 Red wire (A)?

Yes - Go to next step.

No - Test F1 fusible link. Check 200 Red wire connections. Go to next step.



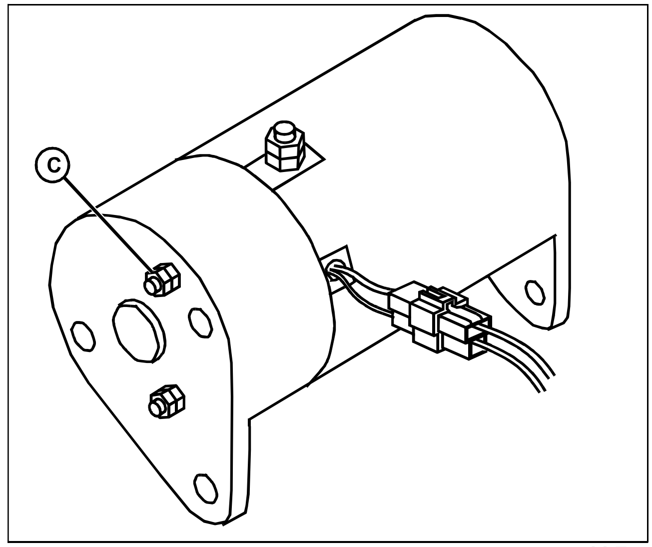
MIF

(2) Is continuity to ground present at K1 starting solenoid - 130 Blk wire (B)?

Yes - Go to next step.

No - Check 130, 100, and 165 Blk wires and connections. Go to next step.

System: Cranking Circuit Unswitched Power



MIF

(3) Is continuity to ground present at G2 starting motor/generator - A2 terminal, 160 Blk wire (C)?

Yes - Test complete.

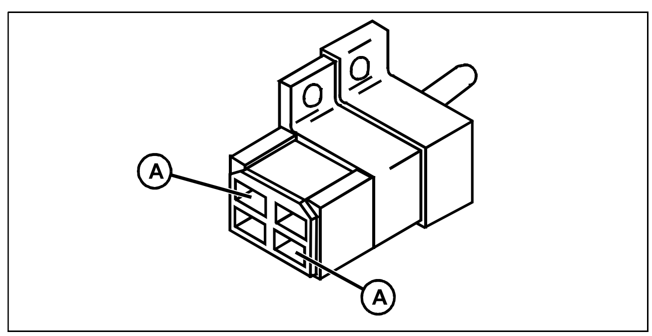
No - Check 230 and 240 Red wires and connections. If ok, replace starting solenoid. Go to next step.

Cranking Circuit Switched Power

Test Conditions:

- Key switch in run position
- Park brake unlocked
- Spark plug disconnected
- Transmission in neutral

System: Cranking Circuit Switched Power



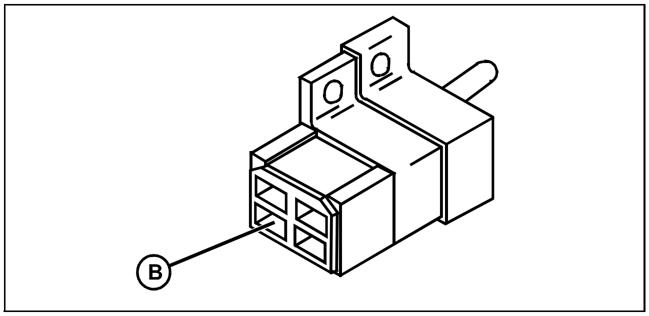
MIF

(1) Is battery voltage present at S4 park brake switch - 770 Pur and 410 Yel wires (A)?

Yes - Go to next step.

System: Cranking Circuit Switched Power

No - Check park brake switch adjustment. Check 770 Pur, 410 Yel, 415 Yel/Red and 400 Yel/Red wires and connections. If ok, replace key switch. Go to next step.



MIF

(2) Is battery voltage present at S3 foot throttle switch - 705 Pur wire (B)?

Yes - Test complete.

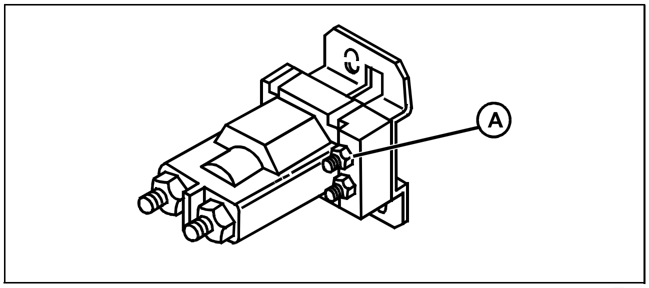
No - Check 705 Pur wire and connections. If ok, replace park brake switch.

Foot Throttle Switched Power

Test Conditions:

- Key switch in run position
- Park brake unlocked
- Spark plug disconnected
- Transmission in neutral
- Throttle pedal depressed

System: Foot Throttle Switched Power



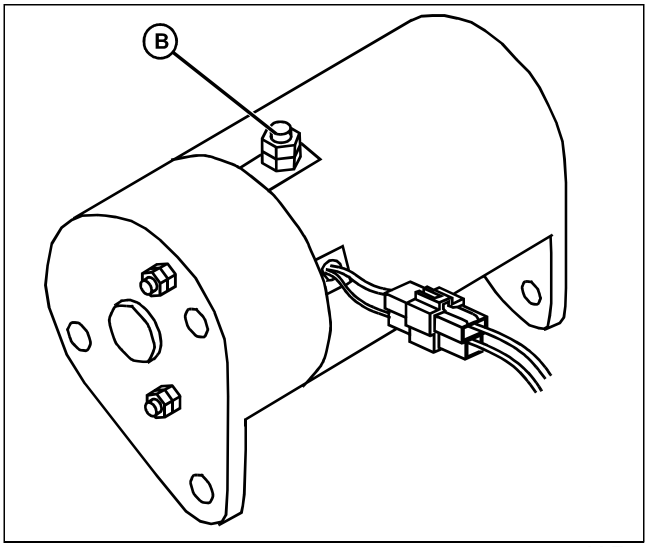
MIF

(1) Is battery voltage present at K1 starting solenoid - 730 and 700 Pur wires (A)?

Yes - Go to next step.

No - Check foot throttle switch adjustment. Check 730 and 700 Pur wires and connections. If ok, replace foot throttle switch. Go to next step.

System: Foot Throttle Switched Power



MIF

(2) Is battery voltage present at G2 starting motor/ generator - F2 terminal, 240 Red wire (B) with starting motor turning engine?

Yes - Test complete.

No - Check 230 and 240 Red wires and connections. If ok, replace starting solenoid. Test complete.

Ignition Circuit Operation

Function:

To create a spark at the correct time that ignites the fuel/air mixture in the cylinder. To ground the system to keep the engine from starting or to shut off the engine.

Operating Conditions:

To produce a spark, the key switch must be in the RUN position, the park brake must be OFF, and the foot throttle switch must be DEPRESSED.

System Operation:

The ignition system is a transistor-controlled magneto design. Ignition timing is controlled by the transistor and is not adjustable. The engine is shut off by grounding the ignition coil. With the ignition coil grounded, a spark cannot be produced.

Placing the key switch in the RUN position eliminates one path to ground for ignition current.

When the magneto run relay is energized, the relay contacts open and the second path to ground for ignition current is eliminated. When both paths are eliminated a spark can be produced.

The magneto run relay can be energized under the following conditions:

- Key switch in RUN position
- Park brake DISENGAGED (OFF)
- Foot throttle pedal DEPRESSED

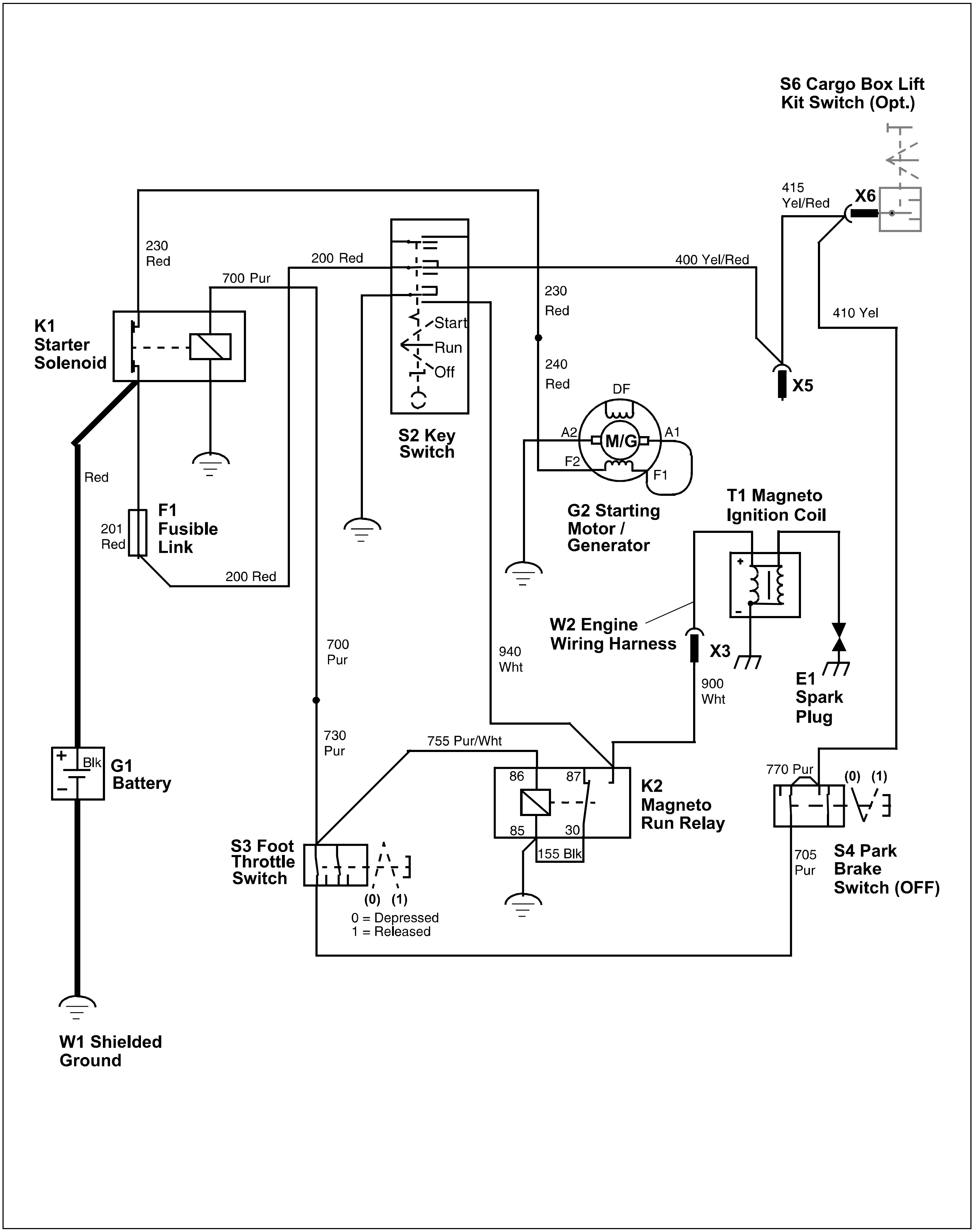
As the flywheel turns, (See “Cranking Circuit Operation” on page 90.) a magnet in the flywheel starts to align with the ignition coil and produces current in the primary windings by electromagnetic induction. The low voltage current flows to ignition module. The ignition module controls the current flow in the primary windings of the ignition coil.

In the spark stage (spark produced), the flywheel magnet is fully aligned with the ignition coil and high voltage (maximum current) is induced in the primary coil. This high voltage current causes the ignition module to ground the primary coil windings. The sudden reduction of current flow, induces high voltage current in the secondary coil. The high voltage current flows through the ignition coil wire to the spark plug. The voltage is now high enough to jump the spark plug gap and a spark is produced.

If the park brake is ENGAGED, the foot throttle switch is open (Drivers foot off throttle), or the key switch is placed in the OFF position the magneto run relay is deenergized. With the magneto run relay deenergized, ground is provided for the ignition coil and the engine will shut off.

If the key switch is placed in the OFF position, ground is provided for the ignition coil and the engine will shut off.

Ignition Circuit Schematic

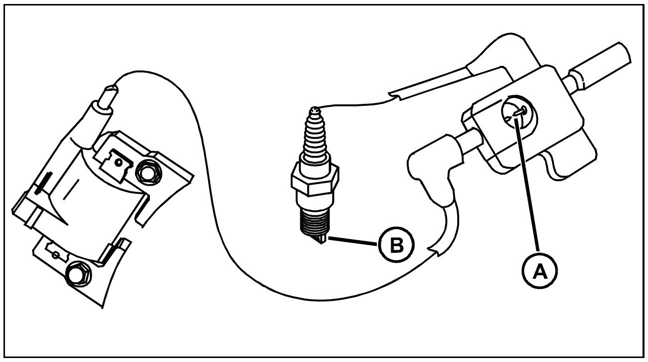


Ignition Circuit Diagnosis

Test Conditions:

- Key switch in RUN position
- Park brake OFF
- Foot throttle switch CLOSED (pedal depressed)

System: Ignition Circuit



(1) Is there a hot blue spark in the spark tester (A)?

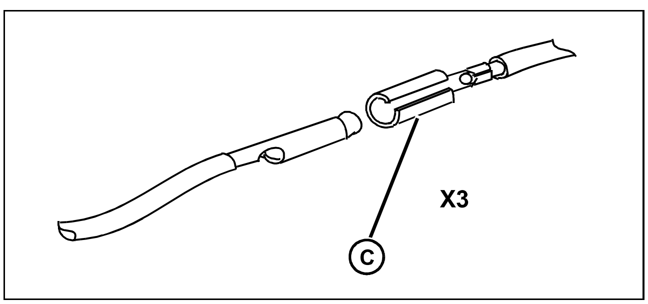
Yes - Check spark plug. Go to next step.

No - Test ignition coil. Check armature air gap. Check for grounded primary lead. Check for leaking or grounded secondary plug wire.

(2) Is the spark plug (B) fouled and does it have an incorrect spark gap?

Yes - Replace spark plug. Adjust air gap.

No - Go to next step.

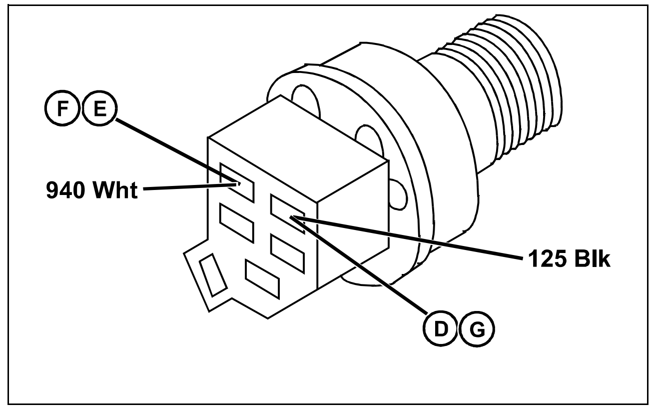


(3) Disconnect engine connector (C). Is there a spark present at tester?

Yes - Go to next step.

No - Continue testing ignition circuit through key switch.

System: Ignition Circuit



(4) Is there continuity between key switch connector (D) and engine connector, with no continuity to ground?

Yes - Go to next step.

No - Check 125, 110, 105, 100 and 165 Blk wires and connections.

(5) Is there continuity between key switch connector (E) and magneto run relay, with no continuity to ground?

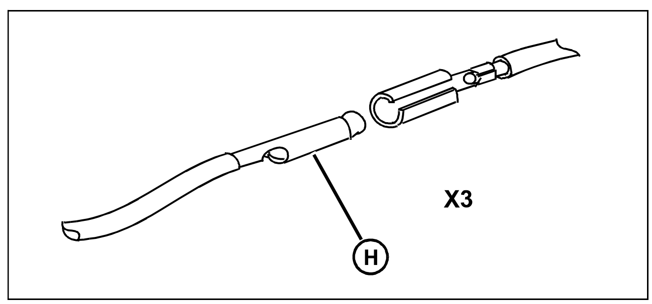
Yes - Go to next step.

No - Check 940 Wht wire and connections. See "Cranking Circuit Operation" on page 90.

(6) Is there continuity between key switch connector 940 Wht wire (F) and 125 Blk wire (G) with he key switch in the RUN position?

Yes - Replace key switch.

No - Go to next step.

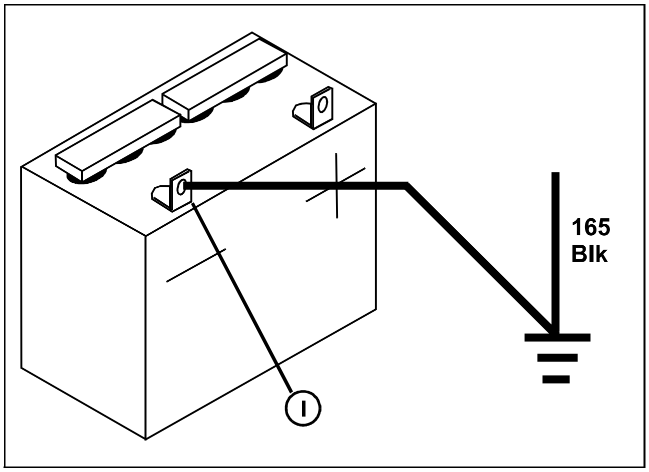


(7) Is there continuity between X3 connector (H) and magneto run relay, with no continuity to ground?

Yes - Go to next step.

No - Check 900 Wht wire and connections.

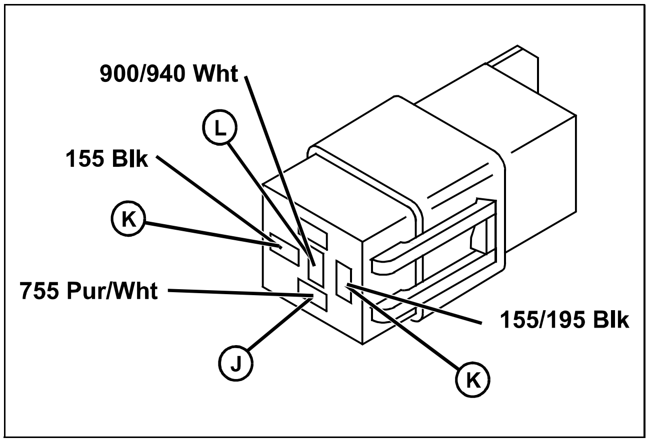
System: Ignition Circuit



(8) Is there continuity from battery negative post (I) to ground?

Yes - Go to next step.

No - Clean connections or replace negative battery cable.



(9) Is there battery voltage at magneto run relay (J)?

Yes - Go to next step.

No - Check 755 Pur wire and connections. See “Cranking Circuit Diagnosis” on page 92.

(10) Is there continuity to ground at each end of the 155 Blk jumper wire (K)?

Yes - Go to next step.

No - Check 155 Blk wire and connections.

(11) Is there continuity from magneto run relay (L) to ground?

Yes - End of tests.

System: Ignition Circuit

No - Replace magneto run relay.

Charging Circuit Operation

Function:

To maintain battery voltage between 11.8 and 13.2 volts.

Operating Conditions:

The engine must be running for the charging system to operate.

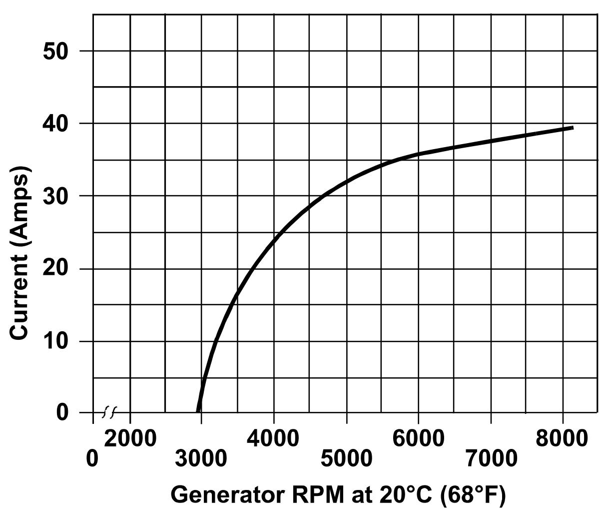
System Operation:

The charging system is a rotor and stator design. Charging output is controlled by a voltage regulator.

With the engine running, battery current flows from battery positive terminal to starting motor/generator terminals DF and F2, and voltage regulator.

The 205 Red wire allows the voltage regulator to monitor battery voltage. When voltage drops below 14.4 VDC, the voltage regulator electronically closes the charging coil ground circuit (595 Grn to regulator, and 160, 100 and 165 Blk wires to ground. With the charging coil ground circuit closed current is induced in the charging circuit coils and flows through 220 and 230 Red wires and starter solenoid to the positive (+) battery terminal.

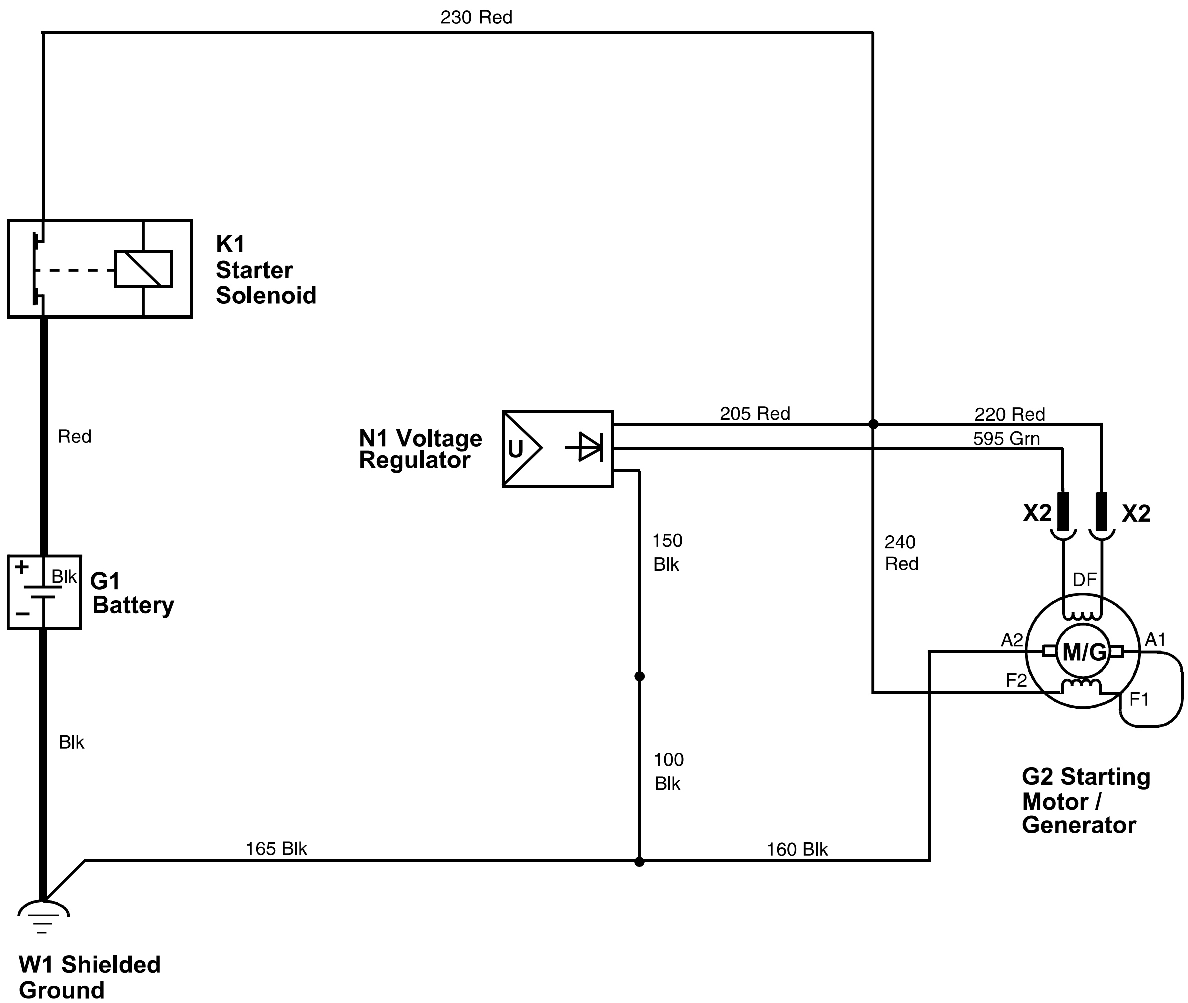
NOTE: The variable amperage output of the generator is speed dependent (See Table). Up to 2950 rpm (1270 Engine RPM) the starting motor/generator draws amperage from the battery. Above 2950 rpm the starting motor/generator charges the battery.



When the battery is fully charged, the voltage regulator stops current flow to the battery.

The ground circuit provides a path to ground for the voltage regulator and starting motor/generator.

Charging Circuit Electrical Schematic

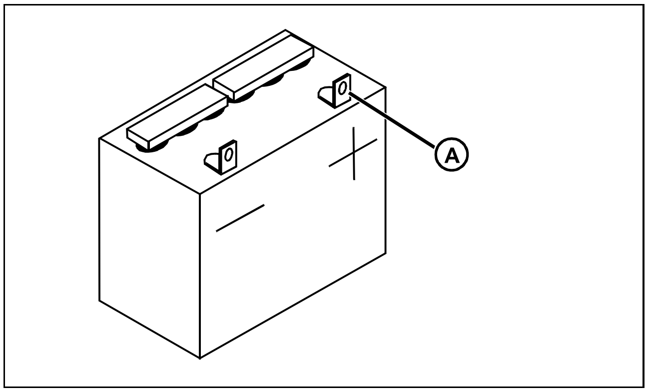


Charging Circuit Diagnosis

Test Conditions:

- Machine parked safely
- Key switch OFF

System: Charging Circuit



(1) Is there 11.8 to 13.2 volts at the battery positive terminal (A)?

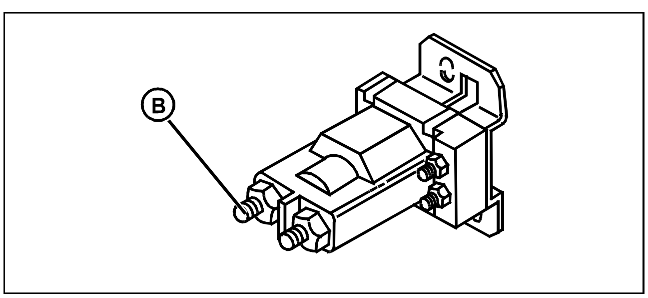
Yes - Go to next step.

No - Test battery. See “Battery Test” on page 104.

Test Conditions:

- Wheels blocked
- Park brake OFF
- Transmission LOCKED in neutral (use 6mm bolt and nut). See “Transaxle Neutral Lock” on page 121 in the Power Train section.
- Engine running at high idle.

System: Charging Circuit

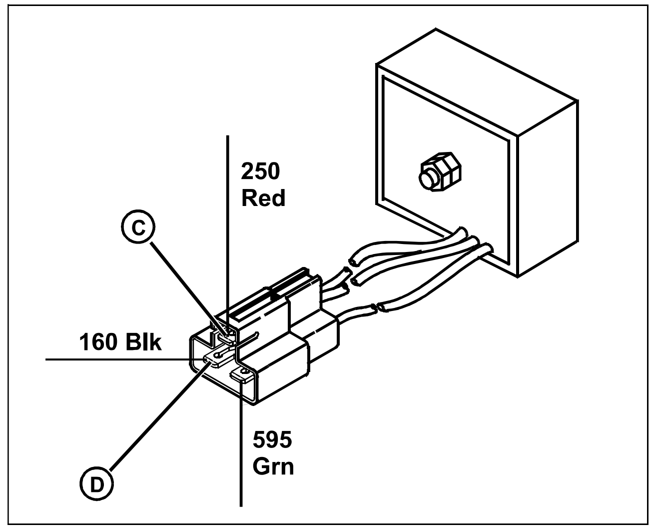


(1) Is there a minimum 14.4 ±0.5 VDC at the starter solenoid 230 Red wire connector (B)?

Yes - Go to next step.

System: Charging Circuit

No - Check starter solenoid. See “Cranking Circuit Diagnosis” on page 92.



(2) Is there a minimum 14.4 ± 0.5 VDC at the voltage regulator 230 Red wire connector (C)?

Yes - Go to next step.

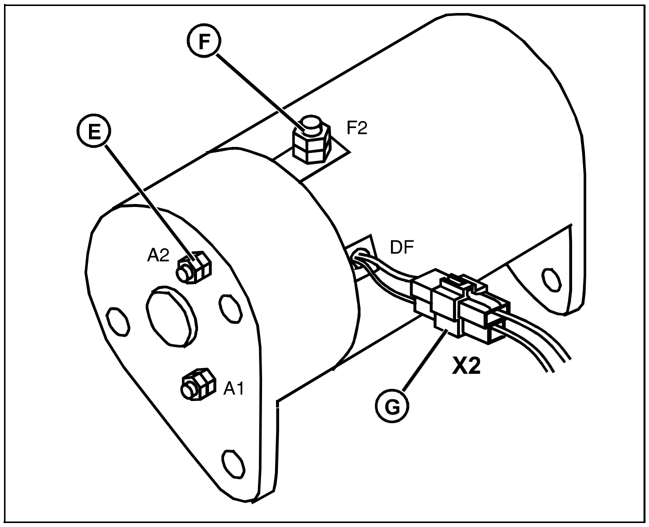
No - Check 205 and 230 Red wires and connections.

(3) Is there greater than 0 volts and less than 0.2 volts at the voltage regulator 160 Blk wire connector (D)?

Yes - Go to next step.

No - Greater than 0.2 volts: Check battery cable to engine ground and connections. Check 160, 100 and 165 Blk wires and connections. Replace voltage regulator.

System: Charging Circuit



(4) Is there greater than 0 volts and less than 0.2 volts at the starting motor/generator A2 160 Blk wire connector (E)?

Yes - Go to next step.

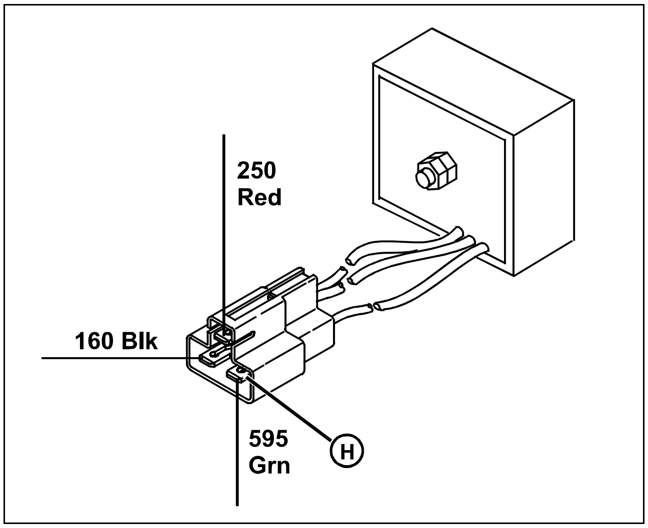
No - Check 240 Red wire and connections. Check 160 Blk wire and connections.

(5) Is there a minimum 14.4 ± 0.5 VDC at the starting motor/generator F2 240 Red wire connector (F)?

Yes - Go to next step.

No - Check starting motor/generator cable connector X2 (G): Check 220 Red wire and connections. Check 595 Grn wire and connections. Test starting motor/generator. See "Starting Motor No-Load Amperage and RPM Tests" on page 108.

System: Charging Circuit



(6) Is there greater than 0 volts and less than 12.0 volts at the voltage regulator 595 Grn wire connector (H)?

Yes - End of tests.

No - Check 595 Grn wire and connections. Replace voltage regulator.

Standard Headlight Circuit Operation

NOTE: If the Light and Horn kit option is added, the new wiring harness plugs into the W1 main wiring harness connectors (X5 and X4). The original domestic light wiring harness is removed.

Function:

Provides power to the headlights.

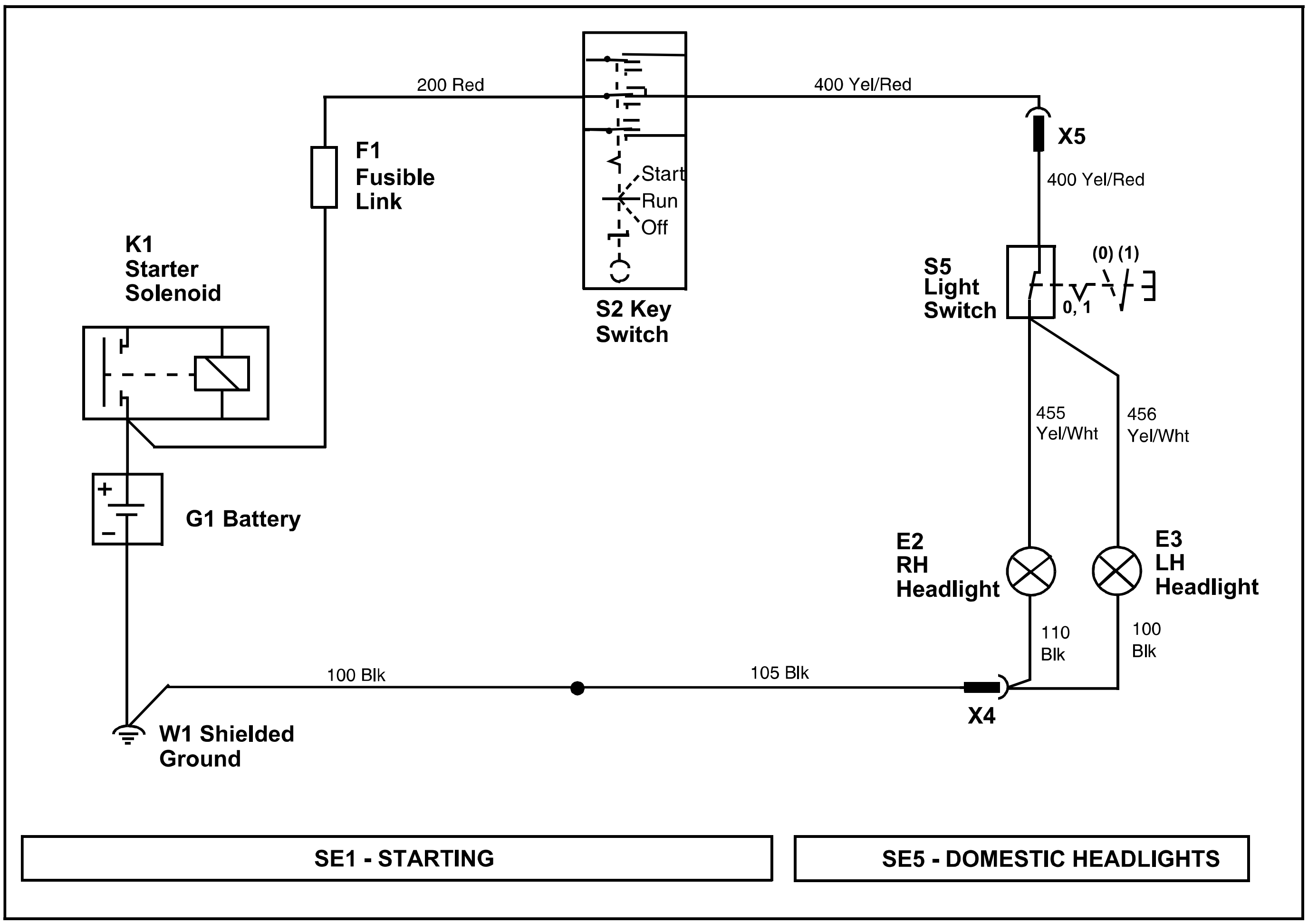
Operating Conditions:

The key switch must be in the RUN position.

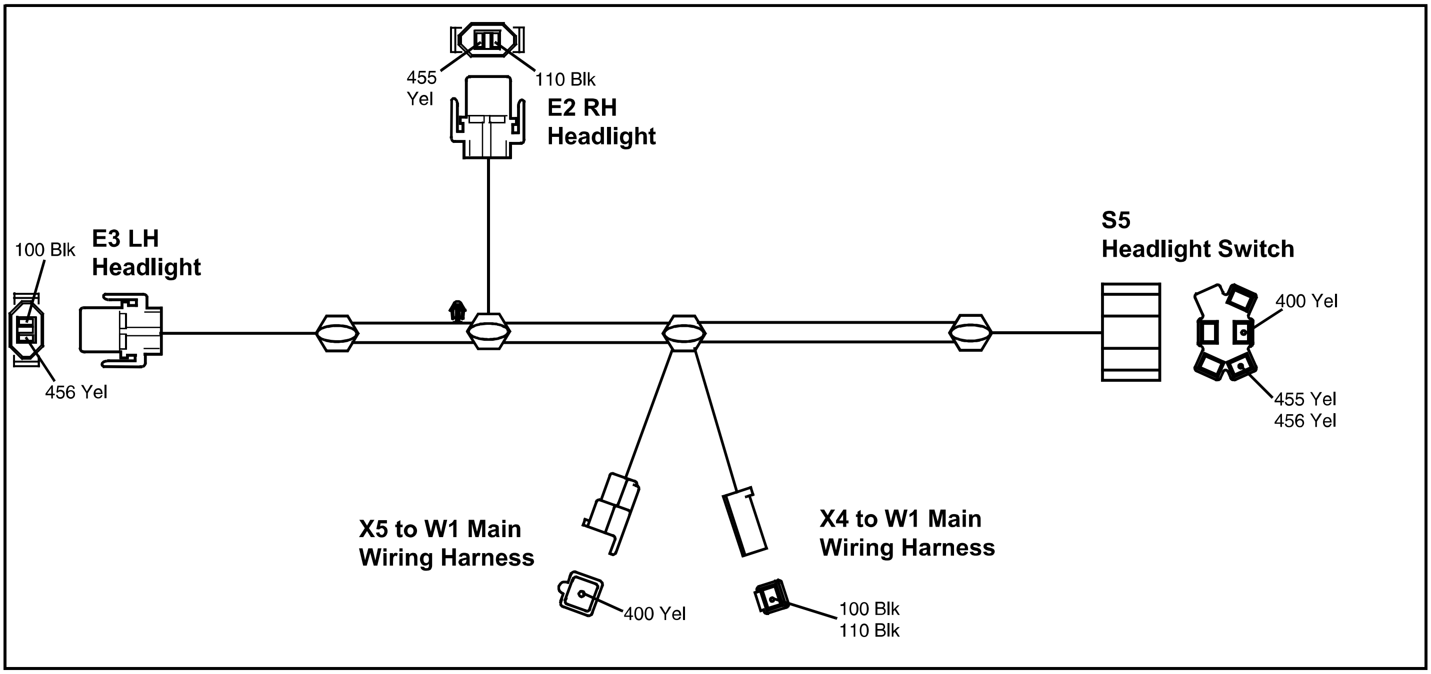
Theory of Operation:

The W3 standard headlight wiring harness is attached to the W1 main wiring harness. Power from the headlight harness connector (X5) is connected to the light switch. Current than flows from the light switch to the headlights. Ground circuit is obtained through the headlight harness connector (X4) and 105 and 100 Blk wires to engine ground.

Standard Headlight Electrical Schematic



Standard Headlight Wiring Harness

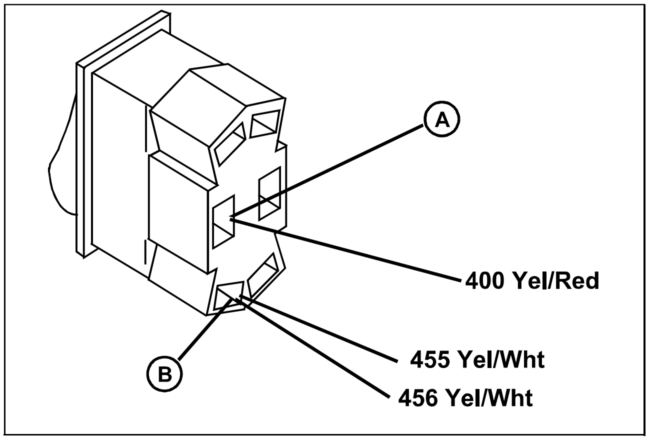


Standard Headlight Circuit Diagnosis

Test Conditions:

- Key switch in the RUN position.
- Park brake ENGAGED
- Light switch ON

System: Headlight Circuit



(1) Is there battery voltage at the headlight switch 400 Yel/Red wire (A)?

Yes - Go to next step.

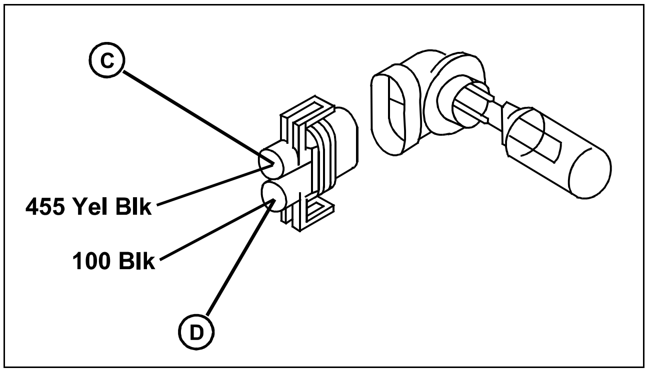
No - See “Power Circuit Diagnosis” on page 88. Check connection at headlight switch.

System: Headlight Circuit

(2) Is there battery voltage at headlight switch 455 and 456 Yel/Wht wires (B)?

Yes - Go to next step.

No - Check switch is in ON position. Replace switch.



(3) Is there battery voltage at LH headlight 455 Yel/Wht wire (C)?

Yes - Go to next step.

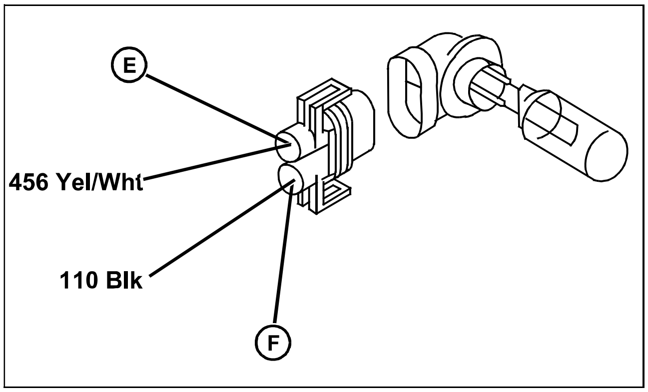
No - Check 455 Yel/Wht wire and connections.

(4) Is there greater than 0 volts and less than 0.2 volts at LH headlight 100 Blk wire (D)?

Yes - Go to next step.

No - Greater than 0.2 volts: Check harness connector (X4) and 100 Blk wires and connections.

System: Headlight Circuit



(5) Is there battery voltage at RH headlight 456 Yel/Wht wire (C)?

Yes - Go to next step.

No - Check 456 Yel/Wht wire and connections.

(6) Is there greater than 0 volts and less than 0.2 volts at RH headlight 110 Blk wire (D)?

Yes - End of tests.

No - Greater than 0.2 volts: Check harness connector (X4) and 110 Blk wire and connections.

Tests and Adjustments

Battery Test

Reason:

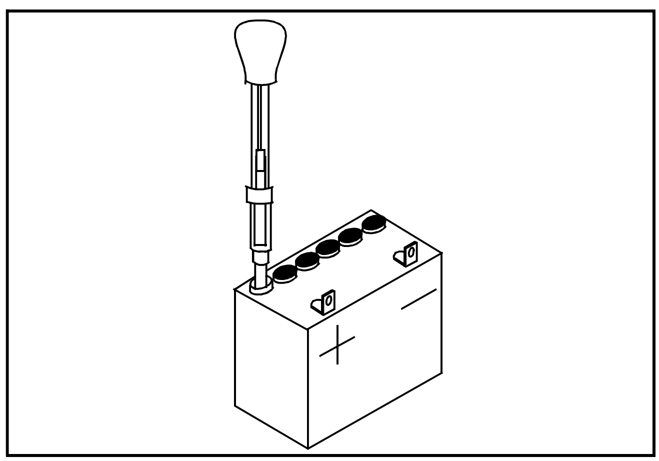
To check condition of battery and determine battery voltage.

Equipment:

- Hydrometer
- Voltmeter or JTO5685 Battery Tester

Procedure:

1. Park machine on level surface and turn key switch OFF.
2. Park brake LOCKED and cargo box RAISED.
3. Remove seats and operator's station black plastic shroud.
4. Clean cable ends, battery terminals and top of battery.
5. Remove battery to workbench.
6. Inspect battery terminals and case for breakage or cracks.
7. Check electrolyte level in each battery cell. Add clean, soft water as needed. If water was added, charge battery for 20 minutes at 10 amps.
8. Remove surface charge by placing a small load on the battery for 15 seconds.



9. Use an hydrometer to check for a **minimum specific gravity of 1.225 with less than 50 point variation in each cell.**

Results:

- if all cells less than 1.175, charge battery at 10 amp rate (see Charge Battery);
- If all cells less than 1.225 with less than 50 point variation, charge battery at 10 amp rate (see Charge

Battery);

- If all cells more than 1.225 with less than 50 point variation, load test battery (see Battery Load Test);
- If more than 50 point variation, replace battery.
- Use a voltmeter or JTO5685 Battery Tester to check for a **minimum battery voltage of 12.4 volts.**

Results:

- If battery voltage less than 12.4 VDC, charge battery (see Charge Battery);
- If battery voltage more than 12.4 VDC, test specific gravity (see Step 9);
- Install battery.

Charge Battery

Reason:

To increase battery charge after battery has been discharged.

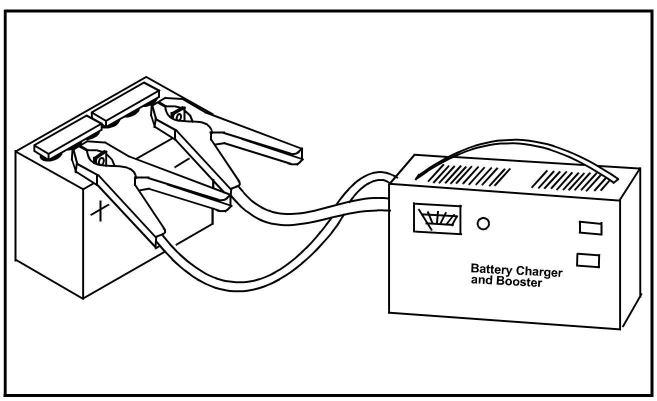
Equipment:

- Battery charger (variable rate)

Procedure:

NOTE: See "Battery Test" in this group before charging battery.

1. Park machine on level surface and turn key switch OFF.
2. Park brake LOCKED and cargo box RAISED.
3. Remove seats and operator's station black plastic shroud.
4. Clean cable ends, battery terminals and top of battery.
5. Remove battery to workbench.



6. Connect variable rate charger to battery.

NOTE: Maximum charge time at boost setting is 10 minutes. Allow additional 5 minutes for each 10 degrees below 70° F.

7. Start charger at SLOW rate. Increase charge rate ONE setting at a time. Check charger ampmeter after 1 minute at each setting. Maintain 10 amp charge rate. Use boost setting as necessary.
8. Check if battery is accepting a 10 amp charge after 10 minutes at boost setting.

Results:

- If battery WILL NOT accept 10 amp charge after 10 minutes at boost setting, replace battery;
- If battery is accepting 10 amp charge after 10 minutes at boost setting, and battery did NOT need water, go to Steps 10 and 11;
- If battery is accepting 10 amp charge after 10 minutes at boost setting, but battery DID need water or all cells were BELOW 1.175, go to Steps 9 and 10.
- Set charger at 15-25 amps.

IMPORTANT: Avoid damage! Decrease charge rate if battery gases or bubbles excessively or becomes too warm to touch.

- Check specific gravity after 30 minutes (60 minutes for maintenance-free battery).

Results:

- If MORE THAN 50 point variation between cells, replace battery;
- If LESS THAN 50 point variation between cells, go to Steps 11 and 12.

NOTE: If battery was discharged at slow or unknown rate, charge at 10-15 amps for 6-12 hours. (Maintenance-free battery: 12-24 hours.) If battery was discharged at fast rate, charge at 20-25 amps for 2-4 hours. (Maintenance-free battery: 4-8 hours.)

- Continue to charge battery until specific gravity is **1.230 – 1.265 points.**
- Load test battery. See "Battery Load Test".
- Install battery.

Battery Load Test

Reason:

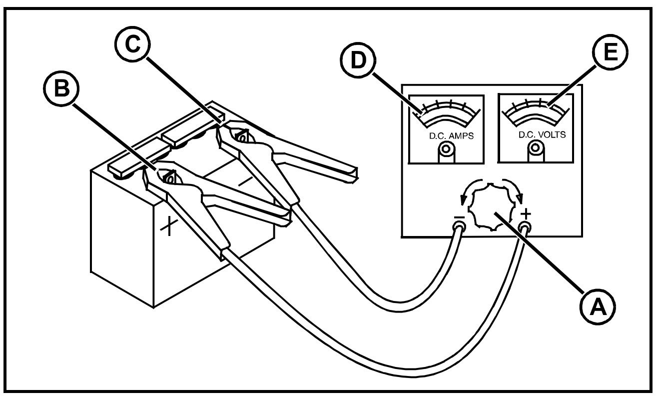
To check condition of battery under load.

Equipment:

- JTO5685 Battery Tester

Procedure:

1. Park machine on level surface and turn key switch OFF.
2. Park brake LOCKED and cargo box RAISED.
3. Remove seats and operator's station black plastic shroud.
4. Clean cable ends, battery terminals and top of battery.
5. Remove battery to workbench.



6. Turn load knob (A) counterclockwise to OFF position.
7. Connect tester positive cable (red) to battery positive (+) terminal (B).
8. Connect tester negative cable (black) to battery negative (–) terminal (C).
9. **Turn load knob (A) of tester clockwise (in) until amperage reading (D) is equal to:**
   - **cold cranking amperage rating of battery (use blue scale).**
   —or—
   - **three times ampere hour rating (use black scale).**
10. **Hold for 15 seconds and turn load knob (A) of tester counterclockwise (out) into OFF position.**
11. Repeat Steps 9 and 10 above and read condition of battery at DC Volts scale (E).

Results:

- If battery DOES NOT pass test and has NOT been charged, charge battery and retest (see Charge Battery).
- If battery DOES NOT pass the test and HAS BEEN charged, replace the battery.

Starter Solenoid Test

Reason:

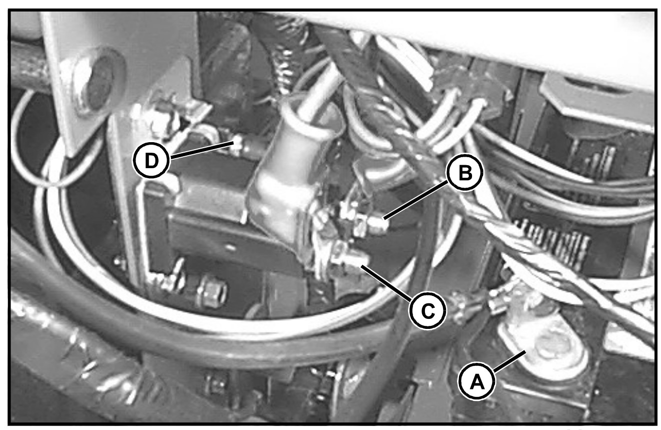
To determine if starter solenoid defective.

Equipment:

- Volt Ohm Meter

Procedure:

1. Park machine on level surface and turn key switch OFF.
2. Transaxle LOCKED in NEUTRAL. (Use a 6 mm bolt and nut.) See "Transaxle Neutral Lock" on page 121 in Power Train section.
3. Wheels blocked and park brake OFF.
4. Disconnect and ground spark plug lead.
5. Park brake LOCKED and cargo box RAISED.
6. Remove seats and operator's station black plastic shroud.
7. Remove rubber boot from starter solenoid connectors.



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8. Connect VOM to negative (–) battery terminal (A) and terminal (B) of starter solenoid. Check for battery voltage.

Results:

- No battery voltage - See "Power Circuit Diagnosis" on page 88. Check battery (+) terminal and starter solenoid terminal (B) for loose connections. Clean any corrosion.
- Battery voltage - go to next step.
- Connect VOM to negative (–) battery terminal (A) and terminal (C) of starter solenoid. Turn ignition key to RUN position, DEPRESS throttle pedal and check for battery voltage.

Results:

- **Battery voltage – Starter solenoid is not defective.**
- **No battery voltage – go to next step.**

• Connect VOM to negative (–) battery terminal (A) and terminal (D) (Pur wire) of starter solenoid. Turn ignition key to RUN position, DEPRESS throttle pedal and check for battery voltage.

Results:

• No battery voltage - See “Cranking Circuit Diagnosis” on page 92. Check 130 Blk wire and connections between starter solenoid and frame ground.

• Battery voltage - Starter solenoid defective. Replace solenoid.

Starting Motor Loaded Amperage Draw Test

Reason:

To determine the amperage required to crank the engine and check starting motor operation under load.

Equipment:

• JTO5685 Battery Tester

Procedure:

1. Park machine on flat surface and turn key switch OFF.

2. Transaxle LOCKED in NEUTRAL. (Use a 6 mm bolt and nut.) See “Transaxle Neutral Lock” on page 121 in Power Train section.

3. Wheels blocked and park brake OFF.

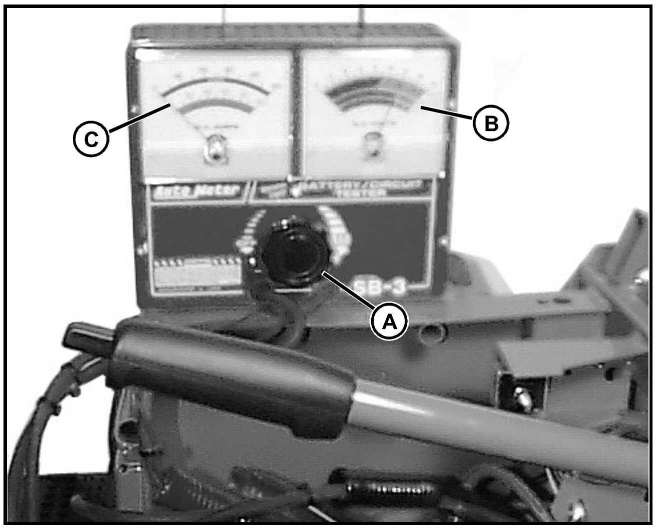
4. Remove seats and operator’s station black plastic shroud.

5. Cargo box RAISED.

6. Test system ground connections and battery (see Ground Circuit Test and Battery Load Test).

7. Disconnect and ground spark plug lead.

IMPORTANT: Avoid damage! Turn load knob (A) fully counterclockwise (out) into OFF position before making any test connections.



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8. Connect JTO5685 Battery Tester to battery.

9. Crank engine—read and record voltage on DC voltage scale (B) of battery tester.

10.Turn key switch to OFF position.

IMPORTANT: Avoid damage! Perform following procedure within 15 seconds to prevent damage to tester and/or machine components.

11.Turn load knob (A) clockwise (in) until DC voltage (B) reads the same as when cranking.

12.Read and record DC amperage (C).

13.Turn load knob (A) completely counterclockwise (out) into OFF position.

Results:

• **Maximum starting motor draw should be 51 amps at 750 rpm.**

• If amperage is above specification, perform Starting Motor No-Load Amperage and RPM Test to determine if starting motor is binding or damaged.

• If starting motor is good, check internal engine components for binding, wear, or damage.

Starting Motor No-Load Amperage and RPM Tests

Reason:

To determine if starting motor is binding or has excessive amperage draw under no-load.

Equipment:

- Fluke Multi-Meter (Set to 10 Amp DC scale)
- JDM71 Vibration Tachometer or JT07270 Digital Pulse Tachometer

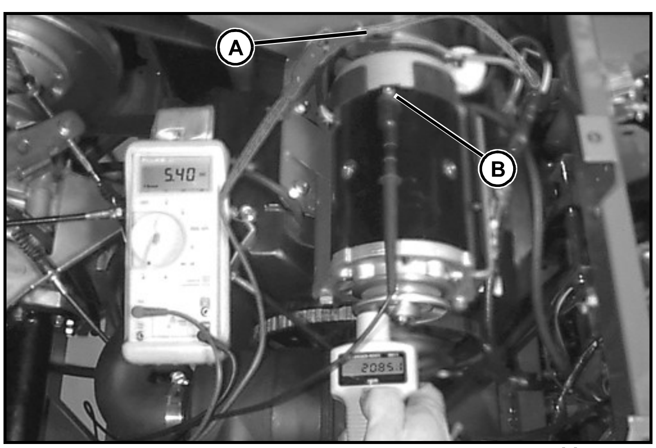
Procedure:

NOTE: Check that battery is fully charged and of proper size to ensure accuracy of test.

1. Park machine on flat surface and turn key switch OFF.
2. Transaxle LOCKED in NEUTRAL. (Use a six mm bolt and nut.) See "Transaxle Neutral Lock" on page 121 in Power Train section.
3. Wheels blocked and park brake OFF.
4. Cargo box RAISED.
5. Remove belt between starting motor/generator and engine sheaves.
6. Disconnect 12 VDC (240 Red) wire from starting motor/generator (F2) terminal.

IMPORTANT: Avoid damage! When connecting wires and meter, ensure connections are not touching any surface where a ground short may occur. Wrap connections with electrical tape if necessary.

7. Connect Fluke Multi-Meter in series with 240 Red wire (A) and starting motor/generator (F2) terminal (B).



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8. Use reflective tape on starting motor/generator pulley and JTO5719 Photo Tachometer to measure starting motor/generator rpm's.

NOTE: Fluke Multi-Meter set at 10Amp DC scale for following tests.

9. Turn ignition switch to RUN position and depress throttle pedal to start starting motor/generator.

10.Measure and record starting motor/generator amperage draw and rpm's.

Results:

- a good starting motor should have **a maximum amperage reading of six amps and a minimum rotational reading 1000 rpm.**
- If amperage reading is above six amps or starting motor rpm is less than 2050, check for binding or seized bearings, sticky brushes, and dirty or worn commutator.
- Repair or replace starting motor/generator.

Spark Test

Reason:

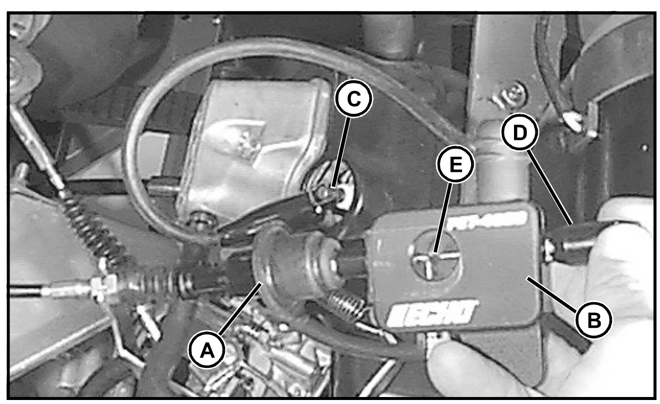
To check overall condition of ignition system.

Equipment:

- D-05351ST — Spark Tester

Procedure:

1. Park machine on level surface and turn key switch OFF.
2. Transaxle LOCKED in NEUTRAL. (Use a six mm bolt and nut.) See "Transaxle Neutral Lock" on page 121 in Power Train section.
3. Wheels blocked and park brake OFF.
4. Cargo box RAISED.



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5. Remove high tension lead (A) from spark plug and connect to spark tester (B).
6. Connect spark tester lead to spark plug (C).
7. Adjust spark tester gap to **4.2 mm (0.166 in.)** with screw

(D).

NOTE: Do not adjust spark tester gap beyond 5.0 mm (0.200 in.) as damage to ignition system components could occur.

8. Turn key switch to RUN position and start engine.
9. Watch spark (E) at spark tester.

Results:

- If engine will start, watch spark with engine running. There should be a strong, steady, blue spark.
- If spark is weak, or if no spark, install a new spark plug and test again.
- If spark is still weak, or still no spark, run tests on individual components to find cause of malfunction.

Spark Plug Cap Test

Reason:

To determine if spark plug cap is defective.

Equipment:

- Ohmmeter

Procedure:

1. Park machine on level surface and turn key switch OFF.
2. Park brake ON.
3. Cargo box RAISED.
4. Disconnect spark plug cap.

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5. Measure resistance across spark plug cap terminals.

Results:

- Resistance should be **approximately 5000 ohms**, the same as marked on the spark plug cap.
- If resistance DOES NOT meet specification, replace spark plug cap.

Park Brake Switch Test

Reason:

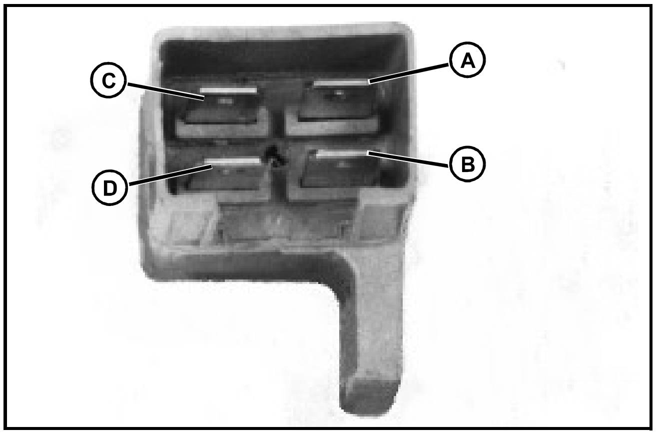
To ensure the park brake switch has continuity when switch plunger DEPRESSED (park brake OFF).

Equipment:

- Ohmmeter

Procedure:

1. Park machine on level surface and turn key switch OFF.
2. Remove seats, and operator's station black plastic shroud.
3. Disconnect harness connector from park brake switch.



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4. Check continuity between connectors (A and B (yellow)).

Results:

- there should BE continuity between terminals (A and B) when plunger is RELEASED (Park brake ON),
- there should NOT BE continuity between terminals (A and B) when plunger is DEPRESSED (Park brake OFF).
- If continuity is NOT correct, replace switch.
- Check continuity between connectors (C and D).

Results:

- there should NOT BE continuity between terminals (C and D) when plunger is RELEASED (Park brake ON),
- there should BE continuity between terminals (C and D) when plunger is DEPRESSED (Park brake OFF).
- If continuity is NOT correct, replace switch.

Light Switch Test

Reason:

To make sure the light switch terminals have continuity when the light switch is **ON**.

Equipment:

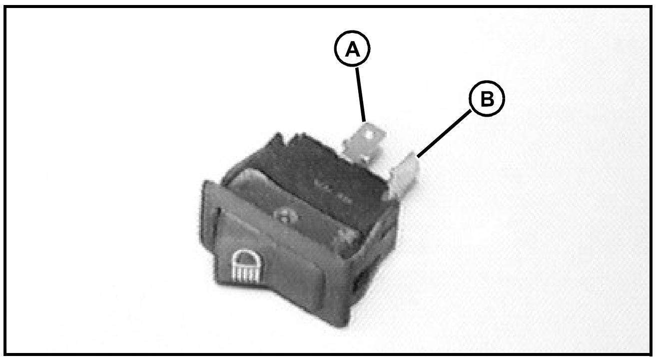
- Ohmmeter or Continuity Tester

Procedure:

1. Park machine on level surface and turn key switch OFF.
2. Lock park brake.

NOTE: You may want to remove front hood for easy access to dash panel electrical components.

3. Disconnect light switch connector.



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4. Move light switch to the ON and then the OFF position. Check continuity between terminals (A and B).

Results:

- **Terminals should have continuity with switch ON.**
- **Terminals should NOT have continuity with switch OFF.**
- If continuity is NOT correct, replace light switch.

Key Switch Test

Reason:

To verify key switch functions are operating properly.

Equipment:

- Ohmmeter or Continuity Tester

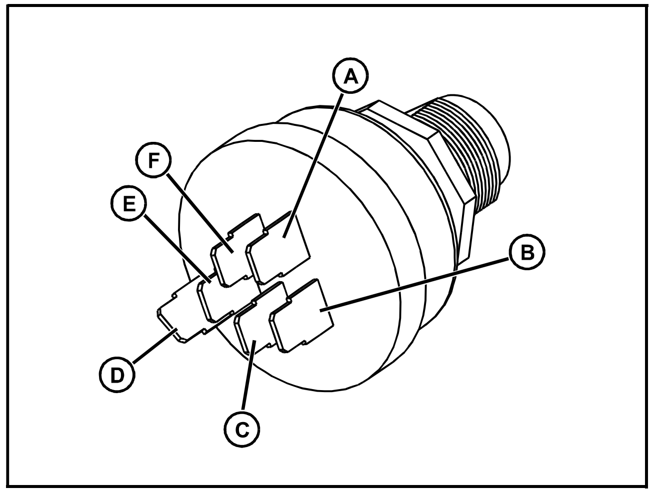
Procedure:

1. Park machine on level surface and turn key switch OFF.
2. Lock park brake.

NOTE: You may want to remove front hood for easy access to dash panel electrical components.

3. Disconnect key switch connector.

NOTE: DO NOT refer to markings stamped on terminals. Identify terminals by art keys ONLY. Terminal combinations other than those listed in chart should NOT have continuity.



MIF

4. Use an ohmmeter to test switch continuity in OFF, RUN, and START positions.

Key Switch Continuity:

Switch Position	Terminal Continuity
OFF	A and B
RUN	C and D
START	C and D, E and F

Results:

- If any continuity is NOT correct, replace switch.

Flywheel Magnet Test

Reason:

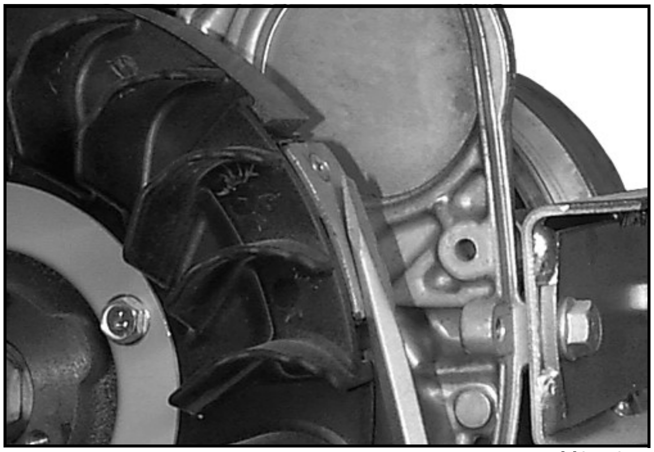
To make sure flywheel magnet(s) have enough force to induce current into ignition coil.

Equipment:

- Screwdriver

Procedure:

1. Park machine on level surface and turn key switch OFF.
2. Park brake ON.
3. Cargo box RAISED.
4. Remove flywheel blower housing from engine.



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5. Loosely hold screwdriver blade about 25 mm (1.0 in.) away from magnet.

Results:

- Magnet should attract blade to it.
- If blade is NOT attracted to magnet, flywheel must be replaced.

Electrical System Amperage Draw Tests

Reason:

To measure amperage draw of electrical components when battery has a discharge problem.

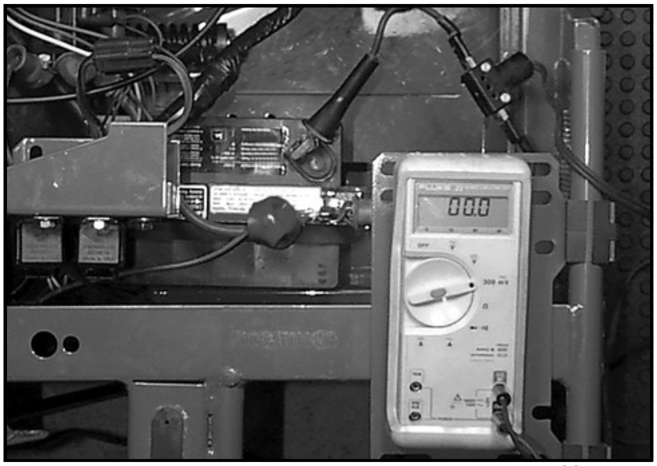
NOTE: The battery will discharge if operating several electrical components at the same time with the engine at low idle.

Equipment:

- Fluke Multi-Meter (Set to 300 mV scale)
- JTO5792 Ammeter Shunt Assembly
- JDM71 Vibration Tachometer or JT07270 Digital Pulse Tachometer

Procedure:

1. Turn key switch to OFF position.
2. Lock park brake.
3. Transaxle LOCKED in NEUTRAL. (Use a six mm bolt and nut.) See “Transaxle Neutral Lock” on page 121 in Power Train section.
4. Remove seats and black plastic shroud.



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5. Disconnect battery positive cable.
6. Connect ammeter shunt to battery positive cable and battery positive terminal.
7. Connect ammeter shunt to multimeter volts connection and set meter to 300 mV scale.
8. Turn key switch to ON position. DO NOT start engine.
9. Turn one component ON at a time and measure amperage draw. Several components can be ON to measure total amperage draw to match a specific operating condition that a battery discharge occurs.

The following tables show approximate charging output and component amperage draw.

NOTE: Fluke Multi-Meter set at 300 mV scale for following tests.

Component Amperage Draw:

NOTE: * Tests apply only to Optional Kits.

Results:

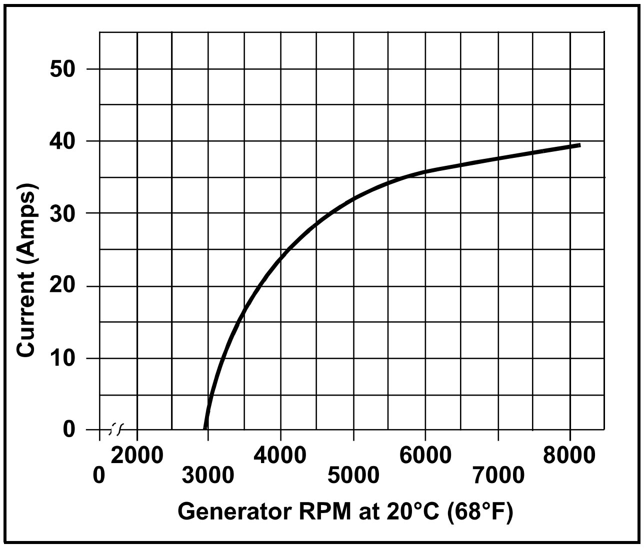
- If component amperage draw exceeds generator output, the battery will discharge. Either reduce amperage draw or do not let engine idle for extended period of time.

NOTE: Disconnect and ground spark plug wire for next test.

- Disconnect and ground spark plug wire.
- Measure amperage draw while turning engine over.

Generator Output

1. Connect spark plug wire.
2. Use reflective tape on starting motor/generator pulley and JTO5719 Photo Tachometer to measure starting motor/generator rpm’s.



Results:

- As starting motor/generator RPM is increased or decreased, measured amperage should follow curve in table shown above.

Ground Circuit Tests

Reason:

To check for opens, loose terminal wire crimps, poor connections, or corrosion in the ground circuit.

Equipment:

- Ohmmeter or Voltmeter

The voltmeter method checks ground connections under load.

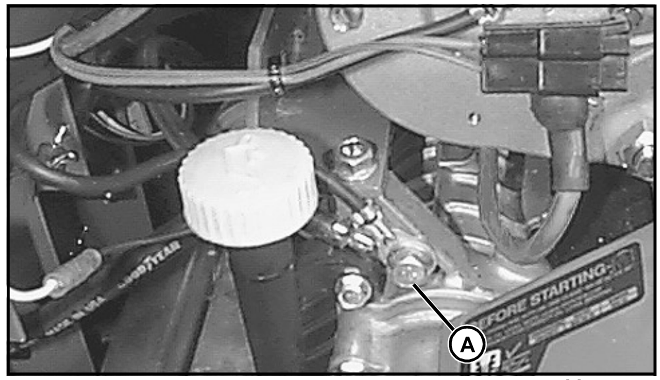
Procedure Using Ohmmeter:

1. Park machine on level surface and turn key switch OFF position.

2. Park brake LOCKED.

3. Cargo box RAISED.

NOTE: DO NOT use the frame as ground connection point. The frame is isolated from battery or engine ground. Use either the battery negative (–) terminal or the engine harness ground (A).



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4. Connect ohmmeter negative (black) lead to negative terminal of battery. Put meter positive (red) lead on negative terminal of battery and record reading.

5. Put meter red lead on ground terminal of circuit or component to be tested that is closest to the battery negative terminal. **Resistance reading must be very close to or the same as the battery negative terminal reading. Work backwards from the battery on the ground side of the problem circuit until the resistance reading increases above 0.1 ohms.** The problem is between the last two test points. If a problem is indicated, disconnect the wiring harness connector to isolate the wire or component and check resistance again. **Maximum allowable resistance in the circuit is 0.1 ohms.** Check both sides of connectors closely as disconnecting and connecting may temporarily solve problem.

Procedure Using Voltmeter:

1. Park machine on level surface and turn key switch ON.

2. Park brake LOCKED.

3. Cargo box RAISED.

4. Connect voltmeter negative (black) lead to negative terminal of battery.

5. Put meter positive (red) lead on ground terminal of circuit or component to be tested. Be sure the component circuit is activated (key on, switches closed) so voltage will be present at the component. Record voltage. **Voltage must be greater than 0 but less than 1 volt.** Some components will have a very small voltage reading on the ground side and still be operating correctly.

Results:

- If voltage is 0, the component is open.
- If voltage is greater than 1 volt, the ground circuit is bad. Check for open wiring, loose terminal wire crimps, poor connections, or corrosion in the ground circuit.

INDEX

CASE

Lesson 4.3 Electrical Analysis

Preface

An electrical analysis using a digital multimeter is essential for a technician's role. When electrical components fail, a technician must analyze the circuit to find the fault, isolate the cause, and repair the circuit.

Voltage drop and current draw tests are common skills technicians perform when diagnosing faults. As current travels across cables, components, and connections in a circuit, voltage is lost due to resistance. The amount of voltage lost is voltage drop. The sum of voltage drops across a circuit should equal the source voltage. Faults in a circuit can increase resistance, thus decreasing the voltage available to each component.

Components that continue to draw current while the engine is off are parasitic to battery life. Technicians perform a parasitic current draw test to determine if a component draws current when it should not. Locating a parasitic battery drain is conducted with a DMM.

OEMs use multiple types of connectors when designing a circuit. Technicians have a base skill in diagnosing faults in connectors and replacing connectors within a circuit. Common circuit connectors include quick disconnects, ring terminals, and soldered connections. Heat shrink tubing is applied over connectors to insulate connectors and prevent moisture from penetrating the connector. Base knowledge in connectors, electrical components, and equipment help technicians install and maintain electrical control systems.

Students test for voltage drop and current draw in agricultural equipment during this lesson. Next, students will construct a wiring harness for an ignition/shutdown circuit. Finally, students develop an electrical system to control a sprayer electronically.

Concepts	**Performance Objectives**
Students will know and understand	*Students will learn concepts by doing*
1. Technicians use diagnostic tools and Ohm's law as part of a systematic troubleshooting process.	• Calculate voltage drop in a circuit. (Activity 4.3.1) • Troubleshoot voltage drops with a digital multimeter. (Project 4.3.2) • Diagnose parasitic battery drain with a digital multimeter. (Activity 4.3.3)
2. Technicians maintain and troubleshoot systems directing electrical current between components.	• Construct an ignition/shutdown circuit using cables and connectors. (Project 4.3.4) • Troubleshoot an ignition/shutdown circuit using a digital multimeter and a schematic. (Project 4.3.4)
3. Technicians use tools to troubleshoot and maintain GPS/GIS equipment.	• Modify a sprayer to include electrical and GPS controls. (Problem 4.3.5) • Develop a troubleshooting and maintenance plan for a GPS sprayer. (Problem 4.3.5)

National AFNR Common Career Technical Core Standards Alignment

Career Ready Practices
1. Act as a responsible and contributing citizen and employee.
• CRP.01.01: Model personal responsibility in the workplace and community.
2. Apply appropriate academic and technical skills.
• CRP.02.02: Use strategic thinking to connect and apply technical concepts to solve problems in the workplace and community.
Environmental Service Systems Pathway (AG-ENV)
1. Use analytical procedures and instruments to manage environmental service systems.
• AG-ENV 1.3: Calibrate and service field equipment and instruments according to manufacturer's specifications.
Power, Structural and Technical (AG-PST)
1. Apply physical science principles and engineering applications related to mechanical equipment, structures, and biological systems to solve problems and improve performance in AFNR power, structural, and technical systems.
• AG-PST 1.2: Use hand and power tools commonly required in power, structural, and technical systems
• AG-PST 1.3: Investigate solutions to AFNR power, structural, and technical systems.
• AG-PST 1.4: Design or modify equipment, structures, or biological systems to improve performance of an AFNR enterprise or business unit.
5. Use control, monitoring, geospatial and other technologies in AFNR power, structural and technical systems.
• AG-PST 5.1: Execute procedures and techniques for monitoring and controlling electrical systems using basic principles of electricity.
• AG-PST 5.2 Design control systems by referencing electrical drawings.
• AG-PST 5.3 Use geospatial technologies in AFNR applications.

Next Generation Science Standards Alignment

Disciplinary Core Ideas	
Physical Science	
PS3: Energy	
PS3.A: Definitions of Energy	• "Electrical energy" may mean energy stored in a battery or energy transmitted by electric currents.

Science and Engineering Practices	
Planning and Carrying Out Investigations	• Select appropriate tools to collect, record, analyze, and evaluate data.
Analyzing and Interpreting Data	• Analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in order to make valid and reliable scientific claims or determine an optimal design solution.

Crosscutting Concepts	
Cause and Effect: Mechanism and Prediction	Events have causes, sometimes simple, sometimes multifaceted. Deciphering causal relationships, and the mechanisms by which they are mediated, is a major activity of science and engineering.
	• Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. • Systems can be designed to cause a desired effect. • Changes in systems may have various causes that may not have equal effects.
Energy and Matter: Flows, Cycles, and Conservation	Tracking energy and matter flows, into, out of, and within systems helps one understand their system's behavior.
	• The total amount of energy and matter in closed systems is conserved.

	• Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system.

Common Core State Standards for High School Mathematics

Modeling standards are indicated by the star symbol (*) throughout other conceptual categories.

CCSS: Conceptual Category – Number and Quantity	
Quantities	*Reason quantitatively and use units to solve problems.

CCSS: Conceptual Category – Algebra	
Reasoning with Equations and Inequalities	Understand solving equations as a process of reasoning and explain the reasoning. Solve equations and inequalities in one variable. Solve systems of equations.

Common Core State Standards for English Language Arts

CCSS: English Language Arts Standards » Science & Technical Subjects » Grade 11-12	
Key Ideas and Details	• **RST.11-12.1 –** Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account.
Craft and Structure	• **RST.11-12.4 –** Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to grades 11-12 texts and topics.
Integration of Knowledge and Ideas	• **RST.11-12.9 –** Synthesize information from a range of sources (e.g., texts, experiments, simulations) into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible.
Range of Reading and Level of Text Complexity	• **RST.11-12.10 –** By the end of grade 12, read and comprehend science/technical texts in the grades 11-CCR text complexity band independently and proficiently.

Essential Questions

1. What is the relationship between resistance and voltage drop?
2. What factors contribute to voltage drop?
3. How does a technician measure the current draw with a DMM?
4. What is a parasitic battery drain?
5. How are connectors used within a circuit?
6. How do technicians limit a faulted connection?
7. How are electrical systems and GPS systems used to control agricultural equipment?

Key Terms

Crimp	**Current draw**	**Female connector**
Heat shrink	**Male connector**	**Parasitic battery drain**
Quick disconnects	**Ring terminal**	**Solder**
Soldering	**Voltage drop**	**Wire strippers**

Day-to-Day Plans
Time: 14 days

*Refer to the Teacher Resources section for specific information on teaching this lesson, in particular **Lesson 4.3 Teacher Notes**, **Lesson 4.3 Glossary**, **Lesson 4.3 Materials**, and other support documents.*

Day 1:

- Present **Concepts**, **Performance Objectives**, **Essential Questions**, and **Key Terms** to provide a lesson overview.
- Provide students **Presentation Notes** pages to be used throughout the video to record notes and reflections. Students add these pages to their *Agriscience Notebook*.
- Present LunchBox Session© **Open and Short Circuit Faults**.
- Students take notes using the *Presentation Notes* pages provided by the teacher.
- Provide students with a copy of **Activity 4.3.1 Voltage Drop**.
- Students complete *Activity 4.3.1 Voltage Drop*.

Days 2:

- Provide students *Presentation Notes* pages to be used throughout the video to record notes and reflections. Students add these pages to their *Agriscience Notebook*.
- Play the DVD **Electrical Testing – Voltage Drop** (EETC CE3101).
- Students take notes using the *Presentation Notes* pages provided by the teacher.
- Provide students with a copy of **Project 4.3.2 Troubleshooting Drops**, **Work/Repair Order Template**, and the **Work/Repair Order Evaluation Rubric**.
- Provide student groups with a copy of the **New Regent Service Manual**.
- Demonstrate how to use a battery post terminal cleaner.
- Students complete Part One of *Project 4.3.2 Troubleshooting Drops*.

Day 3:

- Assemble the Basic Electrical Training Boards as outlined in *Lesson 4.3 Teacher Notes*.
- Provide student groups with a card from **Project 4.3.2 Complaint Cards**.
- Student groups complete Part Two of *Project 4.3.2 Troubleshooting Drops*.
- Students individually complete a *Work/Repair Order Template*.
- Evaluate the project using the *Work/Repair Order Evaluation Rubric*.

Day 4:

- Provide students with a copy of **Activity 4.3.3 Current Draw**.
- Provide equipment for parasitic draw tests.
- Student groups work to complete *Activity 4.3.1 Current Draw*.

Day 5:

- Provide students with a copy of **Project 4.3.4 Checking Connections**, **Ignition/Shutdown Schematic**, *Work/Repair Order Template*, and the *Work/Repair Order Evaluation Rubric*.
- Present LunchBox Session© **Electrical Connectors** and **Basic Soldering**.
- Demonstrate how to strip a cable, crimp a connector, solder a wire, clean a soldering iron, and how to insulate with heat shrink tubing.
- Students complete Part One of *Activity 4.3.4 Checking Connections* during the Lunchbox Sessions© and teacher demonstration.

Days 6

- Students work in groups to complete Parts Two and Three of *Activity 4.3.4 Checking Connections*.
- Students work in groups to start Part Three of *Activity 4.3.4 Checking Connections*.

Days 7 – 8:

- Students will complete the Ignition/Shutdown Circuit construction in Part Three *of Activity 4.3.4 Checking Connections*.
- Students add faults to their board with three errors.
- Students trade boards with another group and diagnose the errors.
- Student groups complete a *Work/Repair Order Template*.

- Evaluate student groups with the *Work/Repair Order Evaluation Rubric*.

Days 9 – 12:

- Provide students with a copy of **Problem 4.3.5 Monitoring Spray**, **FIMCO 30 Gallon Sprayer Manual**, and the **Student Guide to Assessing Problems**.
- Students work in groups to complete *Problem 4.3.5 Monitoring Spray*.

Day 13:

- Students work as a group to present their prototypes.
- Evaluate student groups with the *Guide to Assessing Problems*.

Day 14:

- Distribute **Lesson 4.3 Check for Understanding**.
- Students complete *Lesson 4.3 Check for Understanding* and submit for evaluation.
- Use **Lesson 4.3 Check for Understanding Key** to evaluate student assessments.

Instructional Resources

LunchBox Sessions©

Open and Short Circuit Faults

Electrical Connectors

Basic Soldering

Student Support Documents

Lesson 4.3 Glossary

Presentation Notes

Activity 4.3.1 Voltage Drop

Project 4.3.2 Troubleshooting Drops

Activity 4.3.3 Current Draw

Project 4.3.4 Checking Connections

Problem 4.3.5 Monitoring Spray

New Regent Service Manual

Ignition/Shutdown Schematic

FIMCO 30 Gallon Sprayer Manual

Teacher Resources

Lesson 4.3 Electrical Analysis PDF

Lesson 4.3 Teacher Notes

Lesson 4.3 Materials

Lesson 4.3 Check for Understanding

Project 4.3.2 Complaint Cards

Answer Keys and Assessment Rubrics

Lesson 4.3 Check for Understanding Answer Key

Work/Repair Order Rubric

Student Guide to Assessing Problems

Student Project Development Template

Work/Repair Order Template

Reference Sources

Briggs and Stratton Customer Education. *Electrical Testing- Voltage Drops, Increasing Profit*. EETC.

Briggs and Stratton Customer Education (2014). *Electrical Training Manual*.

Fluke. (2021). *Electrical automotive troubleshooting.* **https://www.fluke.com/en-us/learn/blog/automotive/electrical-automotive-troubleshooting#:~:text=%E2%80%9CVoltage%20dropping%E2%80%9D%20a%20circuit%20tells,correctly%2C%20then%20replace%20the%20component**

Herren, R. V., & Donahue, R. L. (2000). *Delmar's agriscience dictionary with searchable CD-ROM*. Albany, NY: Delmar.

Lunchbox Sessions© (2021). *Basic Soldering*. **https://www.lunchboxsessions.com/materials/connectors/soldering-basics-lesson**

Lunchbox Sessions© (2021). *Electrical Connectors*. **https://www.lunchboxsessions.com/materials/connectors/connectors-lesson**

Lunchbox Sessions© (2021). *Open and Short Circuit Faults*. **https://www.lunchboxsessions.com/materials/open-short-circuit-faults/open-short-circuit-faults-lesson**

FFA Connections

This lesson provides conceptual and procedural knowledge required for participation in the following FFA activities:

- Agricultural Proficiency
  - **Agricultural Mechanics Design and Fabrication – Entrepreneurship/Placement**
  - **Agricultural Mechanics Repair and Maintenance –Placement**
  - **Agricultural Mechanics Repair and Maintenance –Entrepreneurship**
  - **Agriscience Research – Integrated Systems**
- Agriscience Fair
  - **Power, Structural and Technical Systems**
- Career Development Events
  - **Agricultural Technology & Mechanical Systems**
- Educational Resources
  - **SAE Idea Cards-Power, Structural and Technical Systems**
  - **Power, Structural and Technical System Careers**
  - **Power, Structural and Technical Systems Career Focus Area Resources**
  - Power, Structural and Technical Careers **(Word)**

Skills and knowledge from this lesson support the development and implementation of service-learning projects that address electrical systems.

- **Service-Learning and Living to Serve Grant**s
  - Service-learning projects focused on diagnosing electrical system issues in agricultural and other outdoor equipment.
  - Project ideas include hosting a spring tune-up or winterization event for local community members for lawnmowers and other equipment with electrical systems.
  - Living to Serve Grants provide funding to FFA chapters to support service-learning and community service projects.

For more information, visit the **National FFA Organization** website.

SAE for All

Immersion SAE

Students interested in this lesson's topics should explore the following related Immersion SAEs. An immersion SAE is optional and replaces the agricultural literacy component of the Foundational SAE.

- Placement/Internship
    - **Drones in Agriculture SAE | Jacob Reed**
- **SAE Video Choice Board**
    - This document serves as a resource to incorporate SAE videos into the classroom. These videos allow students to learn about and develop/enhance their SAEs. There are a series of choice boards available: six-week nine-week, quarter, first-half of the semester and second-half of the semester. Choose the format that best suits your classroom.

For more information on the guiding principles for implementing SAE programs, visit the **SAE for All: Evolving Essentials** site.

Critical Thinking and Application Extensions

Explanation

1. Students will interview a technician to research common faults in GPS systems.

Application

2. Students test parasitic battery drain and voltage drop in a personal or family car.
3. Students will inspect connectors in a tractor and look for faults.

Self-Knowledge

4. Students will experiment with the effectiveness of heat shrink to insulate and protect connectors.

CASE

Lesson 4.3 Teacher Notes

Lesson 4.3 Electrical Analysis

In preparation for teaching this lesson, review Concepts, Performance Objectives, Essential Questions, and Key Terms, along with the presentations. Also, review all activity, project, and problem directions, expectations, and work students complete.

During this lesson, students test for voltage drop and current draw in agricultural equipment. Next, students use these procedures to test for voltage drops in connections and parasitic battery drain in agricultural equipment. Then, students create a wiring harness to create an ignition/shutdown circuit. Finally, students develop an electrical system to control a sprayer electronically and monitor pressure, boom height, and GPS position.

LunchBox Sessions©

Register for one **LunchBox Session©** account with rights for presenting to your class. LunchBox Sessions© are short information sessions technicians can use to refresh themselves on fundamental mechanics.

Open and Short Circuit Faults

This session explains how technicians can diagnose open and shorts within circuits using a digital multimeter (DMM).

Electrical Connectors

Electrical connectors are used in equipment to hold cables to components or to splice cables together. This session reviews the types of connectors and how to use them.

Basic Soldering

Technicians use soldering to fuse cables to electrical connectors, terminals, or circuit boards using electrical solder. This session demonstrates how to use a soldering iron.

Activities, Projects, and Problems

Activity 4.3.1 Voltage Drop

Voltage drop is the voltage lost in a circuit due to resistance. First, students calculate the expected voltage drop in a circuit using Ohm's Law. Next, students measure voltage drop using a DMM. The sum of each component's voltage drop should equal the source voltage of the circuit.

Teacher Preparation

1. Review **Lunchbox Session© Open and Short Circuit Faults**.
2. Use a DMM to test battery voltage to ensure the 12V batteries are charged. Charge any battery under 12.2V for the next day. Place the red clamp of the battery charger on the positive battery post and the black clamp on the negative post. Plug in the charger. When the light on the charger blinks green, unplug and disconnect the charger. Remove the black clamp before the red. Consult the **Battery Charger User Manual** for additional instructions.

Student Performance
During Part One, students individually calculate the expected voltage drops of the circuit shown in Figure 1. Next, they collect readings for battery voltage and the resistance of each component. Using these measurements, students calculate the expected drop at each component.

In Part Two, students work in groups to assemble the circuit shown in Figure 1 and measure the voltage drops of each component using a DMM.

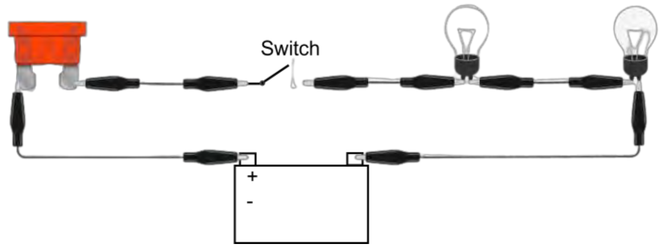


Figure 1. Voltage Drop Schematic

Results and Evaluation
Anticipated results are in Table 1. Table 2 includes potential responses to analysis questions. At the end of the activity, students should understand how the sum of a circuits voltage drop is equal to total circuit voltage.

Table 1. ***Circuit Readings***

Component	Reading
Circuit Readings	
Battery voltage	**12.6V (Vary based on charge)**
Switch (closed)	**0Ω**
Bulb 1	**2.6Ω**
Bulb 2	**2.6Ω**
Circuit Calculations	
Total Resistance	**0Ω + 2.6Ω + 2.6Ω = 5.2Ω**
Total Amperage	**12.6V/5.2Ω = 2.42 amps**
Switch Voltage	**OΩ × 2.42 amps = 0V**
Bulb 1 Voltage	**2.6Ω × 2.42 amps = 6.292V**
Bulb 2 Voltage	**2.6 Ω × 2.42 amps = 6.292V**

Table 2. ***Analysis Questions and Potential Responses***

Prediction Questions		
Q1	Will the actual voltage be consistent with the calculations in Table 3? Why or why not?	*Answers will vary based on predictions. Students may predict that there will be differences based upon extra resistance in the system.*
Analysis Questions		
Q2	How would the voltage drop change in the circuit if there was a short across bulb two?	*A short could decrease the resistance of the circuit, increasing the voltage drop at bulb one.*
Q3	How would the voltage drop change in the circuit if there was corrosion on an alligator clip?	*Corrosion adds resistance to the circuit. There would be a voltage drop between the cable and the connection where the alligator clip is clamped.*

Project 4.3.2 Troubleshooting Drops

Students measure for a voltage drop across battery connections and troubleshoot a simulated customer complaint on the Basic Electrical Training Board.

Teacher Preparation

1. Use a DMM to test battery voltage to ensure the 12V batteries are charged. Charge any battery under 12.2V before the next day. Place the red clamp of the battery charger on the positive battery post and the black clamp on the negative post. Plug in the charger. When the light on the charger blinks green, unplug and disconnect the charger. Remove the black clamp before the red. Consult the *Battery Charger User Manual* for additional instructions.
2. Order the DVD *Electrical Testing – Voltage Drop, Increasing Profits (CE3101)* from EETC. Play the *Voltage Drop* section for students.
3. Obtain tractors, lawnmowers, skid steers, and/or trucks for students to measure the voltage drop across battery terminals. The process for this on a tractor is the same for a vehicle. Note: some compact vehicles place the battery in a hard-to-reach position. Verify that the battery is accessible beforehand.
4. Print the electrical portion of the **New Regent Service Manual** for each group, or post the document on your local LMS platform.
5. Print 2 copies of the **Project 4.3.2 Complaint Cards**. Cut out a card for each group. You need five cards for a class or 20. Some groups will have the same complaint.
6. Prepare and label Basic Electrical Training Boards for each group to troubleshoot. Assign groups to troubleshoot the boards corresponding to the number on their complaint card. Assemble the cranking circuit shown in Figure 2 for each board. Table 3 includes the problem and supplies needed for each complaint. Modify the circuit to match each complaint.
7. Mix 300ml of water and half a box of baking soda in a 600ml beaker. Students use this baking soda solution to clean battery terminals during Part One.
8. Review the use of a battery post terminal cleaner and demonstrate it to students. The cleaner is added to each post and moved back and forth until all corrosion and neutralized salts are gone.

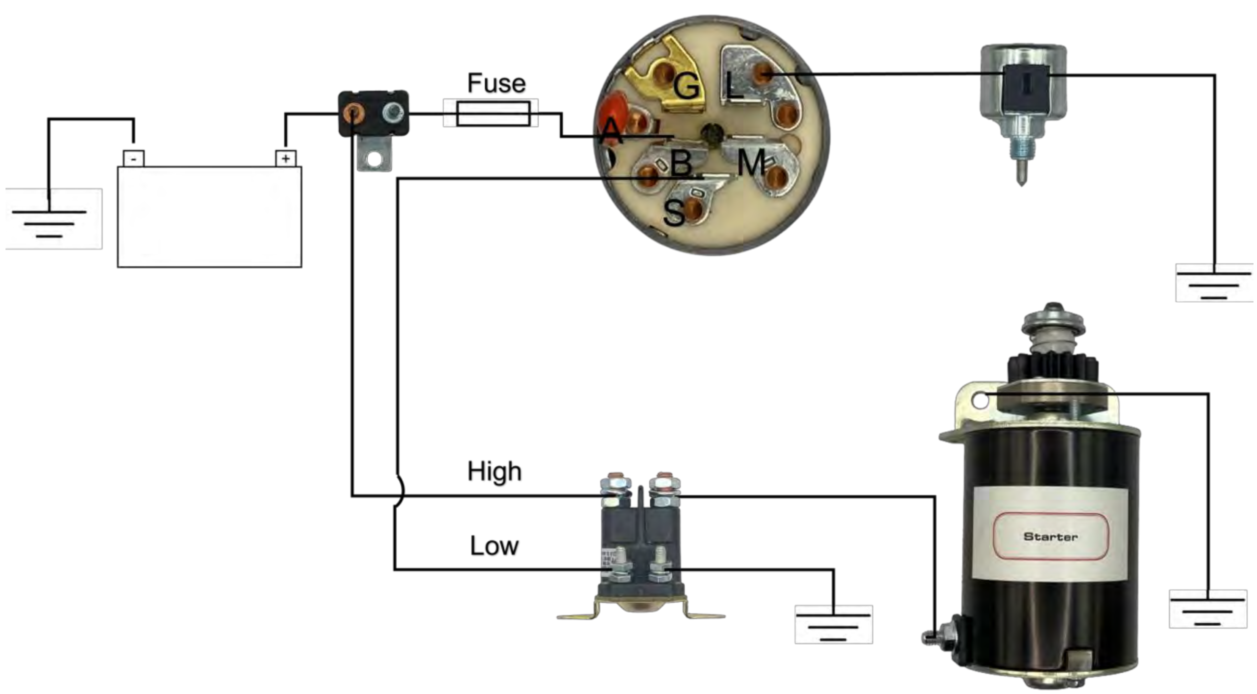


Figure 2. Cranking Circuit

Table 3. ***Training Board Prep***

Complaint	Problem/Procedure	Materials
Complaint Card #1 Jamie Owatonna's lawn mower will not turn over. The lawnmower has fresh gasoline, and the lights come on. The customer believes the battery is okay.	The solenoid on the board has failed. Remove the solenoid using a Philips screwdriver. Disconnect the cables on the high side of the circuit using a ½" socket and ratchet. Add the faulted solenoid to the board and connect it to the circuit.	• Phillips screwdriver • Socket, $^1/_2$", ¼" drive • Socket wrench ¼" drive • Faulty solenoid
Complaint Card #2 Jim Rice's lawn mower will not start. The customer charged the battery, and nothing happened.	The positive connection on the starter is corroded. Remove the cable and insulate the connector using electrical tape before reconnecting the cable. Cover the connection with the rubber boot.	• Socket, $^7/_{16}$", ¼" drive • Socket wrench ¼" drive • Electrical tape
Complaint Card #3 Josh Wilton recently brought in a lawnmower for an oil change. A few weeks later, the engine will not turn over.	The starter is not grounded. Disconnect the metal strip along the top side of the ground terminal block by loosening each screw until you can remove the strip.	• Phillips screwdriver

Student Performance

Part One

Students measure the voltage drop across battery connections. Next, students clean the battery posts and connectors using the baking soda solution and a battery post terminal cleaner. Next, students add a thin layer of dielectric grease before reconnecting the battery cables and answering analysis questions.

Part Two

Students obtain a customer complaint card and use the *New Regent Service Manual* to follow service flow charts and conduct component tests. After isolating the problem, students repair the circuit and verify its operation. The starter should turn over when completed. Students work individually to complete a **Work/Repair Order Template**.

Results and Evaluation

At the end of this activity, students should be able to diagnose and repair voltage drops at the battery cable. Next, student groups should demonstrate use of the DMM to diagnose faults in a starting circuit. Evaluate the *Work/Repair Order Template* using the **Work/Repair Order Rubric**. Table 4 includes potential responses to analysis questions.

Table 4. ***Analysis Questions and Potential Responses***

Q1	How did the voltage drop conditions improve after cleaning the posts?	*Answers will vary. Expect results between 0.0V and 0.5V depending upon the condition of terminals.*
Q2	What is the role of dielectric grease?	*The grease is a barrier between the metal components, keeping the connectors and posts from corroding. In addition, the grease has high electrical conductivity and will not add resistance to the circuit.*
Q3	Where else can voltage drops occur in battery cables?	*Poorly crimped connections across a battery cable can add resistance and create a voltage drop.*

Activity 4.3.3 Current Draw

Students practice conducting current draw tests by measuring the electricity used in a circuit.

Teacher Preparation

1. Use a DMM to test battery voltage to ensure the 12V batteries are charged. Charge any battery under 12.2V for the next day. Place the red clamp of the battery charger on the positive battery post and the black clamp on the negative post. Plug in the charger. When the light on the charger blinks green, unplug and disconnect the charger. Remove the black clamp before the red. Consult the *Battery Charger User Manual* for additional instructions.
2. Obtain tractors, lawnmowers, skid steers, and/or trucks for students to measure the voltage drop across battery terminals. If using vehicles, open the doors and tape the door sensors down at all access points before performing the test. Depending upon the model, the vehicle's computer draws power for 30 minutes to two hours after turning off the engine. The fuse box should be accessible to students to perform the parasitic battery drain test.

Student Performance

Part One

Students assemble the circuit shown in Figure 3. Then, students measure resistance in the circuit to calculate the expected current draw. Next, students activate the circuit and measure the current draw with a DMM.

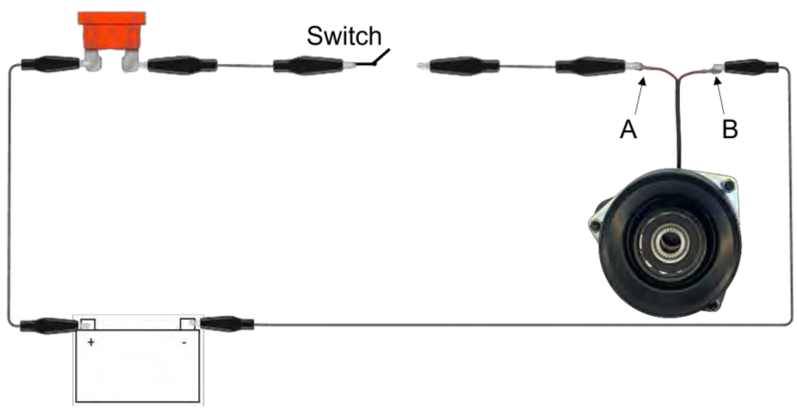


Figure 3. Electric Clutch

Students use a DMM to conduct a parasitic battery drain test in Part Two. Students first inspect and clean battery cables if needed. Next, students record a simulated drain by turning on and off the headlights. Students use that data to answer the analysis questions on the student data page. Finally, students continue with the parasitic battery drain test by removing each fuse. If a group finds a parasitic battery drain, consider adding an extension activity to investigate the drain further to isolate the cause and correct the fault.

Results and Evaluation

Example calculations for Part One are in Table 5. Use example responses in Table 6 to guide students through analysis questions.

Table 5. ***Electric Clutch Readings***

Reading		Data	
Resistance	Electric Clutch	**3Ω**	
Voltage	Battery Voltage	**12.6V**	
Reading		**Switch Off**	**Switch On**
Voltage Drop	Measured Voltage Drop	**0V**	**10.9V**
Amperage	Calculated Current Draw		**current =** $\frac{12.6V}{3\Omega}$ **4.2 amps**
	Measured Current Draw		**Answers will vary 3.7–3.9 amps**

Table 6. ***Analysis Questions and Potential Responses***

Q1	Is the calculated current draw different from the draw measured with the digital multimeter? Why or why not?	*Answers will vary. There should be a slight difference due to extra resistance in the system.*
Q2	Was the initial parasitic battery drain permissible?	*Answers will vary on the amount, but the headlights should pull an amperage higher than what is permissible.*
Q3	What happened to the battery drain after you removed the fuse?	*The drain should reduce.*
Q4	How can a technician use fuses to troubleshoot parasitic battery drain?	*Technicians pull fuses to check for parasitic drain. If the drain falls when pulling the fuse, there might be a component malfunction within the branch connected to that circuit.*
Q5	Why is the permissible drain on a tractor lower than on automobiles?	*Vehicles have more complex computer systems onboard that require continual operation, such as alarms and clocks. More modern tractors will have a higher permissible drain than older models.*

Project 4.3.4 Checking Connections

Students practice wiring techniques and testing for faults and resistance. Then they construct and test a wiring harness for a starter system.

Teacher Preparation

1. Review **Lunchbox Session© Electrical Connectors** and **Lunchbox Session© Basic Soldering**.
2. Use a DMM to test battery voltage to ensure the 12V batteries are charged. Charge any battery under 12.2V for the next day. Place the red clamp of the battery charger on the positive battery post and the black clamp on the negative post. Plug in the charger. When the light on the charger blinks green, unplug and disconnect the charger. Remove the black clamp before the red. Consult the *Battery Charger User Manual* for additional instructions.
3. Students take notes during teacher demonstrations on how to strip wire, crimp connections, apply heat shrink, solder wire, and soldering iron cleaning during Part One. Watch the following YouTube videos to review the processes before the demonstration, as needed.
    - Stripping cable, crimping cable, apply heat shrink: **https://www.youtube.com/watch?v=kjSGCSwNuAg**
    - Soldering wires **https://www.youtube.com/watch?v=Q9G9gaokqvM**

4. Prepare five cables for students to evaluate in Part Three. Use new wires or old wires from local agricultural equipment dealers. Mark the cables A–E. The following are examples of cables to prepare.
    - Cables with incomplete connections.
        - o Place connectors at both ends, with one connector placed over the cable insulation.
    - Cable with connections on both ends.
    - Cables with cuts on the insulation of the cable.
    - Cables with broken wires surrounded by insulation
5. Obtain materials for student groups to produce wiring harnesses. Various connectors are needed, but female disconnects will be the highest in demand as students use them to connect to terminals.
    - Electrical connectors assorted, 16 ga
    - 16 gauge Electric Hook Up Wire Kit, 100 feet, assorted colors
    - Heat shrink, assorted sizes
    - Cut or obtain precut heat shrink in ¼″ x 4″ strips for Part Two

Student Performance

Part One

Students record information in Table 1 of the student data page during the Lunchbox Sessions© and teacher demonstration.

Part Two

Students prepare a cable with three 4″ sections of 16 ga cable. They add male and female connections to two cables and connect them. Next, students solder a wire together. Figure 4 shows an example cable that students construct. Students measure resistance by placing the leads of a DMM on each end of the cable. Students should determine the fault and repair the connection if they measure any resistance. Next, students apply heat shrink to portions A, B, and C, as seen in Figure 4. Note: if students use non-insulated quick disconnects, they insulate the entire connection to prevent short circuits.

Figure 4. Cables Connections

Part Three

Students repeat Step 5 from Part Two to test the five cables provided by their teacher. They record the connection faults and recommended repairs on the student data page.

Part Four

Student groups use the **Ignition/Shutdown Schematic** to assemble the ignition and shutdown circuit. The *Ignition/Shutdown Schematic* details the ignition and shutdown circuits on a New Regent™ riding lawnmower, including two safety switches and a PTO switch that turns on the mower deck. The tractor must meet the following conditions for the engine to start.

- The operator must place their foot on the pedal for the starter to initiate.
- The PTO switch is pushed, and the clutch is disengaged.
- The operator must be seated for the engine to start and continue running.

They build the circuit using cable, connectors, heat shrink, and solder. After confirming that the board meets the criteria of the ignition and shutdown circuit, students create faults in three locations and trade their boards with another group. Finally, students use the schematic and a DMM to troubleshoot the board, find the problems and correct the errors. Students use the *Work/Repair Order Template* to document work.

Results and Evaluation

Evaluate the Work/Repair Order Template with the *Work/Repair Order Rubric.* Use the potential responses in Table 7 to aid students with analysis questions.

Table 7. *Analysis Questions and Potential Responses*

Q1	A cable should have no resistance across connections. Why?	*Cables should carry the voltage without resistance. Resistance in a cable or a connection will result in a voltage drop and decrease voltage available to other components in the circuit.*
Q2	Did your cable have resistance? If so, where were the faults?	*Answers will vary.*
Q3	What is the role of the heat shrink?	*The heat shrink insulates the wire to prevent a short circuit.*

Problem 4.3.5 Monitoring Spray

GPS sprayers include components to apply chemical and electrical equipment to monitor pressure, flow rate, sprayer position, and boom height. Students create an electrical system to monitor and control a **FIMCO 30 Gallon Trailer Sprayer**.

Problems require students to identify needs, establish goals and constraints, seek knowledge via exhaustive research, synthesize new knowledge, tackle project management issues, take risks, work with their mentors, and develop work ethics and habits that contribute to life-long learning. As such, developing prescribed assessment guidelines and rubrics for Problems constrains student development. Rather than placing limitations on student discovery, you are encouraged to assess students on their approach and process to solving the problem rather than arriving at the correct answer or developing a specific product. Student-directed learning is very high when using problem-based learning methods.

Teacher Preparation

1. Use a DMM to test battery voltage to ensure the 12V batteries are charged. Charge any battery under 12.2V for the next day. Place the red clamp of the battery charger on the positive battery post and the black clamp on the negative post. Plug in the charger. When the light on the charger blinks green, unplug and disconnect the charger. Remove the black clamp before the red. Consult the *Battery Charger User Manual* for additional instructions.
2. Obtain a FIMCO 30 Gallon Trailer Sprayer or a similar model from local retailers. The model is commercially available online and through local farm supply stores such as Tractor Supply Company and Orscheln's. Another option is to create the sprayer on a piece of plywood. If building a baseboard, purchase the pump and sprayer manifold parts of the trailer sprayer. The only electrical components on the base sprayer or board should be the pump, pump switch, and battery.
3. Obtain a 5/16″x 1/8″ female union for each student group. The union allows the Pressure 400 sensor to fit within the sprayer manifold to replace the dial pressure gauge. Figure 5 shows an example of this arrangement.
4. Print the **FIMCO 30 Gallon Trailer Sprayer User Manual** or post it on your local LMS platform.

Figure 5. Sprayer Manifold, Union, and Pressure Sensor

Student Performance
Challenge students with creating an electrical monitoring system for a sprayer for a sports turf firm. The system should signal the operator's pressure readings and boom height during use. The sprayer should also operate within designated GPS coordinates. Figures 6 shows an example of a finished product. After constructing a prototype, the students prepare a presentation for the class. The students present the product's operation, troubleshooting protocol, and safety features during the presentation. Criteria for the prototype are listed below.

Sprayer Criteria

- Sprays only when the board is within the designated GPS coordinates.
- Signals when the system pressure meets OEM standards.
- Signals when the system pressure is above or below OEM standards.
- Signals when the boom is at the OEM recommended height.
- Signals when the boom is above or below the OEM recommended height.
- All connections are properly insulated.
- The system protects lower-voltage circuits from a high voltage surge.

Results and Evaluation
Evaluate student presentations and prototypes using the **Student Guide to Assessing Problems**. Figure 6 shows an example of a finished product.

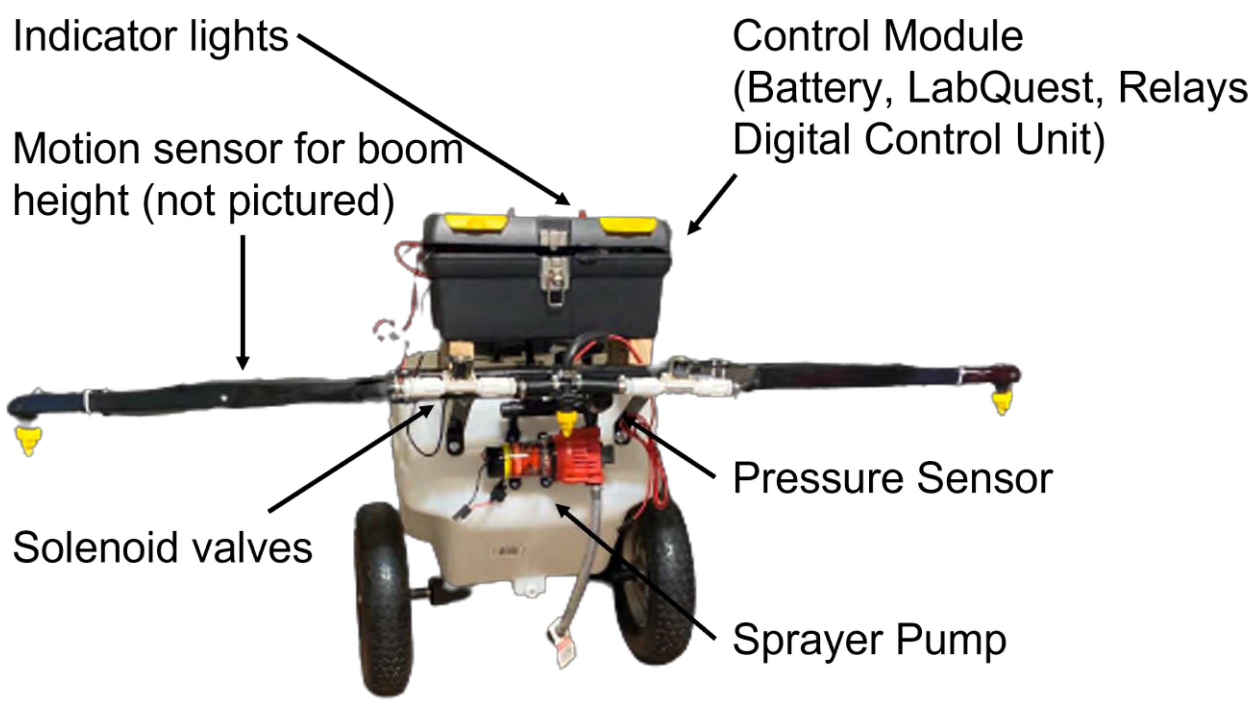


Figure 6. GPS Sprayer Trailer

Assessment

Lesson 4.3 Check for Understanding

Lesson 4.3 Check for Understanding is included for you to use as an assessment tool for this lesson. Use **Lesson 4.3 Check for Understanding Answer Key** for evaluation purposes.

Name____ **CASE**

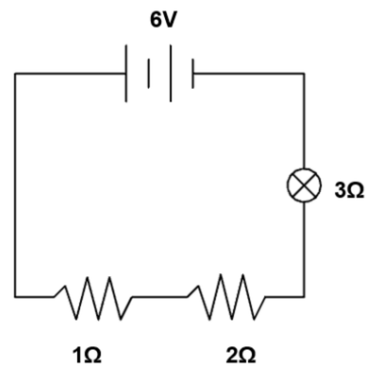
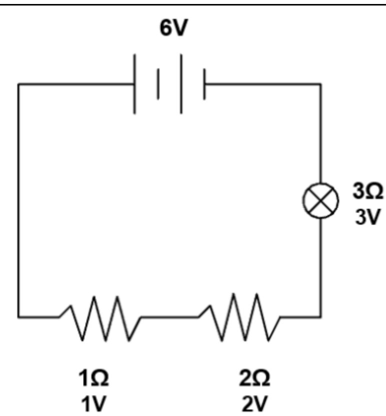
Activity 4.3.1 Voltage Drop

Purpose

All circuits have resistance to electrical flow. As current travels across cables and connections in a circuit, voltage is lost due to resistance. The amount of voltage lost is voltage drop. Technicians measure voltage drops in a circuit using a digital multimeter, a schematic, and an understanding of Ohm's Law.

Technicians use resistance and amperage measurements to calculate the expected voltage drop at each component. The sum of the voltage drop at each component will equal the source voltage. Faulty components, corroded connections, or knicked wires can increase the circuit's resistance, decreasing the voltage available to each circuit component. Table 1 shows how technicians use Ohm's Law to calculate voltage drop.

Table 1. *Calculating Voltage Drop*

Steps	Example
1. Measure battery voltage. 2. Measure the resistance of each component in a circuit.	
3. Calculate total resistance in a circuit.	$R_{total} = R_1 + R_2 + R_3 \ldots$ $R_{total} = 3\Omega + 1\Omega + 2\Omega$ $R_{total} = 6\Omega$
4. Use Ohm's Law to calculate the amperage in the circuit.	battery voltage = amperage x total resistance 6V = amperage x 6Ω 1 amp
5. Use Ohm's Law to calculate the expected voltage drop at each component.	voltage = amperage x component resistance lamp voltage = 1 amp x 3Ω lamp = 3 volts
6. The total voltage drop across the circuit should equal the battery voltage.	

Materials

Per group of four students:

- Basic Electrical Training Board
- Battery, 12V
- Calculator
- Digital multimeter (DMM)
- Fuse, 10A
- (6) Wire with alligator clips

Per student:

- *Agriscience Notebook*
- *Logbook*
- Pen
- Safety glasses

Procedure

Work individually to calculate the expected voltage drop. Then work in a group to construct the circuit and compare the energized circuit to your calculations.

Part One – Voltage Drop Calculations

1. Put on safety glasses and tie back long hair.
2. Use the DMM to measure the battery voltage and record it in Table 2 of *Activity 4.3.1 Student Data*.
3. Collect the resistance values on the Basic Electrical Training Board for the following components and record them in Table 2.
    - Switch (closed)
    - Bulb 1
    - Bulb 2
4. Calculate the total resistance for the circuit shown in Figure 1 and record it in Table 3.
    - Show your work in the *calculations* section.

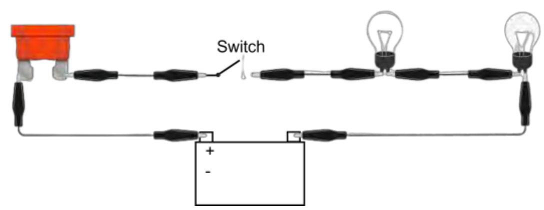


Figure 1. Voltage Drop Schematic

5. Use Ohm's Law to calculate the amperage of the circuit and record it in Table 3.
    - Show your work in the *calculations* section.
6. Calculate the expected voltage at each component and record it in Table 3.
    - Show your work in the *calculations* section.
7. Answer the *Prediction Question*.

Part Two – Voltage Drop

1. Assemble the circuit shown in Figure 1.
2. Turn on the switch (closed position).
3. Measure the voltage at the switch by placing the leads at each terminal and record them in Table 4.
4. Repeat Step 3 with *Bulb One* and *Bulb Two*.
5. Answer the *Part Two Analysis Questions*.

Conclusion

1. How is voltage drop calculated?

2. How does an improper connection impact the voltage available to a component?

Name____

Activity 4.3.1 Student Data

Table 2. ***Circuit Readings***

Component	Measurements
Battery voltage	
Switch (closed)	
Bulb 1	
Bulb 2	

Table 3. ***Circuit Calculations***

Component	Reading	Calculations
Total Resistance		
Total Amperage		
Switch Voltage		
Bulb 1 Voltage		
Bulb 2 Voltage		

Prediction Question

Q1 Will the actual voltage be consistent with the calculations in Table 3? Why or why not?

Table 4. ***Circuit Readings***

Component	Reading
Switch Voltage	
Bulb 1 Voltage	
Bulb 2 Voltage	
Total Voltage Drop	

Part Two Analysis Questions

Q1 How would the voltage drop change in the circuit if there was a short across bulb two?

Q2 How would the voltage drop change in the circuit if there was corrosion on an alligator clip?

Name____ CASE

Project 4.3.2 Troubleshooting Drops

Purpose

Most often, a bad battery or battery terminals corrosion is the cause of electrical issues. When the problem is more complex, the technician performs a voltage drop test to isolate the cause. OEMs will only compensate dealers for the parts and labor needed to repair the problem, including an electrical diagnosis, when conducting warranty work. The key to profitability in a service department is efficient technicians performing the correct diagnosis based upon the complaint. If the technician performs the wrong diagnostic procedure, the local shop pays the labor cost, not the OEM.

A digital multimeter is essential for measuring voltage drop by measuring the potential voltage of each lead and displaying the difference between the two points on the monitor. Figure 1 shows a digital multimeter testing the potential difference between the positive battery post and the battery cable. A proper connection should read zero volts. If the battery post has corrosion or the cable was improperly crimped, a voltage drop will decrease the voltage available to the rest of the circuit. Other examples of electrical faults creating drops include:

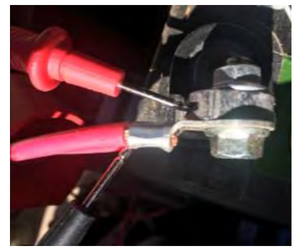


Figure 1. Testing for Potential Difference

- Connections: broken or corroded
- Wires: Knicked or shorted
- Coils: Frayed copper wire with the coils of relays and solenoids

What documentation helps a technician troubleshoot voltage drops? What equipment are most prone to voltage drop issues?

Materials

Per group of four students:

- Basic Electrical Training Board with pre-assembled circuit
- Battery post terminal cleaner
- Digital multimeter (DMM)
- Equipment with 12V system
- *New Regent Service Manual*
- *Project 4.3.2 Complaint Card*
- Socket wrench, ¼″ drive
- Socket, 10mm,¼″ drive

Per class:

- Baking soda solution
- Dielectric grease
- Materials for solving customer complaints
- Steel wool

Per student:

- *Agriscience Notebook*
- *Logbook*
- Nitrile gloves
- Pen
- Safety glasses
- *Work/Repair Order Rubric*
- *Work/Repair Order Template*

Procedure

First, work with your group to test for voltage drop on the battery connections of agricultural equipment. Next, your instructor will provide you with a Basic Electrical Training Board with a voltage drop issue. Use the DMM and a service manual to troubleshoot the problem.

Part One – Voltage Drop

1. Put on safety glasses and nitrile gloves, and tie back long hair.
2. Set up your DMM to measure DC Volts.
3. Measure the voltage drop on the battery's positive post, as shown in Figure 1.
    - Place the read lead on the post.
    - Place the black lead on the cable.
    - The reading is your voltage drop. Record the drop in your *Logbook*.
4. Repeat Step 2 on the ground side.
5. Clean the battery posts and connections.
    - Disconnect the battery cables using a 10mm socket and rachet. Remove the negative battery cable before removing the positive cable.
    - Place the battery post terminal cleaner on each post and turn back and forth to clean the surface until all corrosion is absent.
    - Inspect the cable clamps for corrosion. If necessary, clean with a baking soda solution and steel wool.
    - Add a thin layer of dielectric grease to each battery post.
    - Reconnect the battery cables to the battery. Always reconnect the positive cable first.
6. Repeat Steps 2–3.
7. Answer the analysis questions in your *Logbook*.

   Q1 How did the voltage drop conditions improve after cleaning the posts?
   Q2 What is the role of dielectric grease?
   Q3 Where else can voltage drops occur in battery cables?

Part Two – Troubleshooting Drop

1. Obtain a *Complaint Card* from your teacher.
2. Verify the customer complaint.
3. Locate the *Troubleshooting Flow Charts* and *Component Tests* sections of the service manual.
4. Match the customer complaint to an issue within *Troubleshooting Flow Charts*.
5. Follow the flow charts to isolate the cause and perform the component tests suggested by the troubleshooting flow charts.
6. Document the component tests your group completed and the results of each test in your *Logbook*.
7. Repair the circuit and verify operation.
8. Work individually to complete and submit *a Work/Repair Order Template*. Your instructor will evaluate your submission using the *Work/Repair Order Rubric*.

Conclusion

1. How do technicians use service manuals when troubleshooting voltage drops?

2. Voltage drop issues commonly occur on older equipment. Why is this more prevalent?

CASE

Project 4.3.2 Complaint Cards

Complaint Card #1 Jamie Owatonna's lawn mower will not turn over. The lawnmower has fresh gasoline, and the lights come on. The customer believes the battery is okay.
Complaint Card #2 Jim Rice's lawn mower will not start. The customer charged the battery, and nothing happened.
Complaint Card #3 Josh Wilton recently brought in a lawnmower for an oil change. A few weeks later, the engine will not turn over.

Name____ CASE

Activity 4.3.3 Current Draw

Purpose

Technicians measure current draw used by components connected to a power source. Technicians conduct current draw tests for two reasons: checking component function and parasitic battery drain. Technicians use diagnostic tools and Ohm's Law to measure current draw as part of a systematic troubleshooting process. Ohm's Law can be rearranged to calculate amperage, as shown in Figure 1.

$$\text{voltage} = \text{amperage} \times \text{resistance}$$

$$\frac{\text{voltage}}{\text{resistance}} = \text{amperage}$$

Figure 1. Ohm's Law

An electromagnetic clutch can draw unwanted current in a circuit. Lawnmowers use a clutch to start and stop the rotating cutting blades. The clutch operates when an electromagnet energizes. If that coil shorts, it will impact cutting performance. Technicians can troubleshoot the clutch by checking the resistance and calculating the expected current draw.

An electrical component that continually drains the battery after the equipment is off can cause parasitic battery drain. A standard tractor or lawnmower should have no battery drain when the key is in the off position. However, more complex equipment will continue to use battery power when the engine is off to run clocks, alarms, or engine control units. For example, a farm truck should operate around 50mA of battery drain while the engine is off. The service manual will outline acceptable levels for parasitic battery drain.

Technicians can check for the parasitic battery drain using a three-step process.

1. **Measure current draw:** Check for the current draw when the engine and all electrical devices are off. In more complex equipment, the electrical system might need to rest for an hour before testing due to internal computer operations.
2. **Pull fuses:** Pull and replace fuses one at a time until the parasitic drain is obsolete or at the permissible level defined by the service manual.
3. **Check schematic:** Once you identify the circuit branch with a current draw, check the schematic to determine that circuit's components. Faulty switches, diodes, relays, or wiring harnesses within the circuit could cause the parasitic drain.

Materials

Per group of four students:

- Basic Electrical Training Board
- Battery post terminal cleaner
- Battery, 12V
- Digital multimeter (DMM)
- Fuse, 10A
- Fuse puller
- Socket wrench, ¼″ drive
- Socket, 10mm, ¼″ drive
- Tractor or equipment to test for parasitic battery drain
- (4) Wire with alligator clips

Per student:

- *Agriscience Notebook*
- *Logbook*
- Pen
- Safety glasses

Procedure

Within a group, calculate the current draw of an electric clutch and test the circuit. Next, test for battery drain in agricultural equipment and simulate parasitic amperage draw.

Part One – Current Draw

1. Put on safety glasses and tie back long hair.
2. Measure the resistance of the electromagnetic clutch and record it in Table 1 on *Activity 4.3.3 Student Data*.
   - Set the DMM to measure resistance.
   - Place the DMM red lead at point *A*.
   - Place the DMM black lead at point *B*.
3. Construct the circuit as shown in Figure 2. Ensure that the clutch cables do not touch and short out.

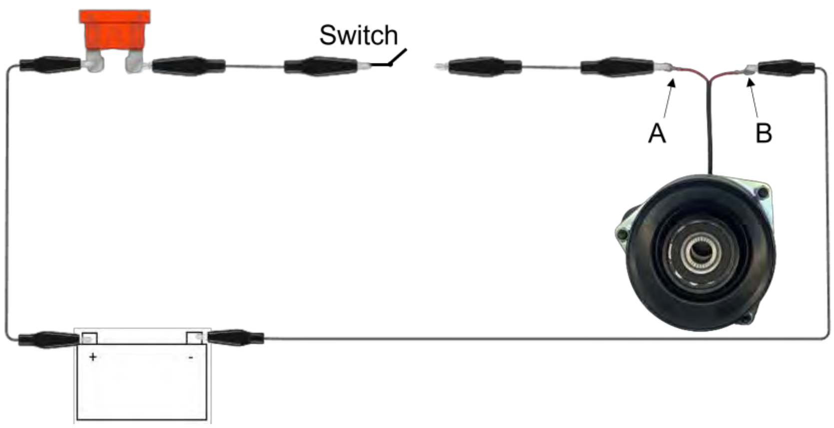


Figure 2. Electric Clutch

4. Measure the battery voltage and record it in Table 1.
5. Place the switch in the *off* position.
6. Measure the clutch's voltage drop. Record the voltage drop in Table 1.
   - Set the DMM to measure DC voltage.
   - Place the DMM red lead at point *A*.
   - Place the DMM black lead at point *B*.
7. Repeat Step 6 with the switch in the *on* position. Record the voltage drop in Table 1.
8. Turn off the switch.
9. Calculate the amperage draw of the circuit and record it in Table 1.

$$\text{amperage draw} = \frac{\text{voltage drop}}{\text{resistance}}$$

10. Turn on the switch and measure the DC amperage draw. Position the DMM as shown in Figure 3. Record the amperage draw in Table 1.
11. Turn off the switch.
12. Answer *Part One Analysis Question*.

Figure 3. Amperage Draw

Part Two – Parasitic Battery Drain

1. Prepare your equipment for the parasitic battery drain test.
   - Open access to the battery.
   - Remove the key from the ignition.
   - Turn off all accessory lights and close the doors, if applicable.
2. Inspect the battery terminals for corrosion and clean as necessary.
   - Remove the negative battery cable before removing the positive cable.
   - Place the battery post terminal cleaner on each post and turn back and forth to clean the surface until all corrosion is absent.
   - When reconnecting the cables, reconnect the positive cable first.
   - Some implements use a 24V system, with two 12V batteries connected in series.
3. Measure the parasitic battery drain by placing the amp clamp over the negative battery cable. Record in Table 2.
4. Simulate a parasitic battery drain by turning on the headlights.
5. Measure the battery drain and record it in Table 2.
6. Pull the fuse for the headlights.
   - Use a fuse puller to reduce damage to the fuse.
7. Record the battery drain in Table 2.
8. Replace the fuse and turn off the headlights.
9. Use information from Table 3 to answer *Part Two Analysis Questions*.
10. Repeat Steps 6–8 for the remaining fuses. Notify your teacher of any circuits with parasitic battery drain over 50mA.
11. Record the measurements in your *Logbook*.

Conclusion

1. How would a technician measure for current draw using a digital multimeter without an amp clamp?

2. How does a technician use Ohm’s Law to calculate an expected amperage draw?

Name____

Activity 4.3.3 Student Data

Table 1. ***Electric Clutch Readings***

Reading		Data	
Resistance	Electric Clutch		
Voltage	Battery Voltage		
Reading		**Switch Off**	**Switch On**
Voltage Drop	Measured Voltage Drop		
Amperage	Calculated Current Draw		
	Measured Current Draw		

Part One Analysis Question

Q1 Is the calculated current draw different from the draw measured with the digital multimeter? Why or why not?

Table 2. ***Parasitic Battery Drain***

Test	Data
Parasitic Battery Drain	
Drain with headlights on	
Drain with the fuse removed	

Table 3. ***Impact of Battery Drain on Automobiles***

Current Drain	Time until the engine won't start
20-50 mA	A permissible discharge rate.
50-100mA	A sign of non-standard electrical adaptions or faulty equipment. A car with an older battery will not start after sitting idle for three to four days.
>100mA	A sign of electrical failure. During colder months, the vehicle will not start after one to two days.

Part Two Analysis Questions

Q2 Was the initial parasitic battery drain permissible?

Q3 What happened to the battery drain after you removed the fuse?

Q4 How can a technician use fuses to troubleshoot parasitic battery drain?

Q5 Why is the permissible drain on a tractor lower than on automobiles?

Name____

Project 4.3.4 Checking Connections

Purpose

OEMs assemble electrical circuits using cables with various connectors. Connectors conduct electrical current to a component, load, ground, or spliced to another cable. Connections used in agricultural equipment include male and female disconnects, ring terminals, soldered connections, and plugs.

Figure 1. Male and Female Disconnects

Quick disconnects splice cables with a connection point, as shown in Figure 1. Industry uses the terms male and female connections. The male connector has a pin that fits into the female connector. Female connections can join cables to component terminals. Figure 2 shows cables with ring terminals to connect a circuit to a terminal block or a junction post. Quick disconnects and ring terminals require crimping a metal clamp around a bare portion of the cable.

Figure 2. Ring Terminal

Soldering is a fusion process of combining two or more electrical parts by melting solder around the connection. Solder is a metal alloy that creates strong and conductive bonds. Soldering uses include connecting pins to circuit boards or splicing cables together. Figure 4 shows a soldering iron fusing pins to a circuit board.

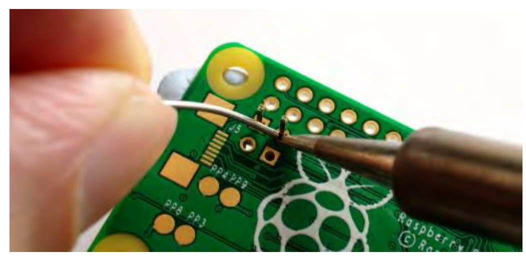


Figure 3. Soldering

Often, electrical failures are a result of a faulted connection. For example, an improperly crimped connection can open a circuit. In addition, electrical connections in agriculture are exposed to moisture and foreign materials, causing corrosion. Figure 4 shows a connector insulated with heat shrink tubing to insulate the end of a connection to prevent corrosion. Technicians use heat shrink for bundling wires and preventing short circuits across terminal connections.

Figure 4. Heat Shrink

How can circuits be assembled to prevent electrical failures? How do technicians diagnose a faulty connection?

Materials

Per group of four students:

- Basic Electrical Training Board
- Battery, 12V
- Digital multimeter (DMM)
- Electrical flux
- Electrical solder
- Fuse, 10A
- Heat shrink, ¼″ x 4″ piece
- Soldering helping hands
- Soldering iron with stand
- Wire crimpers, 12–16 ga
- Wire strippers

Per class:

- Electrical cable, various colors, 16 ga
- Electrical connectors assorted, 16 ga
- (2) Heat gun
- Heat shrink, assorted sizes

Per student:

- *Agriscience Notebook*
- *Employability Evaluation Rubric*
- *Ignition/Shutdown Schematic*
- *Logbook*
- Pen
- Safety glasses
- *Work/Repair Order Rubric*
- *Work/Repair Order Template*

Procedure

Individually review the technical skills used to prepare electrical connections. Next, work in your group to demonstrate electrical connection skills and measure voltage drop in a cable. Then in a group of four, use a schematic to construct and troubleshoot an ignition shutdown circuit.

Part One – Skill Review

Your instructor will present *Lunchbox Sessions* and demonstrate skills to strip cables, crimp connections, solder wire, and apply heat shrink. Record key information in Table 1 of *Project 4.3.4 Student Data*.

Part Two – Skill Demonstration

1. Put on safety glasses and tie back long hair.
2. Cut three 4″ sections of electrical cable.
3. Strip the cables ¼″ from each end.
4. Connect the three cables with spade connectors and electrical solder, as shown in Figure 5.
    - Crimp a **female** disconnect to the end of one cable.
    - Crimp a **male** disconnect to the end of a different cable.
    - Connect the male and female ends.
    - Solder the ends of two cables together.
    - Strip additional length as needed.

Figure 5. Cables Connections

5. Check for resistance in the cable with a DMM by placing the leads on each end of the cable.
    - A correctly spliced cable will have a resistance of 0.0Ω.
    - Use the DMM to troubleshoot your connections for faults.
    - Correct faults as necessary.
6. Cut a 4″ piece of ¼″ heat shrink tubing into one 2″ piece and two 1″ pieces.
    - Cover the entire connection if the quick disconnects are non-insulated (See Figure 1).
7. Slip the heat shrink tubing over the cable to cover points *A*, *B*, and *C* in Figure 5. Use the 2” piece to cover the soldered connection.
8. Apply heat to the heat shrink with a heat gun.
9. Answer *Part One Analysis Questions*.

Part Three – Cable Faults

Your teacher has provided a series of electrical cables with various connections. Repeat Step 5 from Part Two, Step 5 to test the cables. Record the faults and recommended repairs in Table 2.

Part Four – Circuit Construction

Your teacher will assign your group a Basic Electricity Training Board. Use the *Ignition/Shutdown Schematic* to assemble the ignition and shutdown circuit. Construct all cables and connections within the circuit using the supplied cables, connectors, heat shrink, solder, and soldering iron. Your group should test the circuit to ensure it functions as described in the criteria listed below.

Criteria
The *Ignition/Shutdown Schematic* details the ignition and shutdown circuits on a New Regent™ riding lawnmower, including two safety switches and a PTO switch that turns on the mower deck. The tractor must meet the following conditions for the engine to start.

- The operator must place their foot on the pedal for the starter to initiate.
- The PTO switch is pushed, and the clutch is disengaged.
- The operator must be seated for the engine to start and continue running.

After your teacher has checked your system for correct functionality, fault the system in three locations and switch your board with another group.

Use the schematic and a DMM to troubleshoot the other group's faulted board. Then, use the diagnostic process to find the problem and correct the error. Finally, document your repair using a *Work/Repair Order Template*. Your teacher will evaluate your work using the *Work/Repair Order Rubric* and the *Employability Evaluation Rubric*.

Conclusion

1. How does a technician check a connection for faults?

2. What impact will resistance in a connection have on a circuit?

Name____

Project 4.3.4 Student Data

Table 1. ***Skill Review***

Skill	Tools Needed	Process
Stripping a cable		
Crimping a connector		
Soldering a wire		
Cleaning a soldering iron		
Insulating with heat shrink tubing		

Part One Analysis Questions

Q1 A cable should have no resistance across connections. Why?

Q2 Did your cable have resistance? If so, where were the faults?

Q3 What is the role of the heat shrink?

Table 2. ***Skill Review***

Cable	Faults	Recommended Repairs
A		
B		
C		
D		
E		

Name____ CASE

? Problem 4.3.5 Monitoring Spray

Purpose

Agriculturalists rely upon electrical systems to monitor and apply chemical solutions to crops, turf fields, and rangelands. A basic sprayer includes a pump, applicator tank, and boom with nozzles. The pump transfers water mixed with chemicals from the tank to the boom for application. Pumps are powered using a 12V electrical system.

OEMs use transducers to monitor a sprayer. Table 1 reviews the transducers covered in *Project 4.2.5 Sensing Data*. Applicators use GPS systems to guide equipment through a field to reduce consumable costs and increase precision.

Table 1. *Transducers*

Component	Application
Ultrasonic	Ultrasonic transducers use ultrasonic waves to measure the distance from devices. Sprayers use ultrasonic sensing to guide the equipment through a field and keep equipment within rows without damaging crops. Sprayer booms are also equipped with ultrasonic sensors to position the boom above the ground.
Flowmeter	Precision spraying requires a consistent and controlled rate of liquid application. Flow meters help regulate the pump to ensure precise application.
Pressure	The pressure within a sprayer impacts the flow rate and quality of the spray. Sprayer nozzles should apply a mist of small droplets with a slight overlap between nozzles. As the pressure in a sprayer boom decreases, the droplet size increases, and the width of the spray area decreases.

What electrical components does a sprayer need to apply chemical solutions? How does an electrical system monitor transducer data?

Materials

Per group of four students:

Sprayer Parts

- Applicator tank
- Cross with quick outlet, nylon nozzle body, ½”
- Elbow with quick outlet, nylon nozzle body, ½”
- Female union, $^{5}/_{16}$″ x $^{1}/_{8}$″
- FIMCO Manifold Kit
- Hose, ¼″
- Hose, ½″
- Nozzle tips
- Nylon quick caps with gaskets
- Pump
- Teflon tape
- Tip Strainer, 50 mesh
- Various fasteners
- Various tools

Electronic System

- Construction materials provided by the teacher
- Device with internet access
- LabQuest
- Various electrical components
- Various equipment available in the agricultural shop
- Various sensors

Per student:

- *Agriscience Notebook*
- *FIMCO 30 Gallon Trailer Sprayer User Manual*
- *Guide to Assessing Problems*
- *Logbook*
- Nitrile gloves
- Pen
- Safety glasses

Task

A sports turf firm is interested in developing a sprayer that will signal pressure readings and boom height to the operator. Additionally, the firm desires the sprayer to operate within designated GPS coordinates. Finally, they would like to know the advantages and disadvantages of using an electronically monitored sprayer. The firm is concerned with the technical skill of their employees to manage the sprayer electronics and has asked your group to develop a working prototype based on the *FIMCO 30 Gallon Trailer Sprayer*.

Work with your teammates to brainstorm a prototype sprayer model. Construct a sprayer model using parts provided by your teacher and the *FIMCO 30 Gallon Trailer Sprayer User Manual*. Test the sprayer board and pump before adding electrical controls. Next, identify electrical components needed to control the prototype and to protect the circuit(s). The electrical system will monitor the sprayer and communicate pressure and boom height to the operator. The *FIMCO 30 Gallon Trailer Sprayer User Manual* outlines OEM standards. Your design and construction must meet the *Electrical System Criteria*.

Electrical System Criteria

- Sprays only when the system is within the designated GPS coordinates.
- Signals when the system pressure meets OEM standards.
- Signals when the system pressure is above or below OEM standards.
- Signals when the boom is at the OEM recommended height.
- Signals when the boom is above or below the OEM recommended height.
- All connections are properly insulated.
- Lower voltage circuits are protected from a high voltage surge.

Develop a schematic of the circuit(s) and draft a troubleshooting chart for operator use. Finally, present your final sprayer prototype design to the class as your would the sports turf firm. Highlight the following during your presentation.

- Operation
- Electrical components
- Electrical schematic
- Troubleshooting
- Maintenance
- Prototype demonstration

Your teacher will use the *Guide for Assessing Problems* to assess your presentation and prototype.

Conclusion

1. What tools does a technician need to troubleshoot a GPS sprayer?

2. What is the role of a relay in a GPS sprayer?

Name____

CASE

Lesson 4.3 Check for Understanding

1. Use Ohm's to calculate the voltage drop for the circuit in Figure 1. Record your results in Table 1.

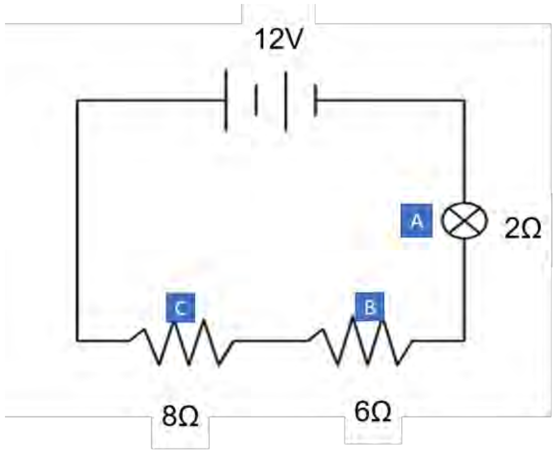


Figure 1. Circuit

Table 1. ***Voltage Drop Results***

Component	Amperage	Resistance	Voltage
A			
B			
C			

2. A technician tests a lawn tractor battery at two points. While the tractor is off, the battery voltage between the positive and negative battery posts is 12.5V. However, the reading between the positive battery post and the positive battery cable is 0.4V. What is the voltage drop, and what factors could contribute to this drop?

3. You are a technician at a local agricultural equipment dealership. A farmer brings in a utility tractor with a 12V system. The battery and alternator were both replaced three months ago, but it seems the alternator is not charging the battery. The battery and the alternator have been tested and are in good condition. List the possible faults and how to check them using a digital multimeter (DMM) below.

4. List two faults that could occur on your GPS sprayer in Table 2. For each fault, list a potential cause, correction, and how to diagnose using a DMM.

Table 2. ***GPS Sprayer Board***

Fault	Potential Cause	Correction	How to Diagnose

Name____

CASE

Lesson 4.3 Check for Understanding Answer Key

1. Use Ohm's to calculate the voltage drop for the circuit in Figure 1. Record your results in Table 1.

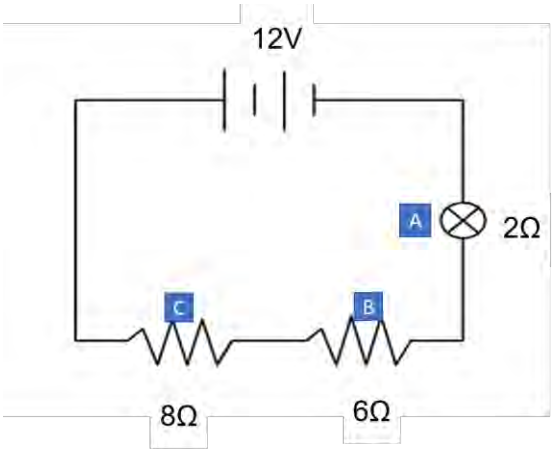


Figure 1. Circuit

Table 1. ***Voltage Drop Results***

Component	Amperage	Resistance	Voltage
A	**0.75**	**2**	**1.5V**
B	**0.75**	**8**	**4.5V**
C	**0.75**	**6**	**6V**

2. A technician tests a lawn tractor battery at two points. While the tractor is off, the battery voltage between the positive and negative battery posts is 12.5V. However, the reading between the positive battery post and the positive battery cable is 0.4V. What is the voltage drop, and what factors could contribute to this drop?

The voltage drop is 0.4V.

Factors leading to the voltage drop can include loose terminals, poor connection between the connector and cable, and corrosion of the battery cable.

3. You are a technician at a local agricultural equipment dealership. A farmer brings in a utility tractor with a 12V system. The battery and alternator were both replaced three months ago, but it seems the alternator is not charging the battery. The battery and the alternator have been tested and are in good condition. List the possible faults and how to check them with a digital multimeter (DMM) below.

Answers will vary. Students should identify faults among the connections. Faults may include poor connections, a nicked cable, corrosion, etc. Cables should be tested for continuity and voltage drop across all connections.

4. List two faults that could occur on your GPS sprayer in Table 2. For each fault, list a potential cause, correction, and how to diagnose using a DMM.

Answers will vary. Students may include faults among components, cables, transducers, or batteries. Students should list a potential cause, correction, and methods to diagnose using a DMM for each fault. Table 2 lists two example answers.

Table 2. ***GPS Sprayer Board***

Fault	Potential Cause	Correction	How to Diagnose
The sprayer activates and turns off at the wrong points	Misconnected wires at the relay	Change the wires	Check for continuity between terminals at the relay. The pump should be connected through the N.O. terminal.
The pressure transducer acts sporadically	Short in connection	Find short and repair connection or cable	Check for continuity between the end of cables and other cables. If there is continuity between cables in a harness that should not have continuity, there is a short.

GENERAL INFORMATION

DIAGRAMS

COMPONENT LOCATION AND REPLACEMENT

TROUBLESHOOTING

COMPONENT TESTS

⚠ WARNING

Before beginning any service work, turn the PTO off, set the parking brake, turn the ignition switch off, remove the key, disconnect the spark plug wire, and disconnect the negative battery cable.

GENERAL INFORMATION

The electrical system is a 12-volt, negative ground type. Power for the lights and all electrical accessories is supplied by a lead/acid-type battery which is charged by the alternator.

This section covers the location, replacement, troubleshooting, and testing procedures for the various electrical components that are not associated with the engine. Information on the engine, alternator, ignition system, and starter can be found in the engine manufacturer's instructions.

It should be noted that when portions of the electrical system are serviced, the negative battery cable should be disconnected from the battery to prevent electrical shorts and/or fires.

Section Contents

Section 7 contains the following sub-sections:

General Information – General overview of the electrical system, principles of operation, and definitions of basic electrical terms.

Exploded View Diagrams – Three-dimensional illustrations of the electrical system components.

Electrical One Line Diagrams – Schematics of the electrical system.

Linear Circuit Diagrams – Linear diagrams showing electrical current path with the ignition switch in its three positions.

Component Location and Replacement – Location of electrical components and explanations of how to remove and replace them.

Troubleshooting Flow Charts – Checklist of component tests to solve common electrical problems. Includes references to specific component test procedures.

Component Tests – Testing procedures for specific components.

Introduction

Before tackling any troublesome electrical circuit, first study the appropriate wiring diagrams to get a complete understanding of what makes up that individual circuit. Malfunctions can often be narrowed down by noting if other components, related to the circuit, are operating properly. If several components malfunction at the same time, chances are the problem is in the fuse/breaker, common splice, or ground connection that is common to all the malfunctioning components.

Electrical problems usually stem from simple causes, such as loose or corroded connections, a blown fuse, a tripped circuit breaker, or a bad relay. Visually inspect the condition of all fuses, wires, and connections in a suspected problem circuit before troubleshooting it.

Note: If testing instruments are going to be utilized, study the diagrams ahead of time to plan where the necessary connections will be made in order to accurately pinpoint the trouble spot.

Before attempting to locate a problem with test instruments, use the wiring diagram(s) to decide where to make the connections.

TYPICAL TOOLS NEEDED

- VOM (volt-ohm meter, multi-meter, or equivalent).
- Test Light (circuit tester or continuity tester).
- Jumper wires with alligator clips at both ends.
- Power Supply (variable or 12VDC) or 12VDC Battery.
- Hydrometer.
- Wire Brush or Battery Terminal Brush.
- Clean Pencil Eraser.
- Standard Wrench Set.
- Standard Socket Set.
- Screwdriver Set.

System Description

All Legacy tractor models have five basic electrical circuits, with exception of the diesel model which has six circuits, that represent the different electrical functions of the tractor's electrical system. Each function corresponds to the three positions of the ignition switch: "START," "ON," and "OFF."

- START sends battery power to two sub-circuits:

  1) Sends power to the safety switches (PTO, foot pedal, and seat switches). If all safety switches are closed, the solenoid is activated sending power to the starter.

  2) Sends power to the fuel solenoid, PTO clutch circuit, etc.

- RUN sends battery power to two sub-circuits:

  1) Connects the alternator to the battery through the ignition switch. The alternator coil feeds power back into the battery for recharging.

  2) Sends power to the fuel solenoid and PTO clutch switch.

- OFF grounds the engine ignition coil through the ignition switch, preventing ignition system sparking. The safety interlock system creates its own “OFF” circuit if an unsafe situation exists. The safety system grounds the ignition coil using a combination of:

  1) the PTO switch and seat switch

  or

  2) the brake pedal switch and seat switch
  if an operator is not present in the seat.

Principles of Operation

IGNITION SHUTDOWN SYSTEM

When the ignition switch is in the “START” or “RUN” position, the ignition circuit is open, allowing the engine to run.

When the ignition switch is turned to “OFF,” the engine is shut off by the following:

Air-Cooled Engines

The ignition switch closes, which grounds the ignition coil.

Liquid-Cooled Engines

The ignition switch opens, which shuts off power to the ignition coil.

Diesel Engines

The ignition switch opens, which shuts off power to the fuel pump and solenoid.

CHARGING SYSTEM

While the engine is running, current flows from the alternator to the positive battery post and charges the battery.

CRANKING SYSTEM

The cranking system is composed of the ignition switch, the safety interlock switches, the PTO switch, the solenoid, and the starter.

Cranking system current path:

1. Current travels from the battery through the circuit breaker, through the ignition switch, through the safety switches to the solenoid.
2. If all safety conditions are met, the safety interlock switches allow current to pass through the solenoid, activating the solenoid. The activated solenoid sends power to the starter, cranking the engine.

Safety Interlock System

The safety system can be divided into two sub-systems:

1. the Operator Present sub-system and
2. the Safety Starting sub-system.

Operator Present Sub-System

The operator present sub-system is designed to protect the operator from injury if the operator would leave the seat.

1. **Engine should shut off when the operator rises off the seat if ANY of the following conditions exist:**
   A. Brake pedal is not depressed.
   B. PTO clutch switch is engaged.
   C. Cruise control lever is engaged.
2. **Engine should remain on when the operator rises off the seat ONLY if ALL of the following conditions are met:**
   A. Brake pedal is fully depressed (or parking brake set).
   B. Electric clutch switch disengaged.
   C. Cruise control lever is not engaged.

Safety Starting Sub-System

The safety starting sub-system will prevent the engine from cranking if any of the following conditions exist.

1. **Engine should NOT crank if ANY of the following conditions exist:**
   A. PTO clutch switch is engaged.
   B. Brake pedal is not depressed.
   C. Cruise control lever is engaged.
2. **Engine should crank ONLY if ALL of the following conditions are met:**
   A. Electric clutch switch disengaged.
   B. Brake pedal is fully depressed (or parking brake set).
   C. Cruise control lever is not engaged.

Checking Out the System

GENERAL

Both the ignition and charging systems are internal to the tractor engine. Refer to Section 2, TROUBLESHOOTING, or your engine manual for information. See an authorized dealer or appropriate service manual for additional engine troubleshooting information.

BASIC ELECTRICAL TERMS

“Ground” is the negative battery post or any other conductive part of the frame. For best results, use the negative battery post as ground.

“VOM” is a volt-ohm meter, multi-meter, or equivalent.

“VDC” is volts of direct current or the VOM setting used to measure DC voltage.

“Ohm” is units of resistance or the VOM setting used to measure resistance.

“Continuity” is a continuous, unbroken circuit. In this manual continuity is determined with a VOM set to measure ohm. Zero ohm is true continuity. However, due to contact point corrosion and resistance within wires, continuity may measure a few ohm.

“No Continuity” is a broken circuit. In this manual no continuity is determined with a VOM set to measure ohm. No continuity will register as infinite ohm.

“Battery Voltage” is the approximate voltage output of the battery. Keep in mind that “battery voltage” tested at any component will be slightly lower than “battery voltage” tested at the battery terminals due to resistance within connections and wires.

Wiring Diagrams

Since it isn’t possible to include all wiring diagrams for every year covered by this manual, the following diagrams are those that are typical and most commonly needed.

Lower Wiring Harness (All Models)

NOTE: Unless noted otherwise, use the standard hardware torque specification chart.

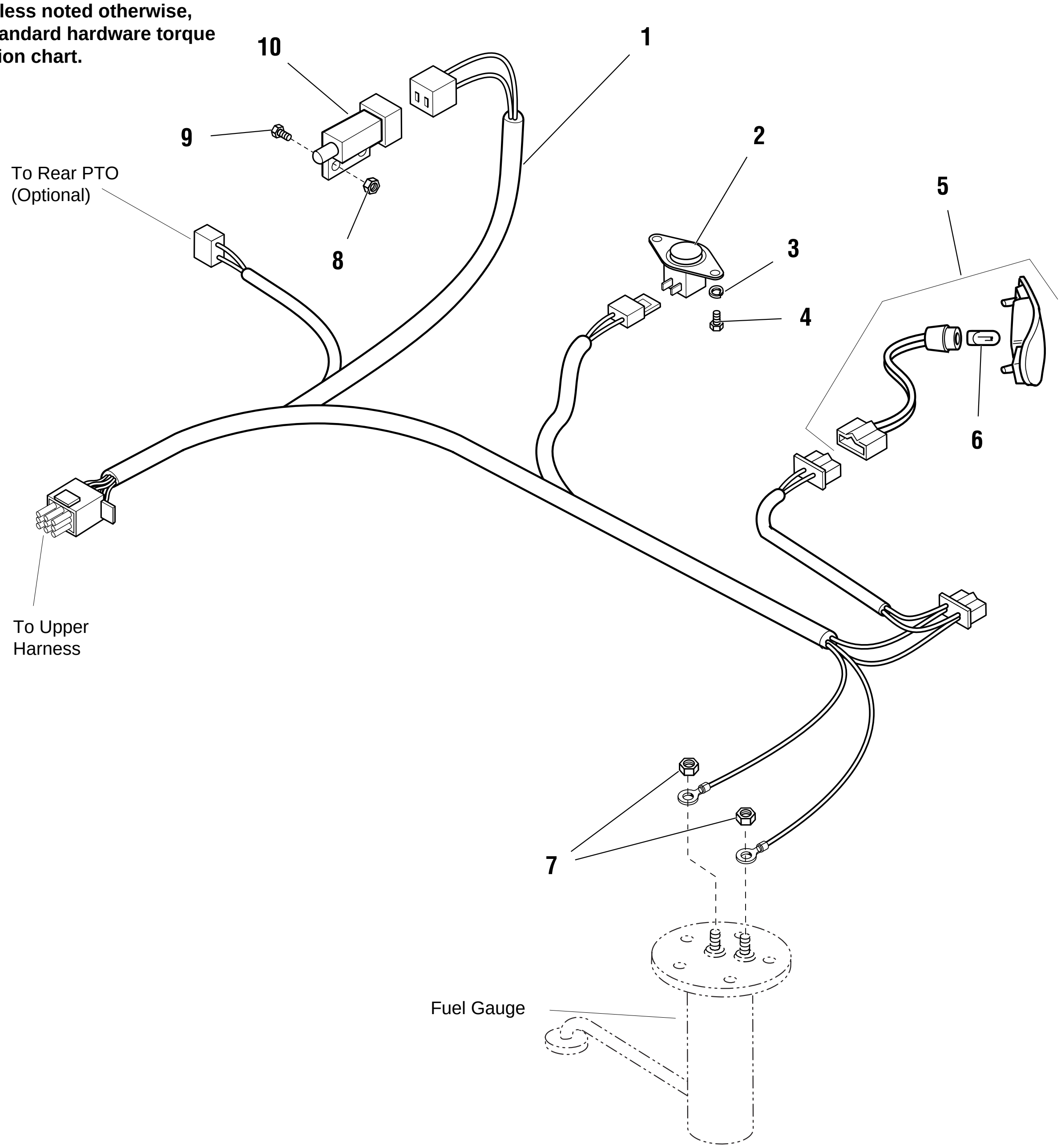


Figure 1. Exploded View Diagram – Lower Wiring Harness (All Models)

REF NO.	QTY.	DESCRIPTION
1	1	HARNESS, Rear
2	1	SWITCH, Seat
3	2	LOCKWASHER
4	2	CAPSCREW
5	2	TAIL LIGHT ASSEMBLY
6	2	BULB, Tail Light
7	2	NUT, Hex Flange
8	2	NUT, KEPS Lock
9	2	CAPSCREW
10	1	SWITCH, Cruise

NOTE: Unless noted otherwise, use the standard hardware torque specification chart.

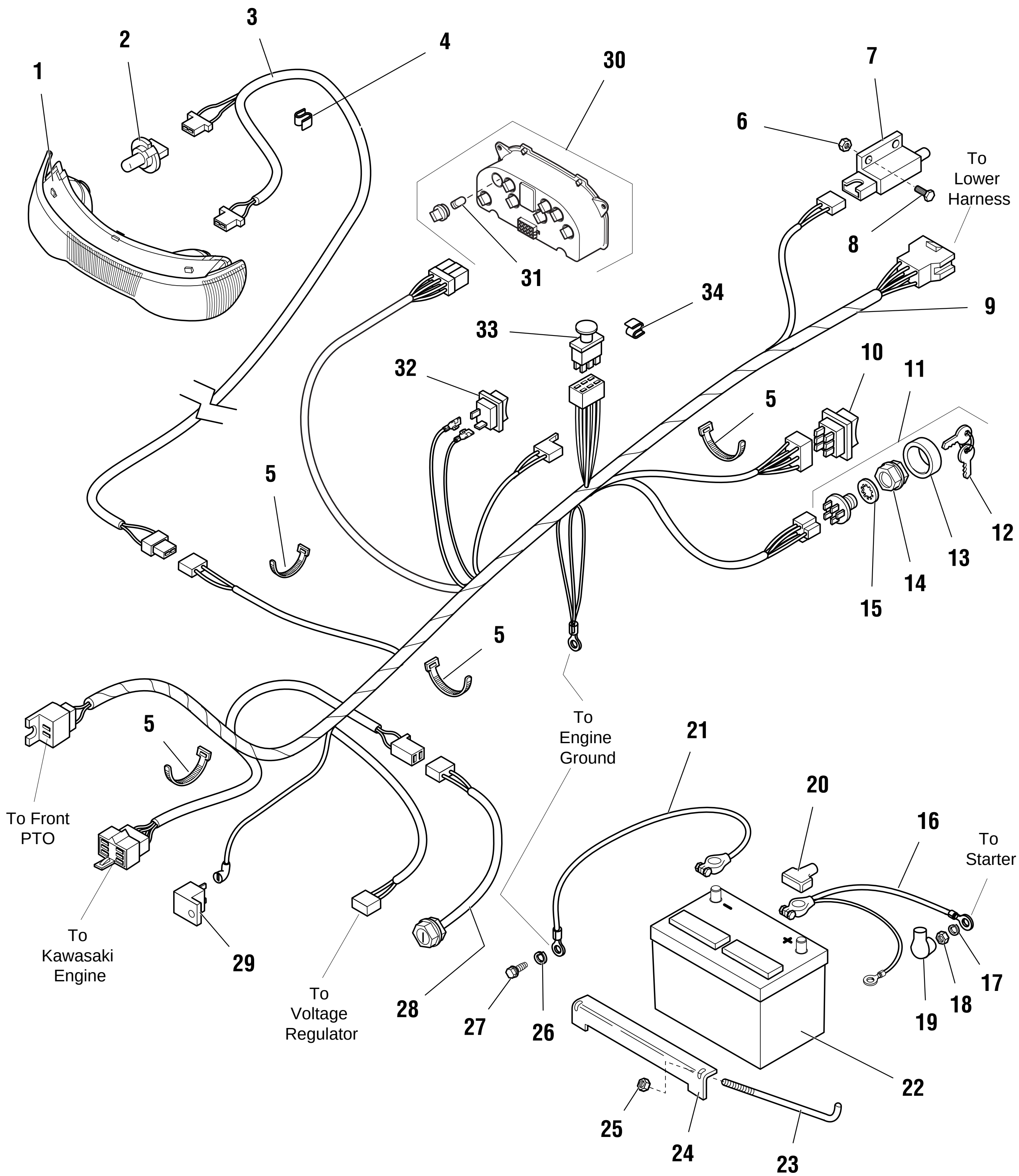


Figure 2. Exploded View Diagram – Upper Wiring Harness (Liquid-Cooled Engine Models)

Upper Wiring Harness (Liquid-Cooled Engine Models)

REF NO.	QTY.	DESCRIPTION
1	1	BEZEL, Headlight
2	2	BULB, Headlight, Halogen
3	1	HARNESS, Headlight
4	1	CLIP
5	7	TIE
6	2	NUT, KEPS Lock
7	1	SWITCH, Interlock (NO/NO)
8	2	CAPSCREW
9	1	HARNESS, Main
10	1	SWITCH, Mower Height Adjust
11	1	SWITCH & KEY ASSEMBLY (Includes Ref 12 thru 15)
12	1	KEYS (Set of 2)
13	1	COVER, Key Switch
14	1	NUT, Hex Flange
15	1	WASHER, Internal Tooth
16	1	CABLE, Battery to Starter
17	1	LOCKWASHER
18	1	NUT, Hex Jam
19	1	COVER, Starter Terminal
20	1	COVER, Positive Battery Terminal
21	1	CABLE, Battery to Ground
22	1	BATTERY
23	2	ROD, Battery Hold-Down
24	1	BRACKET, Battery
25	2	NUT, Hex, Nylon Lock
26	1	LOCKWASHER
27	1	CAPSCREW
28	1	HARNESS, Power Outlet
29	1	CIRCUIT BREAKER
30	1	INSTRUMENT PANEL
31	8	BULB, Instrument Panel
32	1	SWITCH, Headlights
33	1	SWITCH, Front PTO
34	1	CLIP

NOTE: Unless noted otherwise, use the standard hardware torque specification chart.

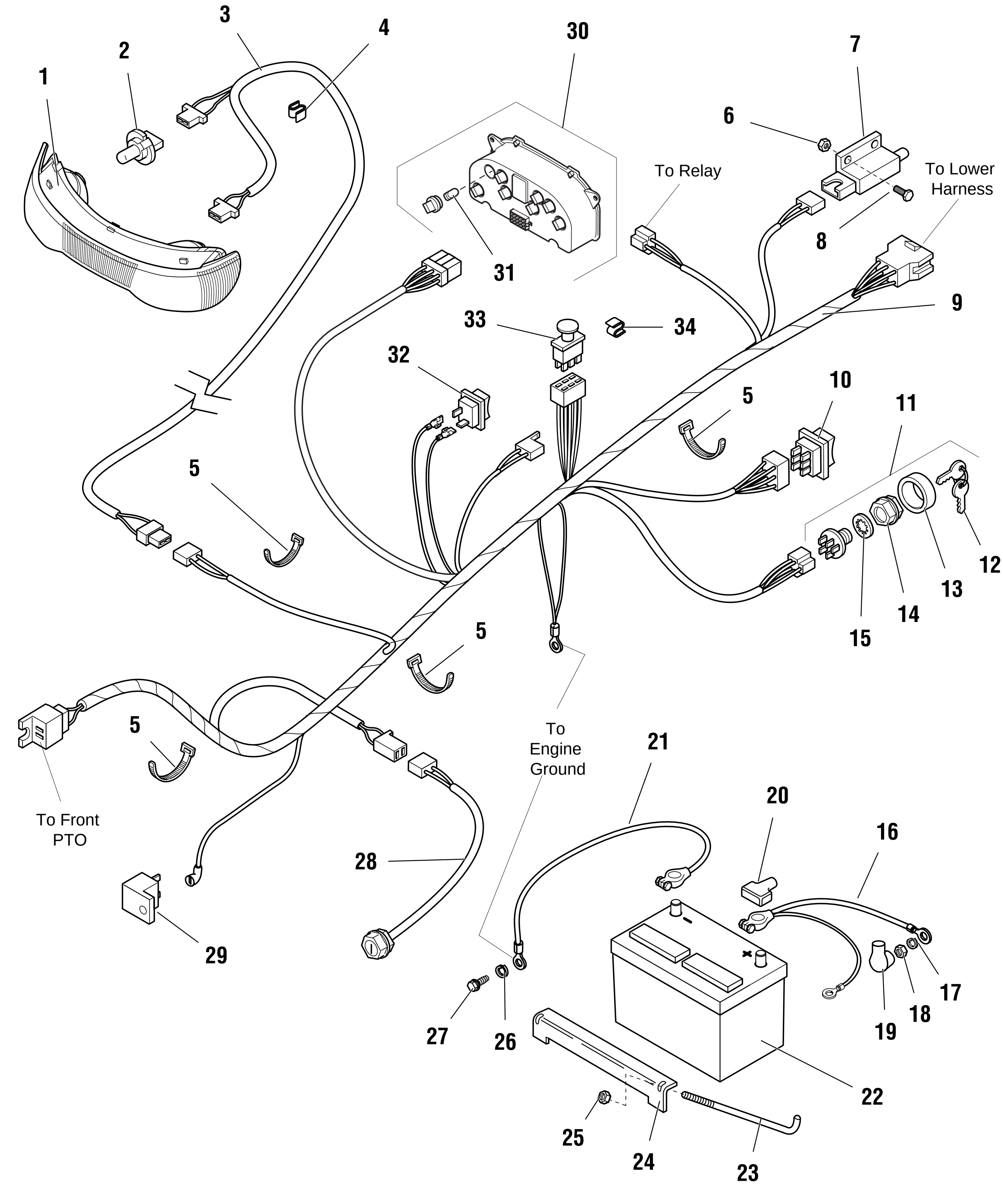


Figure 3. Exploded View Diagram – Upper Wiring Harness (Air-Cooled Engine Models)

Upper Wiring Harness (Air-Cooled Engine Models)

REF NO.	QTY.	DESCRIPTION
1	1	BEZEL, Headlight
2	2	BULB, Headlight, Halogen
3	1	HARNESS, Headlight
4	1	CLIP
5	7	TIE
6	2	NUT, KEPS Lock
7	1	SWITCH, Interlock (NO/NC)
8	2	CAPSCREW
9	1	HARNESS, Main
10	1	SWITCH, Mower Height Adjust
11	1	SWITCH & KEY ASSEMBLY (Includes Ref 12 thru 15)
12	1	KEYS (Set of 2)
13	1	COVER, Key Switch
14	1	NUT, Hex Flange
15	1	WASHER, Internal Tooth
16	1	CABLE, Battery to Starter
17	1	LOCKWASHER
18	1	NUT, Hex Jam
19	1	COVER, Starter Terminal
20	1	COVER, Positive Battery Terminal
21	1	CABLE, Battery to Ground
22	1	BATTERY
23	2	ROD, Battery Hold-Down
24	1	BRACKET, Battery
25	2	NUT, Hex, Nylon Lock
26	1	LOCKWASHER
27	1	CAPSCREW
28	1	HARNESS, Power Outlet
29	1	CIRCUIT BREAKER
30	1	INSTRUMENT PANEL
31	8	BULB, Instrument Panel
32	1	SWITCH, Headlights
33	1	SWITCH, Front PTO
34	1	CLIP

NOTE: Unless noted otherwise, use the standard hardware torque specification chart.

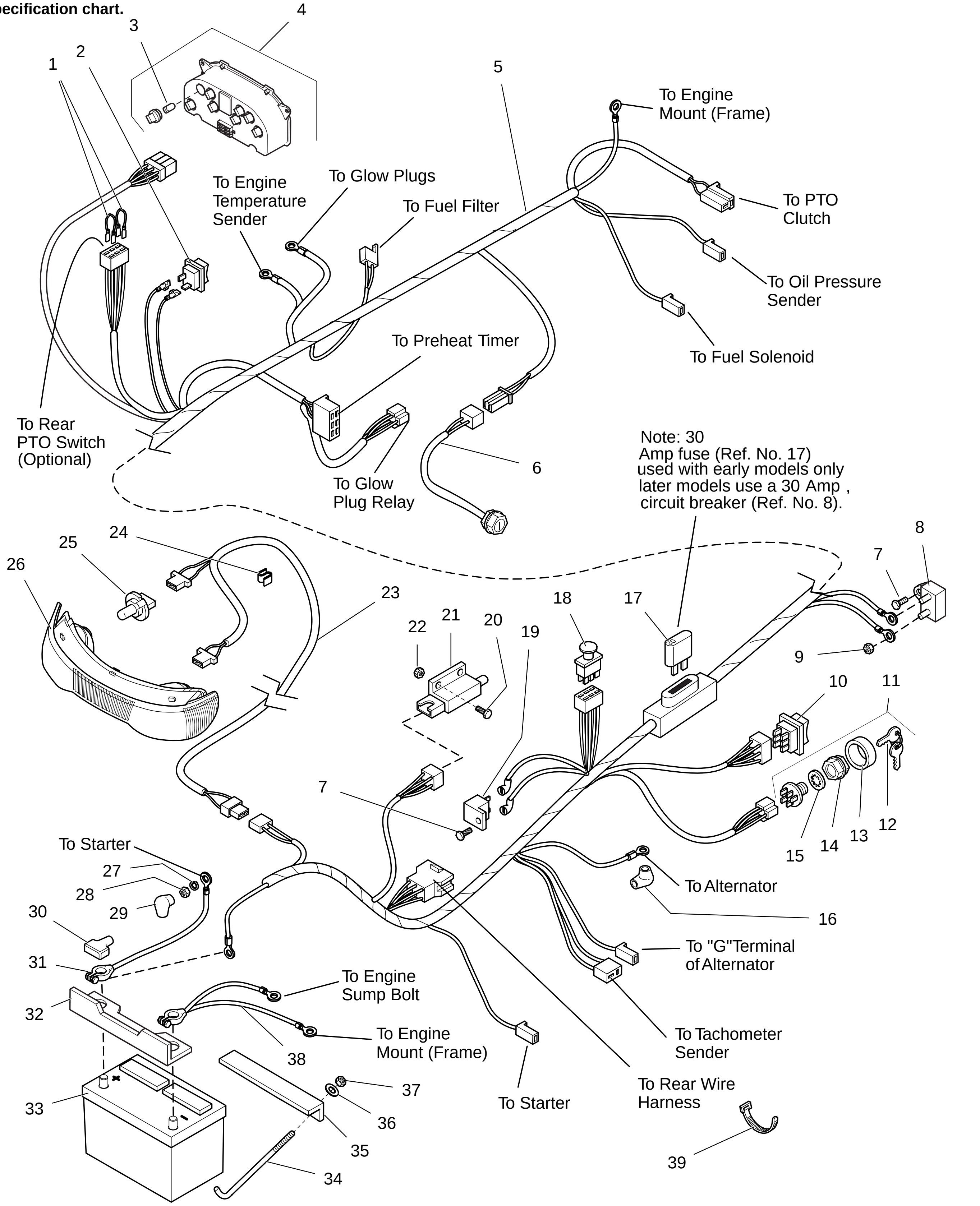
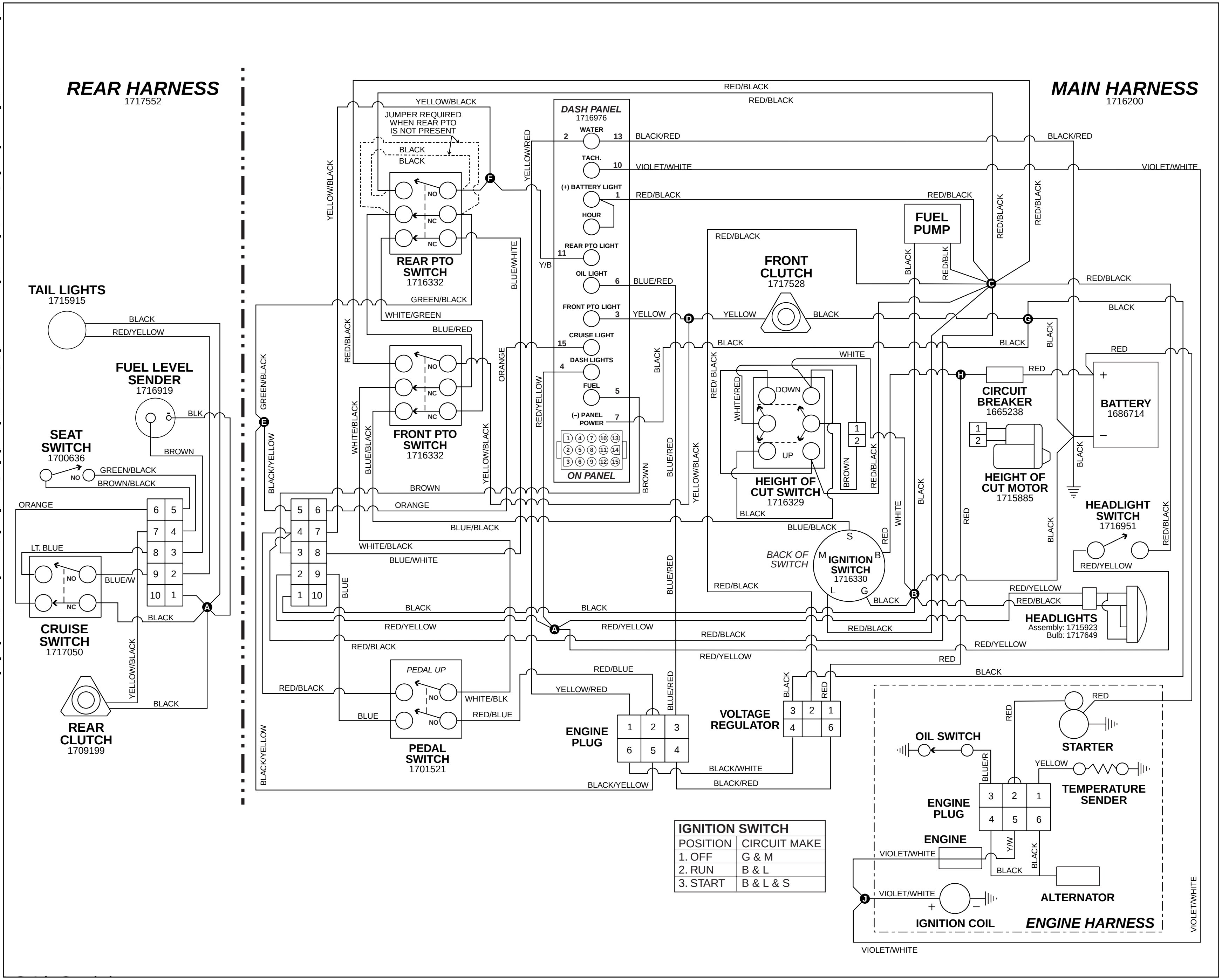


Figure 4. Exploded View Diagram – Upper Wiring Harness (Diesel Engine Models)

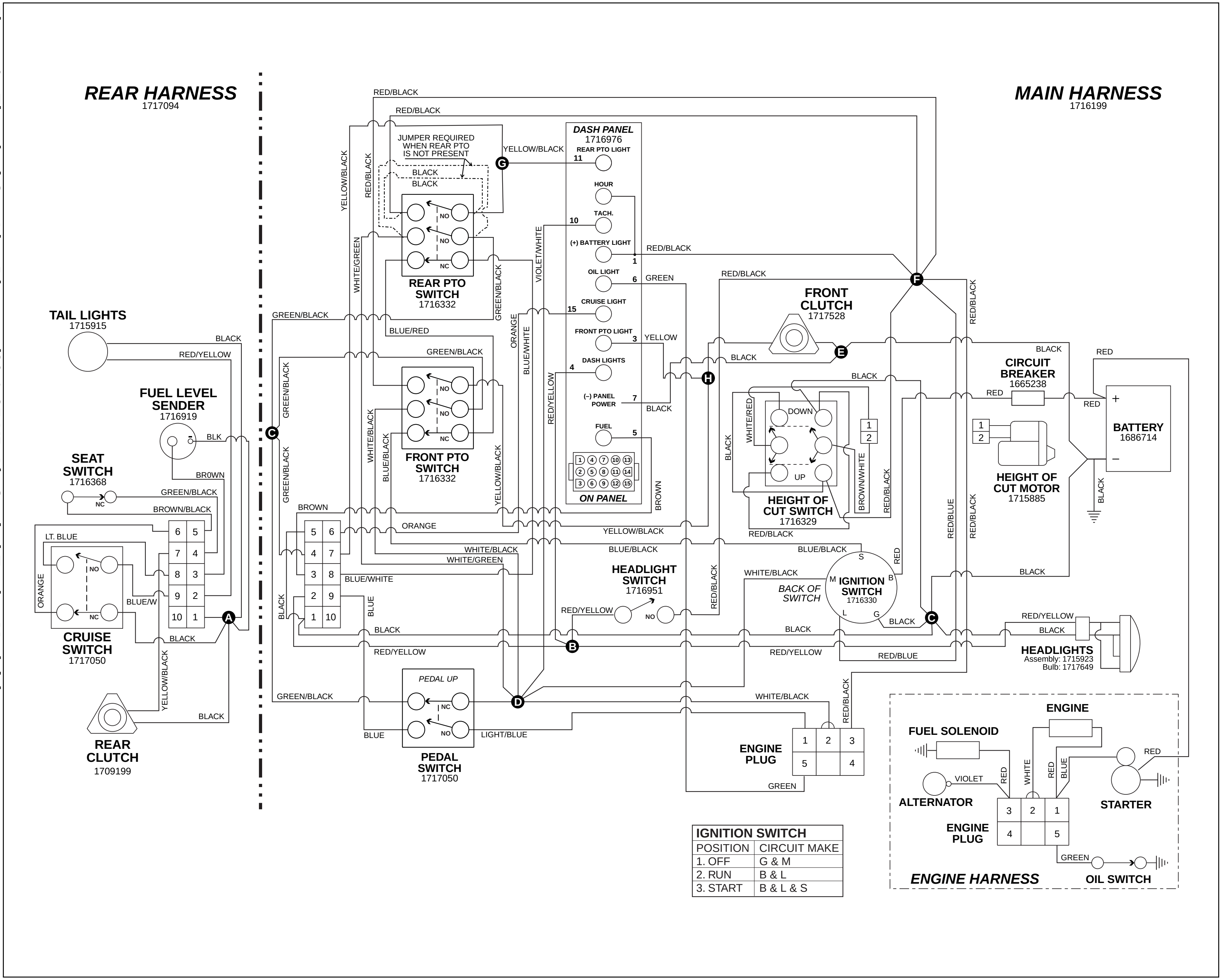
Upper Wiring Harness (Diesel Engine Models)

REF NO.	QTY.	DESCRIPTION
1	2	JUMPER
2	1	SWITCH, Headlights
3	8	BULB, Instrument Panel
4	1	INSTRUMENT PANEL, Diesel
5	1	WIRE HARNESS, Main
6	1	HARNESS, Power Outlet
7	4	FASTENER, Panel
8	1	CIRCUIT BREAKER, 30 Amp (Later Models Only)
9	4	NUT, Hex Flange
10	1	SWITCH, Mower Height Adjust
11	1	SWITCH & KEY ASSEMBLY (Includes Ref 12 thru 15)
12	1	KEYS (Set of 2)
13	1	COVER, Key Switch
14	1	NUT, Hex Flange
15	1	WASHER, Internal Tooth
16	1	COVER, Terminal
17	1	FUSE, 30 Amp, Automotive (Early Models Only)
18	1	SWITCH, Front PTO
19	1	BREAKER, Circuit
20	2	CAPSCREW
21	1	SWITCH, Interlock (NO/NO)
22	2	NUT, Hex Lock
23	1	HARNESS, Headlight
24	1	CLIP
25	2	BULB, Headlight, Halogen
26	1	BEZEL, Headlight
27	1	LOCKWASHER
28	1	NUT, Hex Jam
29	1	COVER, Starter Terminal
30	1	COVER, Positive Battery Terminal
31	1	CABLE, Battery to Starter
32	1	GUARD, Battery
33	1	BATTERY
34	2	ROD, Battery Hold-Down
35	1	BRACKET, Battery
36	2	WASHER, Plain
37	2	NUT, Hex, Nylon Lock
38	1	CABLE, Battery to Ground
39	7	TIE



IGNITION SWITCH	
POSITION	CIRCUIT MAKE
1. OFF	G & M
2. RUN	B & L
3. START	B & L & S

Figure 5. Electrical One Line Diagram (20 HP Liquid-Cooled Engine Models)



IGNITION SWITCH	
POSITION	CIRCUIT MAKE
1. OFF	G & M
2. RUN	B & L
3. START	B & L & S

Figure 6. Electrical One Line Diagram (20 & 25 HP Air-Cooled Engine Models)

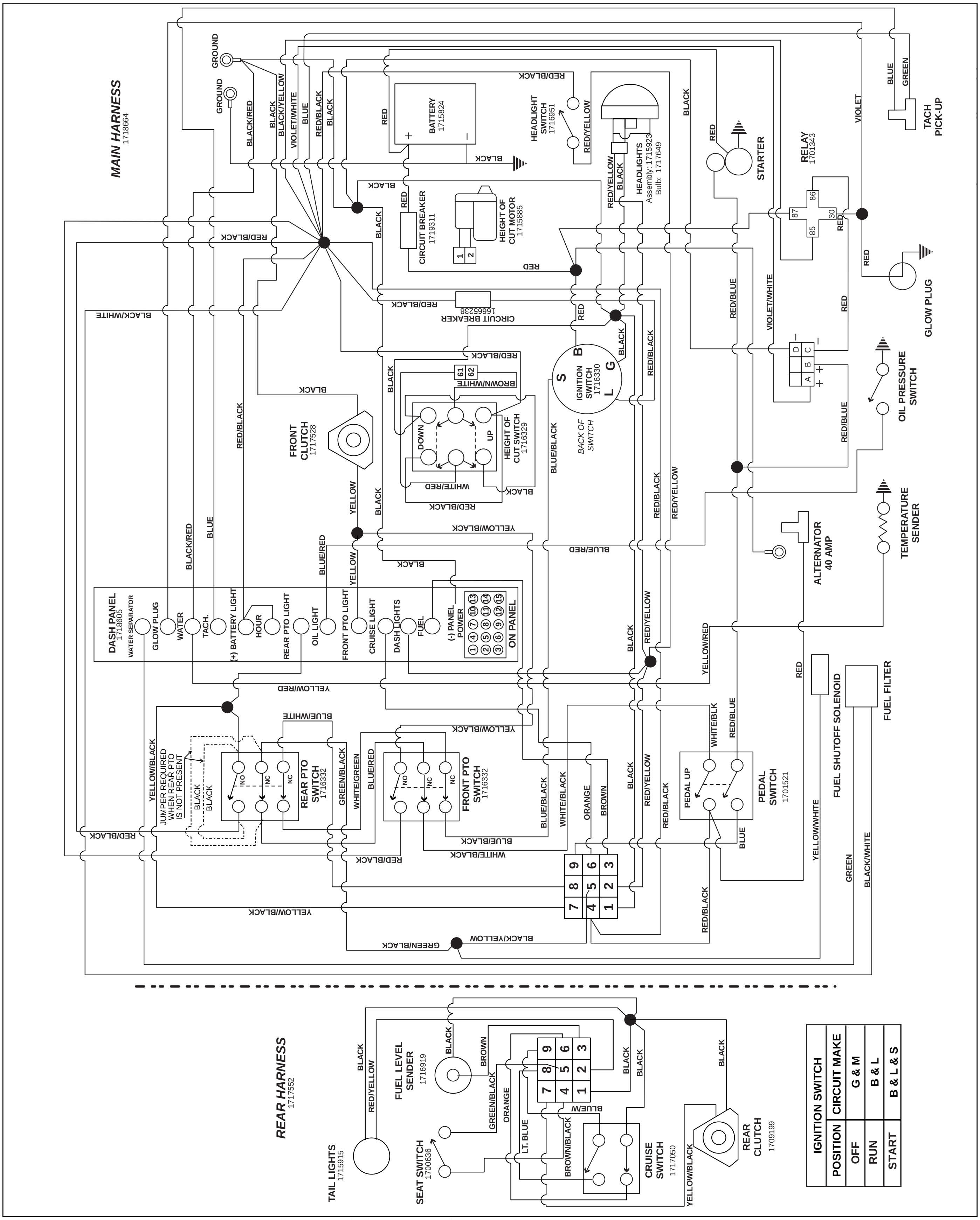


Figure 7. Electrical One Line Diagram (Diesel Engine Models)

LINEAR CIRCUIT DIAGRAMS

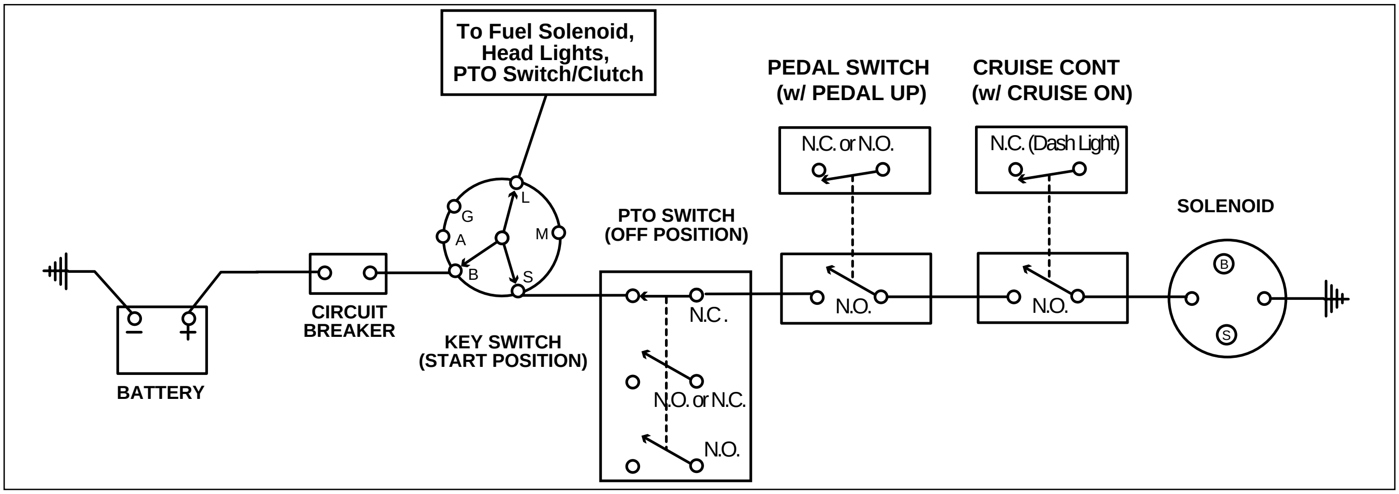


Figure 8. Typical Cranking Linear Circuit Diagram (All Models)

CRANKING CIRCUIT

See Figure 8.

The cranking circuit is only active when the ignition key switch is in the start position.

Power is supplied through the circuit breaker to the B terminal of the ignition switch. When the switch is turned to the start position, contacts are closed between the B - L terminals and B - S terminals of the ignition switch.

The B - S connection applies power to the starter solenoid. This circuit contains safety interlock components that will prevent the tractor from starting if all interlocks are not met.

The B - L connection applies power to the ignition system and other electrical components.

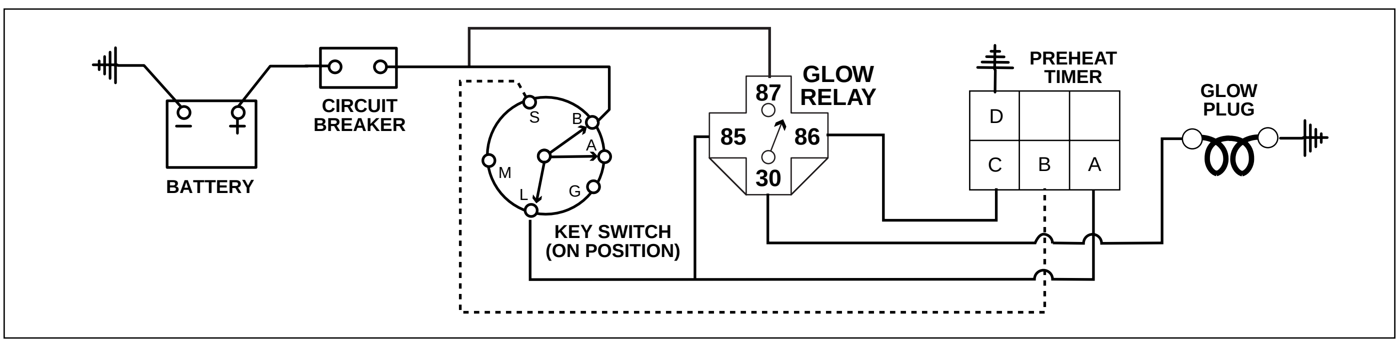


Figure 9. Preheat Linear Circuit Diagram (24.5 HP Diesel Models Only)

PREHEAT CIRCUIT

See Figure 9.

The preheat circuit is only active when the ignition key switch is first placed in the “RUN” (ON) or “START” position. The purpose is to supply current to the glow plug for a timed duration before the engine is started. This allows the glow plugs to heat up to a point that will ignite the compressed fuel.

Power is supplied through the circuit breaker to the B terminal of the ignition switch. When the switch is turned to the “ON” position, contacts are closed between the B - L terminals of the ignition switch.

The B - L connection applies power to terminal 85 of the glow plug relay and terminal A of the preheat timer. At the time when terminal A of the preheat timer is energized, a contact in the preheat timer is closed, connecting terminals C and D. This provides a path to ground for terminal 86 of the glow plug relay through the preheat timer, which energizes the glow plug relay. This closes the contact between terminals 87 and 30, which allows the glow plug to heat up.

The preheat timer will keep the glow plug relay energized for a duration of time as specified by the timer, the ignition key switch is turned off, or when terminal B is energized by turning the ignition key to the “START” position.

CHARGING CIRCUIT

See Figure 10.

The charging circuit is always active, regardless of the position of the ignition switch. The charging circuit is controlled and protected by the voltage regulator which is housed in the alternator. The voltage regulator protects the tractors electrical system by regulating the power output of the alternator, preventing excessive current draw and reverse power feed.

The alternator charges and equalizes the battery after each start and supplies the tractors electrical devices with power during operation.

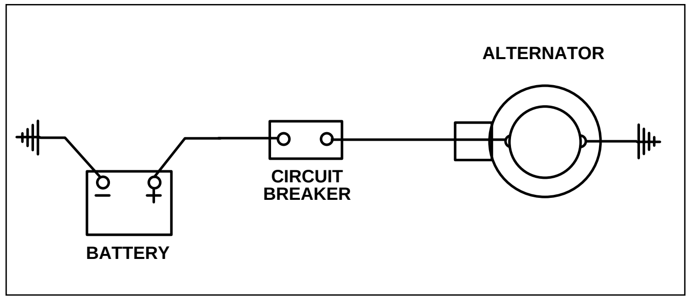


Figure 10. Typical Charging Linear Circuit Diagram (All Models)

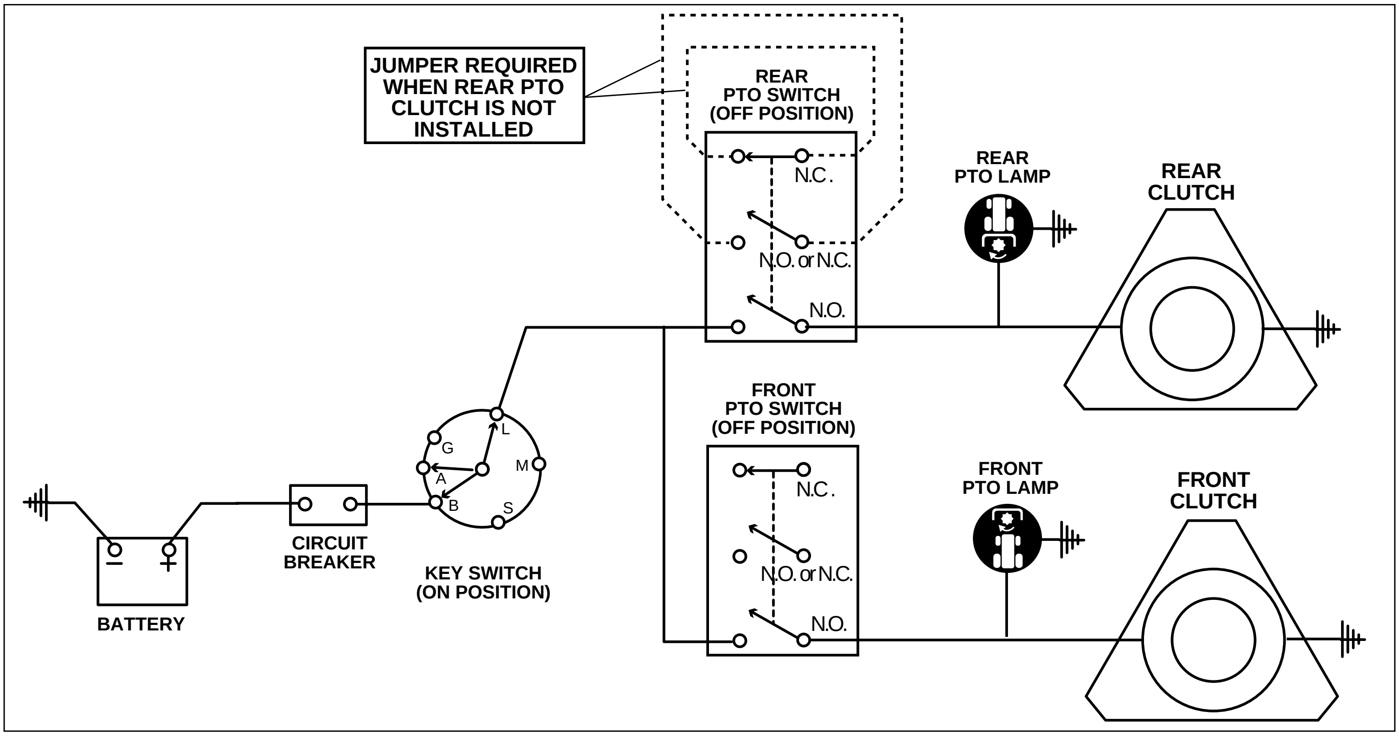


Figure 11. Typical PTO Clutch Linear Circuit Diagram (All Models)

PTO CLUTCH CIRCUIT

See Figure 11.

The PTO clutch circuit becomes active only when the PTO clutch is engaged, which occurs when the PTO clutch switch is engaged (pulled up). Power to the PTO clutch circuit comes from the ignition key switch when it is in the “RUN” (ON) position.

When either PTO clutch switch is depressed the clutch is energized, causing the clutch to engage and drive the attachment connected to the tractor. When the PTO clutch is engaged, the same power that is energizing the clutch is connected to the PTO clutch indicator lamp on the instrument panel.

NOTE: When there is not a rear PTO clutch installed, jumpers will need to be installed on the connector for the rear PTO clutch switch.

IGNITION SHUTDOWN CIRCUIT

See Figures 12 and 13.

Ignition shutdown occurs when the ignition key switch is turned to the “OFF” position or the safety system kills the engine.

When the ignition shutdown occurs, the engine is stopped by the following:

Air-Cooled Models – the magneto is grounded through the ignition key switch (Figure 12).

Diesel Models – power is removed from the fuel injection pump (Figure 13).

Liquid-Cooled Models – power is removed from the ignition coil (Figure 13).

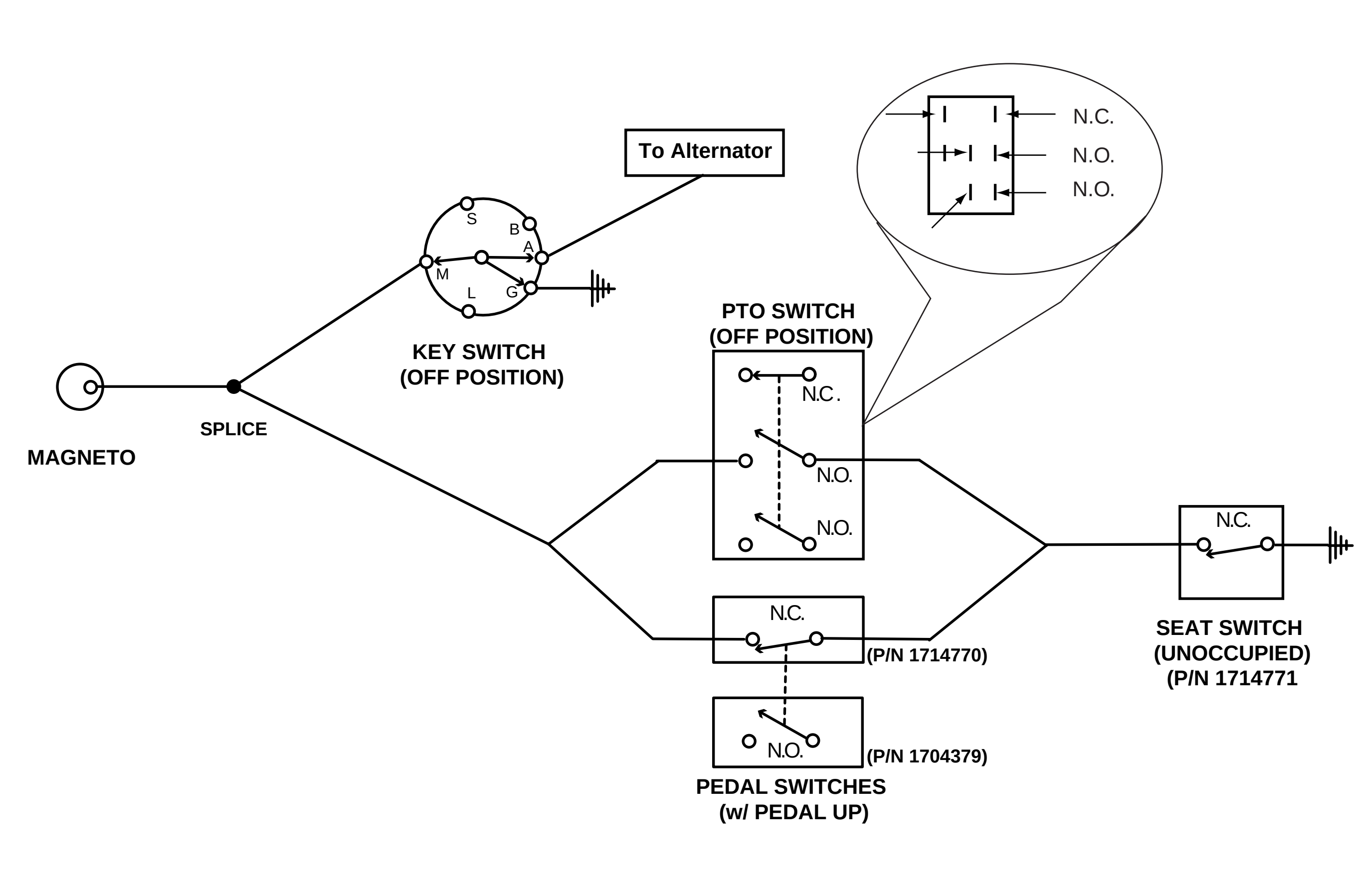


Figure 12. Typical Ignition Shutdown Linear Circuit Diagram (Air-Cooled Models)

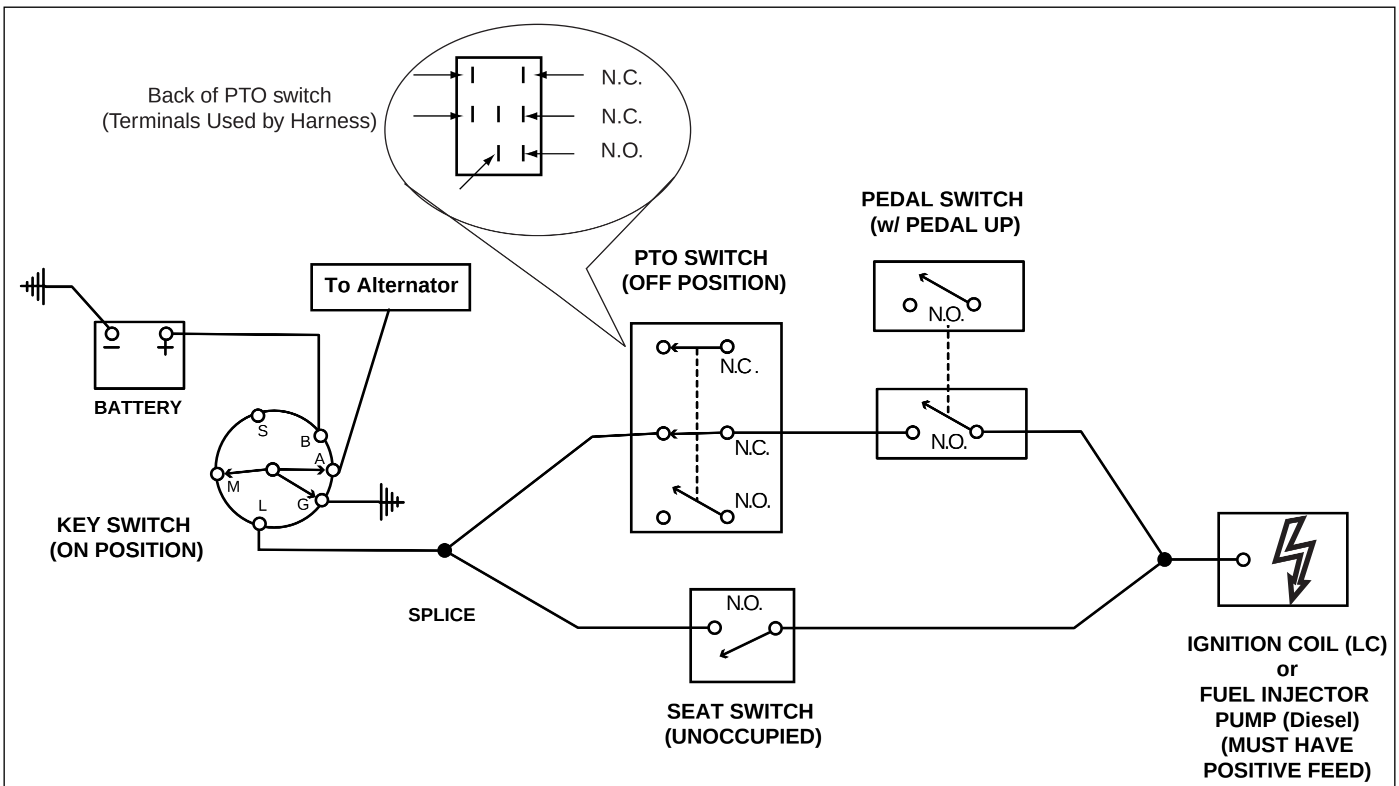


Figure 13. Typical Ignition Shutdown Linear Circuit Diagram (Liquid-Cooled and Diesel Models)

COMPONENT LOCATION AND REPLACEMENT

NOTE: Most models do not require the dashboard to be removed for component replacement or service. If it is required, refer to Section 14, HOOD, DASH, & FOOT REST SERVICE.

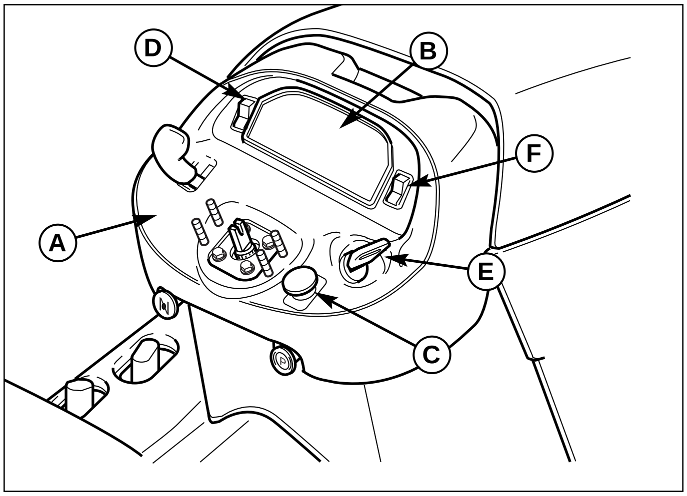


Figure 14. Dashboard Components

A	**Dashboard**	**D.**	**Headlight Switch**
B.	**Instrument Panel**	**E.**	**Ignition Key Switch**
C.	**PTO Switch**	**F.**	**Height of Cut Switch**

HEADLIGHT SWITCH

The headlight switch (D, Figure 14) is located in the dashboard (A) on the left-hand side.

1. Disconnect and secure the negative battery cable, (see Section 6, COMMON SERVICE PROCEDURES).
2. Unplug the wire harness (B, Figure 15) from the back of the switch (C).
3. From behind the dashboard, push in the locking tabs (D) and remove the switch as shown in Figure 35.

NOTE: Be careful to not press on the tabs that hold the contact block to the switch rocker. The parts in the contact block are very small and could get lost if separated.

4. Install headlight switch in reverse order of removal.

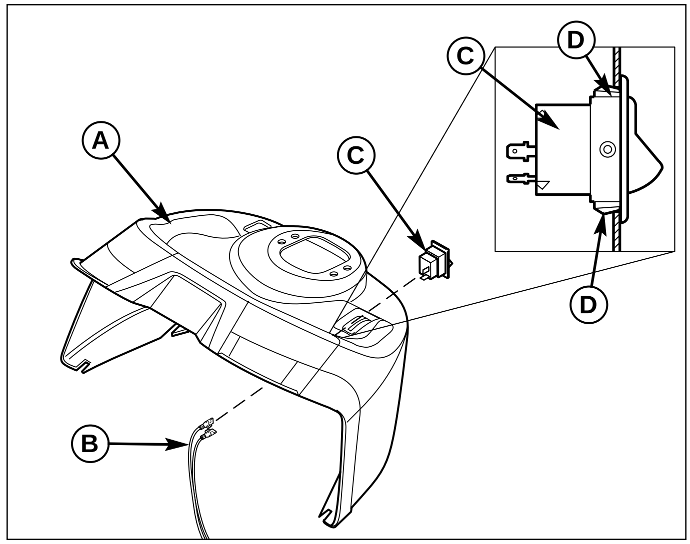


Figure 15. Headlight Switch Replacement

A	**Dashboard**	**C.**	**Headlight Switch**
B.	**Wire Harness**	**D.**	**Locking Tabs**

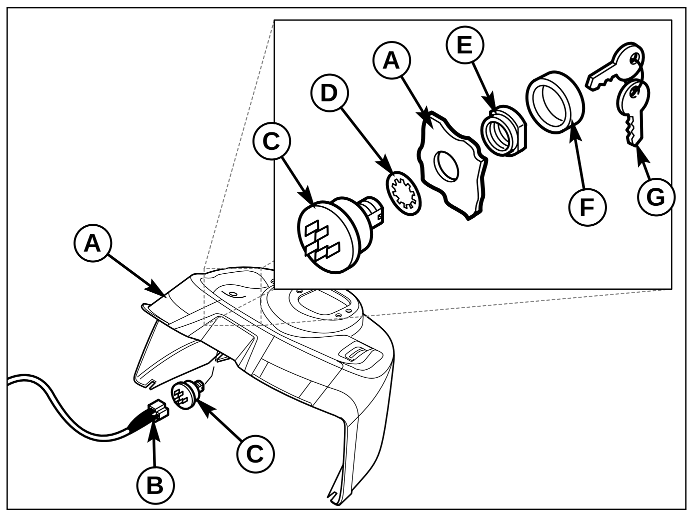


Figure 16. Ignition Key Switch Replacement

A	**Dashboard**	**E.**	**Key Switch Nut**
B.	**Wire Harness**	**F.**	**Cap**
C.	**Ignition Key Switch**	**G.**	**Keys**
D.	**Washer**		

IGNITION KEY SWITCH

The ignition key switch is located in the dashboard on the right-hand side of the steering wheel.

1. Remove the key (G, Figure 16) from the switch if not already done so.
2. Disconnect and secure the negative battery cable, (see Section 6, COMMON SERVICE PROCEDURES).
3. Unplug the wire harness (B) from the back of the ignition key switch (C).
4. Remove the cap (F) using a screwdriver or pliers.
5. Remove the key switch nut (E) from the switch.
6. Remove the switch (C) from the back of the dashboard (A).
7. Reinstall ignition key switch in reverse order of removal.

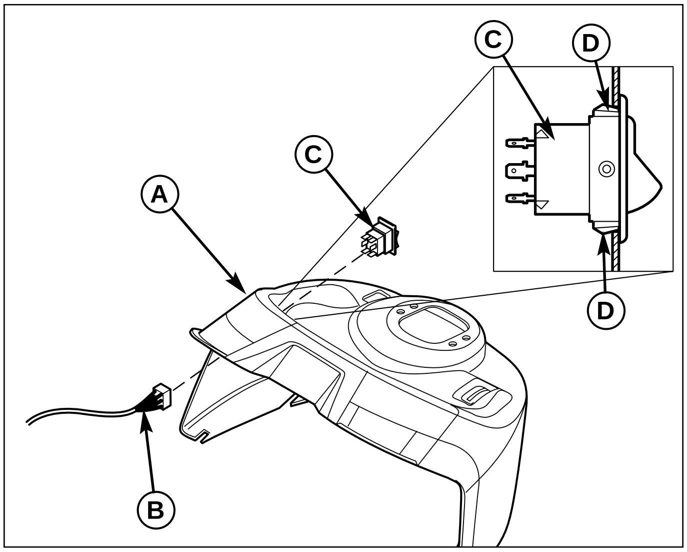


Figure 17. Height of Cut Switch Replacement
A Dashboard **C. Height of Cut Switch**
B. Wire Harness **D. Locking Tabs**

HEIGHT OF CUT SWITCH

The height of cut switch is located in the dashboard on the right-hand side of the steering wheel. The height of cut switch sends power to the outlet under the left foot rest.

1. Disconnect and secure the negative battery cable, (see Section 6, COMMON SERVICE PROCEDURES).
2. Unplug the wire harness (B, Figure 17) from the back of the height of cut switch (C).
3. From behind the dashboard, push in the locking tabs (D) and remove the switch as shown in Figure 17.

NOTE: Be careful to not press on the tabs that hold the contact block to the switch rocker. The parts in the contact block are very small and could get lost if separated.

4. Install height of cut switch in reverse order of removal.

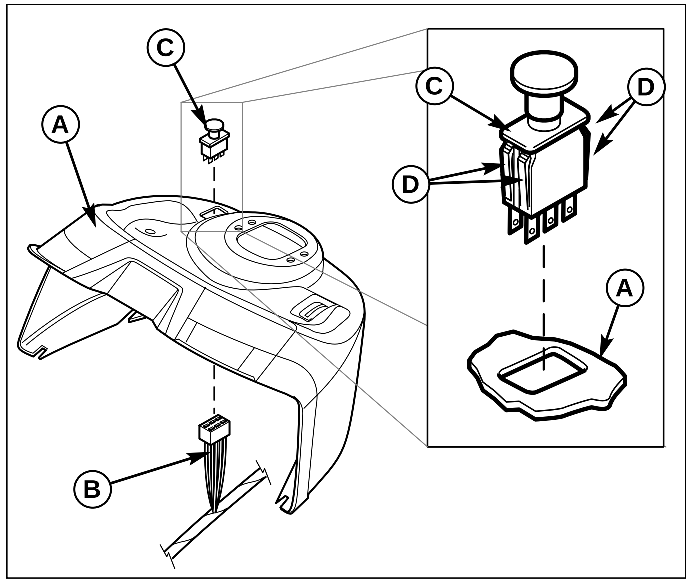


Figure 18. PTO Switch Replacement
A Dashboard **C. PTO Switch**
B. Wire Harness **D. Locking Tabs**

PTO SWITCH

The PTO switch (C, Figure 38) is located in the dashboard (A) on the right-hand side of the steering wheel.

1. Disconnect and secure the negative battery cable, (see Section 6, COMMON SERVICE PROCEDURES).
2. Unplug the wire harness (B, Figure 18) from the back of the switch (C).
3. From behind the dashboard, push in the locking tabs (D) and remove the switch as shown in Figure 18.
4. Install PTO switch in reverse order of removal.

INSTRUMENT PANEL

The instrument panel (B, Figure 39) is located in the dashboard (A) directly above the steering wheel. The instrument panel contains the RPM gauge, temperature gauge, and warning/status lights. Other than the light bulbs, the instrument panel contains no replaceable parts and is serviced as an assembly.

If necessary, refer to Section 8, POWER STEERING SERVICE, for the procedure to remove the steering wheel and dashboard before attempting to remove the instrument panel.

1. Disconnect and secure the negative battery cable, (see Section 6, COMMON SERVICE PROCEDURES).
2. Unplug the wire harness connector (D, Figure 19) from the back of the instrument panel (B).
3. Remove the four screws (C) that are securing the instrument panel to the dash.
4. Remove the instrument panel from the back of the dash.
5. Install instrument panel in reverse order of removal.

INSTRUMENT PANEL LAMPS

The instrument panel warning/status lights are illuminated by individual lamps. On 20 & 25 HP V-Twin Tractors the lamps can be easily replaced without removing the dashboard. The 20 HP Liquid-Cooled Tractor and 24.5 Diesel Tractor may require the steering wheel and dashboard to be removed to replace the lamps.

The lamps are accessed from the back of the instrument panel, (A, Figure 20). Replace lamps with the exact type and rating to prevent damage to the instrument panel and electrical system.

Refer to Section 8, POWER STEERING SERVICE, for the procedure to remove the steering wheel and dashboard if required.

SEAT SWITCH

1. Disconnect and secure the negative battery cable, (see Section 6, COMMON SERVICE PROCEDURES).
2. Tip the seat deck forward to access the bottom of the seat assembly.
3. Disconnect the wire harness (B, Figure 21) from the seat switch (A).
4. Remove the screws (A, Figure 22) and washers (B) and then remove the switch assembly from the seat pan.
5. Install seat switch in reverse order of removal.

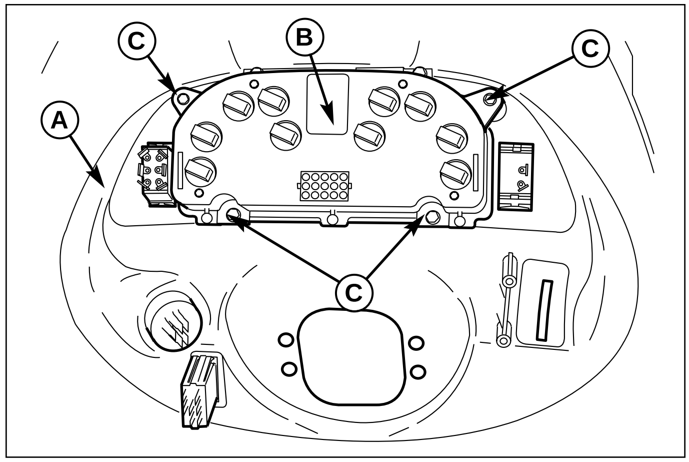


Figure 19. Instrument Panel Replacement
A Dashboard **C. Screws**
B. Instrument Panel **D. Harness Connector**

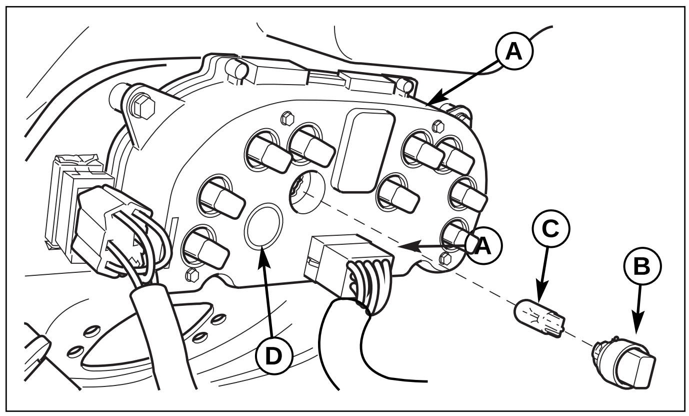


Figure 20. Instrument Panel Lamps Replacement
A. Instrument Panel **C. Lamp**
B. Lamp Socket **D. Lamp Bezel**

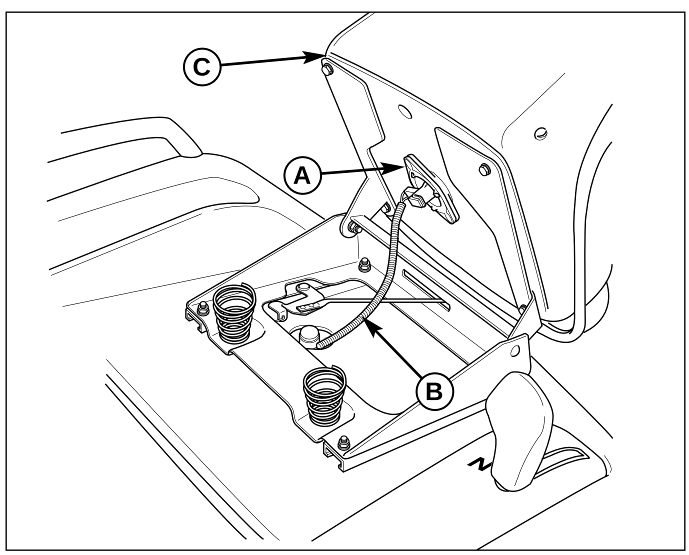


Figure 21. Seat Switch Safety System
A. Seat Switch **C. Seat**
B. Wire Harness

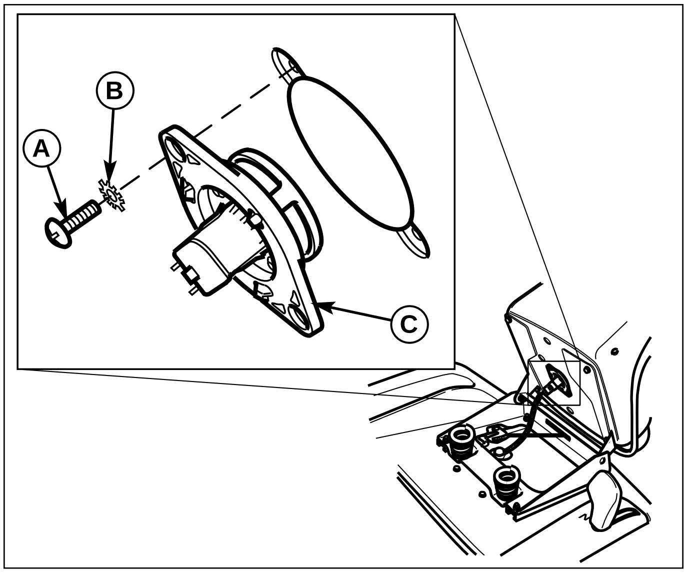


Figure 22. Seat Switch Removal and Replacement
A. Screw **C. Seat Switch**
B. Washer

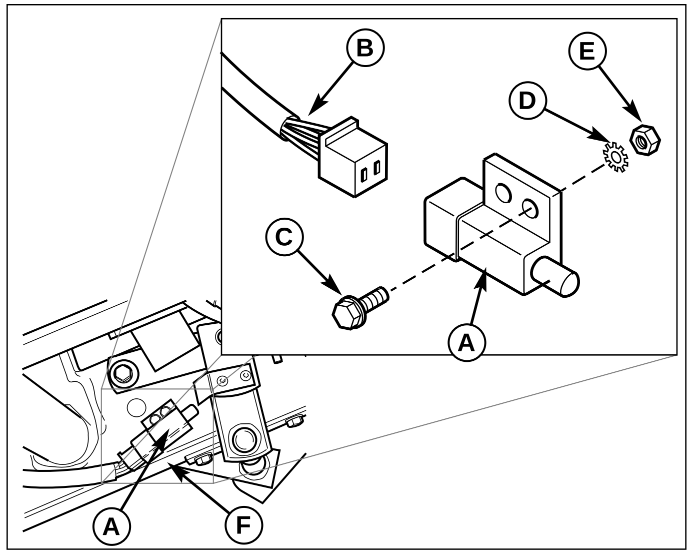


Figure 23. Brake Pedal Switch Removal and Replacement
A. Switch **D. Washer**
B. Wire Harness **E. Nut**
C. Screw **F. Frame**

PTO CLUTCH

For replacement procedure, see Section 12, PTO CLUTCH SERVICE.

BRAKE PEDAL SWITCH

The brake pedal switch is located under right side of frame, next to the pedal.

1. Disconnect and secure the negative battery cable, (see Section 6, COMMON SERVICE PROCEDURES).
2. Elevate the front of the unit. (See Section 6, COMMON SERVICE PROCEDURES, Elevating Front End for Safe Service.)
3. Label and disconnect the wire harness.
4. Remove the screws (C, Figure 23), nuts (E), and washers (D) from the switch (A) and frame (F).
5. Remove the switch (A).
6. Install switch in reverse order of removal.

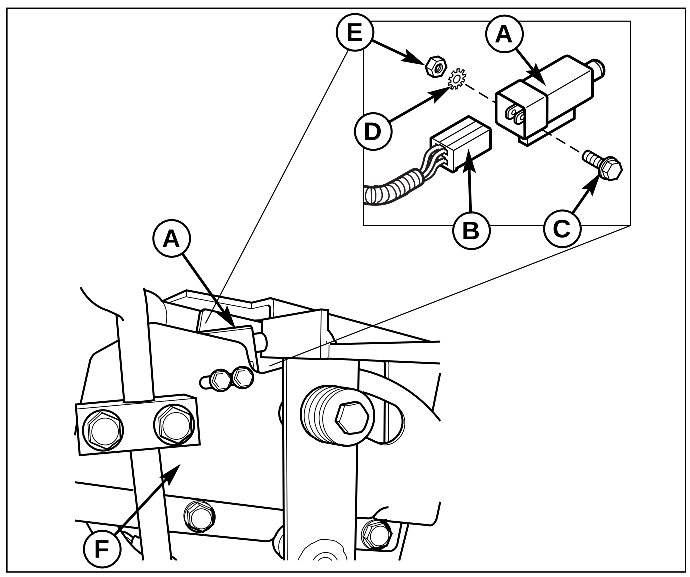


Figure 24. Cruise Switch Removal and Replacement
A. Switch **D. Washer**
B. Wire Harness **E. Nut**
C. Screw **F. Seat Deck Support**

CRUISE CONTROL SWITCH

The cruise control switch is located under right wheel well.

1. Disconnect and secure the negative battery cable, (see Section 6, COMMON SERVICE PROCEDURES).
2. Remove the seat deck. (See Section 14, SEAT DECK SERVICE.)
3. Label and disconnect the wire harness.
4. Remove the screws (C, Figure 24), nuts (E), and washers (D) from the switch (A) and seat deck support (F).
5. Remove the switch (A).
6. Replace the switch in the same orientation as the original and assemble in reverse order.

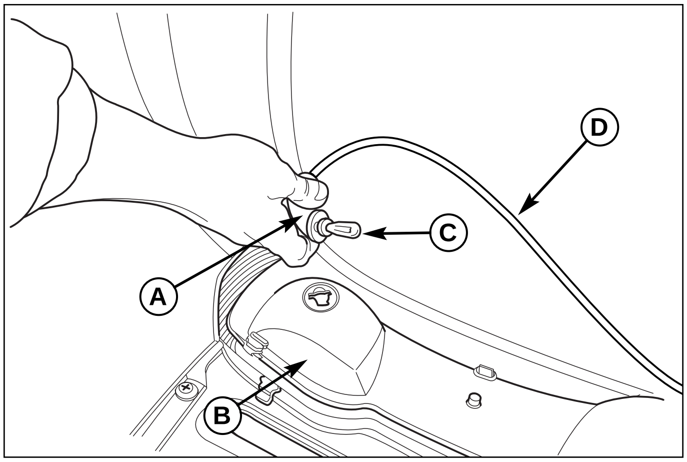


Figure 25. Headlight Lamp Removal and Replacement
A. Socket **C. Halogen Bulb**
B. Headlight Bezel **D. Wire Harness**

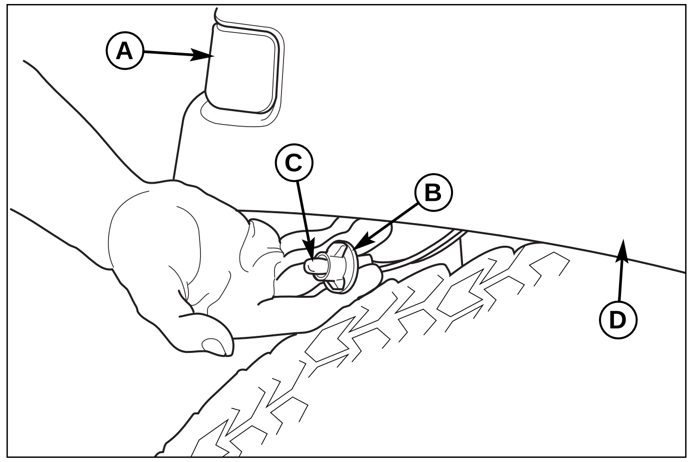


Figure 26. Tail Light Lamp Replacement
A. Tail Light Bezel **C. Bulb**
B. Socket **D. Seat Deck**

HEADLIGHT LAMPS

1. Open the hood.

NOTE: For gas engine models, the forward heat shield will need to be removed, (see Section 14, HOOD, DASH, & FOOT REST SERVICE).

2. Remove the light bulb socket (A, Figure 25) from the bezel (8) by twisting it counterclockwise and pulling it out.
3. Use a rag or gloves to remove and replace the light bulb (C) with an identical halogen bulb. **DO NOT TOUCH THE BULB WITH YOUR BARE HANDS**.
4. Reinstall the socket (A) into the bezel (B).

TAIL LIGHT LAMPS

1. Twist the socket (B, Figure 26) counterclockwise and pull out to remove it from the tail light.
2. Remove and replace the old bulb (C) with a new identical bulb.
3. Reinstall the socket into the tail light bezel (A).

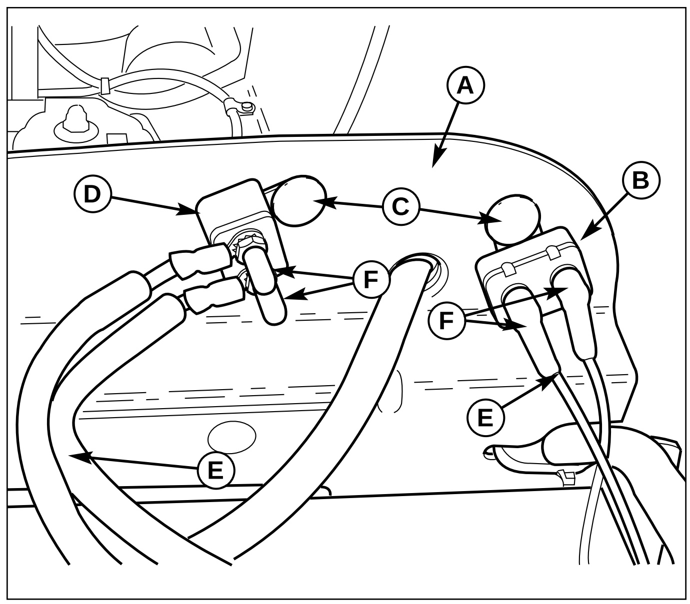


Figure 27. Circuit Breaker Replacement
A. Firewall **D. 30A Circuit Breaker**
B. 20A Circuit Breaker **E. Circuit Breaker Wire**
C. Plastic Fastener **F. Terminals**

CIRCUIT BREAKER

The circuit breakers are located on the firewall in the back of the engine compartment, see Figure 27, Items B and D.

1. Disconnect and secure the negative battery cable, (see Section 6, COMMON SERVICE PROCEDURES).
2. Disconnect the wires (E) from the circuit breaker terminals (F).
3. Remove the plastic fastener (C) securing the body of the circuit breaker to the firewall (A) and remove the circuit breaker.
4. Install circuit breaker in reverse order of removal.

NOTE: The circuit breaker posts are marked “BAT” and “AUX.” The BAT post should be connected to the battery via the solenoid. The AUX post should be connected to the ignition switch.

GLOW PLUG RELAY (24.5 HP DIESEL MODELS ONLY)

The glow plug relay is located on the firewall in the back of the engine compartment, see Figure 28, Item B.

1. Disconnect and secure the negative battery cable, (see Section 6, COMMON SERVICE PROCEDURES).
2. Remove the connector (C) from the glow plug relay (B).
3. Remove the plastic fastener (F) securing the body of the glow plug relay (B) to the firewall (A).
4. Install in reverse order of removal.

PREHEAT TIMER (24.5 HP DIESEL MODELS ONLY)

The preheat timer is located on the firewall in the back of the engine compartment, see Figure 28, Item D.

1. Disconnect and secure the negative battery cable, (see Section 6, COMMON SERVICE PROCEDURES).
2. Remove the connector (E) from the preheat timer (D).
3. Remove the plastic fastener (F) securing the body of the preheat timer (D) to the fire wall (A).
4. Install in reverse order of removal.

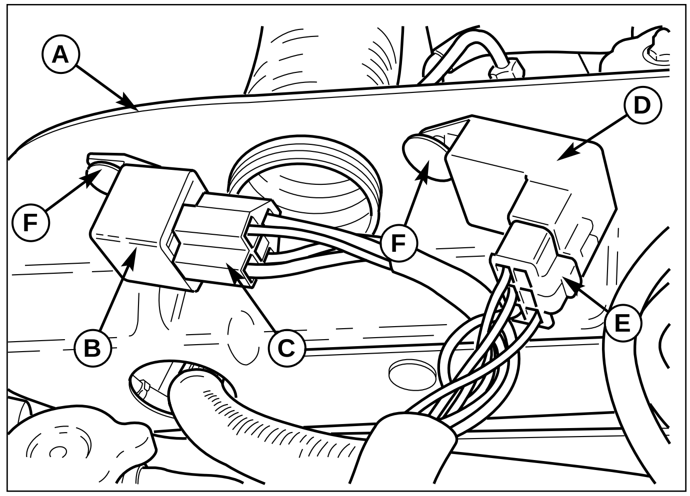


Figure 28. Relay Replacement
A. Firewall
B. Glow Plug Relay
C. Glow Plug Connector
D. Preheat Timer
E. Timer Connector
F. Plastic Fastener

FUEL PUMP/FUEL SOLENOID

Air-cooled engine models have a vacuum-operated fuel pump which is part of the engine. Liquid-cooled engine models have an electronic type of high pressure fuel pump or solenoid, which is different for each model, based on the engine manufacturer. Therefore, it is extremely important to refer to the tractor's specific engine manufacturer's instructions for service, repair, and replacement parts.

NOTE: Before beginning any work on the fuel pump or fuel solenoid, disconnect and secure the negative battery cable.

FUEL FILTER

See Figure 29.

All models have an in-line fuel filter/strainer, only the 24.5 HP Diesel Model has an electronic signal generated from the filter/strainer. This specific filter/strainer has a fuel-water separator. When the water fills to a certain level, an indicator lamp on the instrument panel will illuminate to alert the operator to drain the water accumulator.

Refer to the engine manufacturer's manual for specific information regarding engine component testing and replacement.

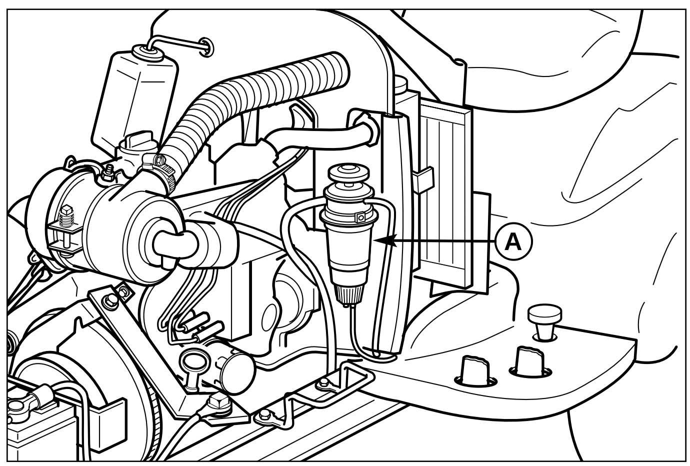


Figure 29. Fuel Filter (Diesel Models)
A. Fuel Filter

FUEL TANK LEVEL SENSOR

The fuel tank level sensor is located inside the fuel tank. It is a float type that is submerged into the tank. The float is on the end of an arm and, as the arm moves up and down, it changes the resistance, which in turn changes the voltage level of the fuel level signal to the instrument panel.

A general testing procedure for the fuel level sensor is provided in the Component Tests section.

1. Disconnect and secure the negative battery cable (see Section 6, COMMON SERVICE PROCEDURES).
2. Remove the seat deck and rear plastic guard, (see Section 15, SEAT DECK SERVICE).
3. Remove the nuts (G, Figure 30) and washer (H) holding the wires (F) to the terminals (I). Label the wires for easy reconnection.
4. Remove all screws (D) and lockwashers (E) holding the sensor assembly (A) on the tank (J) and carefully pull sensor out. Replace gasket (K) if damaged.
5. Reinstall fuel tank level sensor and seat deck in reverse order of this instruction.

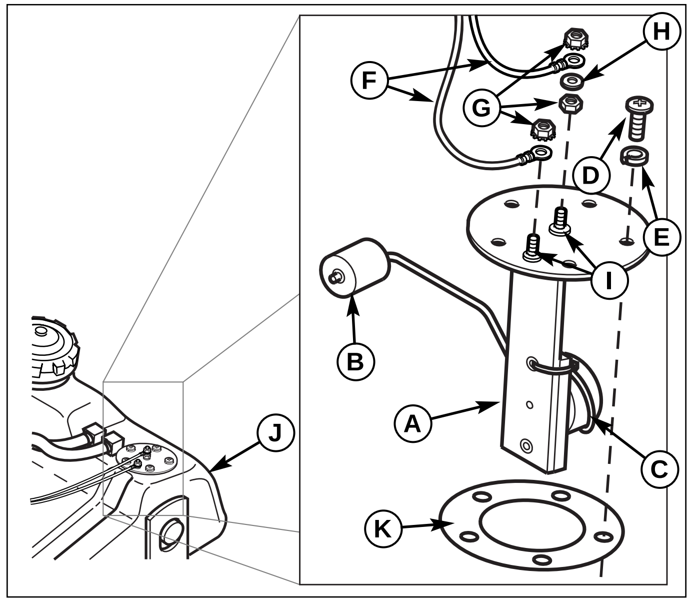


Figure 30. Fuel Level Sensor Assembly

A. Sensor Assembly	**G. Nuts**
B. Float	**H. Washer**
C. Sensor	**I. Terminals**
D. Screw	**J. Fuel Tank**
E. Lockwasher	**K. Gasket**
F. Wires	

COOLANT TEMPERATURE SENSOR (LIQUID-COOLED MODELS ONLY)

For the 20 HP Liquid-Cooled Models, refer to the manufacturer's instructions for service procedures and replacement parts

24.5 HP Diesel Model.

1. Disconnect and secure the negative battery cable, (see Section 6, COMMON SERVICE PROCEDURES).
2. Lift the hood to gain access to the engine. The coolant temperature sensor (A, Figure 31) is located in the water pump housing and can be accessed from the left side of the engine as viewed from the operators seat.
3. Remove the sensor wire (B) from the sensor (A) by removing the hex nut and lockwasher.

NOTE: Since the sensor is brass, which is a softer metal, use extreme caution in removing the sensor to prevent it from being sheared off.

NOTE: If inaccurate coolant temperature indications on the temperature gauge still remain after the sensor is replaced, replace the instrument panel.

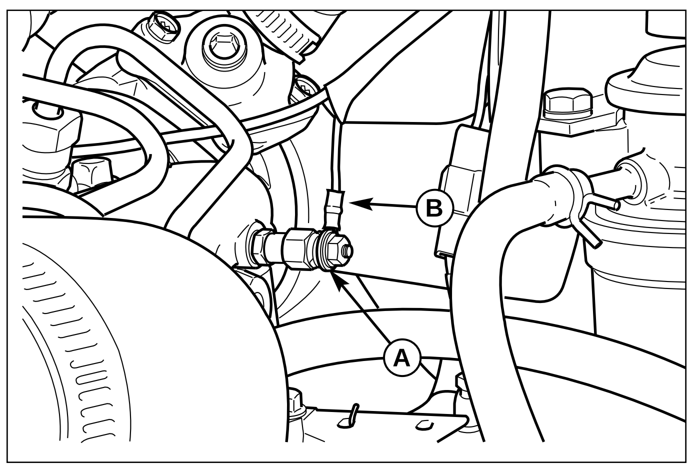


Figure 31. Seat Switch Safety System

A. Coolant Sensor	**B. Sensor Wire**

IGNITION COIL (MAGNETO)

Refer to the engine manufacturer's manual for specific information regarding engine component testing and replacement.

OIL PRESSURE SENSOR

All models contain an oil pressure sensor (sender) which is located on the engine.

Refer to the engine manufacturer's manual for specific information regarding engine component testing and replacement.

If after replacing the oil sensor on the engine, the indicator is still malfunctioning, replace the instrument panel.

ALTERNATOR

All models contain an alternator to charge the battery and supply the tractor with electrical energy during operation.

Refer to the engine manufacturer's manual for specific information regarding engine component testing and replacement.

To determine if the charging function of the alternator is operating correctly, a basic check can be performed. Refer to the Battery Charging Voltage Test in this section.

TACHOMETER

All models contain an electronic tachometer to measure the engine RPM for indication on the instrument panel.

Refer to the engine manufacturer's manual for specific information regarding engine component testing and replacement.

If after replacing the components on the engine, the tachometer continues to malfunction, replace the instrument panel.

VOLTAGE REGULATOR

All models contain a voltage regulator to regulate the current draw on the alternator during operation.

Depending on the engine manufacturer and model, the voltage regulator is either installed on the engine or enclosed in the alternator as a complete unit.

Refer to the engine manufacturer's manual for specific information regarding engine component testing and replacement.

TROUBLESHOOTING

The following troubleshooting flow charts provide an easy reference to the most common electrical problems which may occur. It assumes that there is an actual defective component in the electrical system and that all mechanical and fuel-related malfunctions have been fixed. It does not address "operator error" issues and assumes that the technician has exhausted all common sense solutions to simple problems like loose connectors and bare wires shorting to the frame. Locate the problem you are having, then check all the components in the order listed.

Finally, always establish a clear idea why a problem has occurred and take steps to ensure that it doesn't happen again. Remember, failure of a small component can often be indicative of potential failure or incorrect functioning of a more important component or system.

Refer to the following Component Test section for specific component testing procedures.

A. Check/Clean Wires and Connectors
B. Check/Clean Ground Cable
C. Battery Tests
D. Isolated Battery Voltage Check
E. Charging Voltage Check
F. Preheat Timer Test
G. Glow Plug Relay Test
H. Ignition Switch Tests
I. PTO Switch Test
J. Accessory Power Connector Test
K. Cruise Control Switch Test
L. Height of Cut Switch Test
M. Brake Pedal Switch Tests
N. Seat Switch Safety Interlock Test
O. Seat Switch Test
P. Circuit Breaker Test
Q. PTO Clutch
R. Headlight Switch Test
S. Fuel Solenoid Test
T. Voltage Regulator
U. Alternator
V. Fuel Level Signal Test
W. Fuel Level Sensor Test

Engine will not turn over: (All Models)

Condition	Check	Component Fails Test	Next (Component Tests OK)
Loose, broken, or dirty connectors or wiring.	Refer to *A. Check/Clean Wires and Connectors.*	Replace/repair damaged wires or connectors.	Component Tests OK
Loose, broken, or dirty ground connection.	Refer to *B. Check/Clean Ground Cable.*	Replace/repair damaged ground connection.	Component Tests OK
Battery connections dirty or loose, or worn battery.	Refer to *C. Battery Tests.*	Replace/repair battery cables or replace battery.	Component Tests OK
Dead battery.	Refer to *C. Battery Tests.*	Charge or replace battery.	Component Tests OK
Circuit Breaker Malfunction.	Refer to *P. Circuit Breaker Test.*	Replace circuit breaker.	Component Tests OK
Worn or malfunctioning ignition switch	Refer to *H. Ignition Switch Tests.*	Replace ignition switch.	Component Tests OK
Worn or failed PTO switch.	Refer to *I. PTO Switch Test.*	Replace PTO switch.	Component Tests OK
Worn or malfunctioning brake pedal switch.	Refer to *M. Brake Pedal Switch Tests.*	Replace the brake pedal switch.	Component Tests OK
Worn or malfunctioning cruise control switch.	Refer to *K. Cruise Control Switch Test.*	Replace the cruise control switch.	Component Tests OK
Worn or malfunctioning starter solenoid.	Refer to *Engine Manual.*	Replace the solenoid.	Component Tests OK
Worn or malfunctioning starter.	Refer to *Engine Manual.*	Replace damaged wires or connectors.	Done

Engine will turn over but will not start: (Gas Models)

Check	Refer to	Component Fails Test
Check all wires and connections.	Refer to *A. Check/Clean Wires and Connectors.*	Replace components as required.
Component Tests OK ↓		
Check the ignition switch.	Refer to *H. Ignition Switch Tests.*	Replace the ignition switch.
Component Tests OK ↓		
Check the PTO switch.	Refer to *I. PTO Switch Test.*	Replace the PTO switch.
Component Tests OK ↓		
Check the brake pedal switch.	Refer to *M. Brake Pedal Switch Tests.*	Replace the brake pedal switch.
Component Tests OK ↓		
Check the seat switch.	Refer to *O. Seat Switch Test.*	Replace the seat switch.
Component Tests OK ↓		
Check the engine ignition system.	Refer to *Engine Manual.*	Replace components as required.
Done		

Engine runs for a few seconds then dies: (Gas Models)

Check	Refer to	Component Fails Test
Check the ignition switch.	Refer to *H. Ignition Switch Tests.*	Replace the ignition switch.
Component Tests OK ↓		
Check the fuel system.	Refer to *Engine Manual.*	Replace components as required.
Done		

Engine will turn over but will not start: (Diesel Models)

Check	Refer to	Component Fails Test
Check all wires and connections.	Refer to *A. Check/Clean Wires and Connectors.*	Replace components as required.
Component Tests OK		
Check the ignition switch.	Refer to *H. Ignition Switch Tests.*	Replace the ignition switch.
Component Tests OK		
Check the PTO switch.	Refer to *I. PTO Switch Test.*	Replace the PTO switch.
Component Tests OK		
Check the brake pedal switch.	Refer to *M. Brake Pedal Switch Tests.*	Replace the brake pedal switch.
Component Tests OK		
Check preheat timer.	Refer to *F. Preheat Timer Test.*	Replace the preheat timer.
Component Tests OK		
Check glow plug relay.	Refer to *G. Glow Plug Relay Test.*	Replace the glow plug relay.
Component Tests OK		
Check the seat switch.	Refer to *O. Seat Switch Test.*	Replace the seat switch.
Component Tests OK		
Check the engine ignition system.	Refer to *Engine Manual.*	Replace components as required.
Done		

Engine runs for a few seconds then dies: (Diesel Models)

Check	Refer to	Component Fails Test
Check the ignition switch.	Refer to *H. Ignition Switch Tests.*	Replace the ignition switch.
Component Tests OK		
Check the fuel system.	Refer to *Engine Manual.*	Replace components as required.
Done		

Engine dies when brake pedal released: (All Models)

Check	Refer to	Component Fails Test
Check the brake pedal switch.	Refer to *M. Brake Pedal Switch Tests.*	Replace the brake pedal switch.
Component Tests OK		
Check the seat switch.	Refer to *O. Seat Switch Test.*	Replace the seat switch.
Done		

Engine dies when PTO engaged: (All Models)

Check	Refer to	Component Fails Test
Check the PTO switch.	Refer to *I. PTO Switch Test.*	Replace the PTO switch.
Component Tests OK		
Check the seat switch.	Refer to *O. Seat Switch Test.*	Replace the seat switch.
Done		

PTO clutch will not engage: (All Models)

Check	Refer to	Component Fails Test
Check the PTO switch.	Refer to *I. PTO Switch Test.*	Replace the PTO switch.
Component Tests OK		
Check the ignition switch.	Refer to *H. Ignition Switch Tests.*	Replace the ignition switch.
Component Tests OK		
Check the PTO clutch.	Refer to *Q. PTO Clutch.*	Replace the PTO clutch assembly.
Done		

Battery over-charging: (All Models)

Check	Refer to	Component Fails Test
Check voltage regulator.	Refer to *Engine Manual.*	Replace the defective engine component(s).
Component Tests OK		
Check alternator.	Refer to *Engine Manual.*	Replace the defective engine component(s).
Done		

Battery not charging: (All Models)

Check	Test	Component Fails Test
Check battery.	Refer to *C. Battery Tests.*	Replace the battery.
Component Tests OK		
Check ground.	Refer to *B. Check/Clean Ground Cable.*	Clean both ends of the negative battery cable.
Component Tests OK		
Check circuit breaker.	Refer to *P. Circuit Breaker Test.*	Replace the circuit breaker.
Component Tests OK		
Check voltage regulator.	Refer to *Engine Manual.*	Replace the defective engine component(s).
Component Tests OK		
Check charging voltage.	Refer to *E. Charging Voltage Check.*	Replace the defective engine component(s).
Component Tests OK		
Check engine alternator.	Refer to *Engine Manual.*	Replace the defective engine component(s).
Component Tests OK		
Check ignition switch.	Refer to *H. Ignition Switch Tests.*	Replace the ignition switch.
Done		

Accessory or Mower Deck does not operate with accessory switch: (All Models)

Check	Test	Component Fails Test
Accessory is jammed or bound.	Refer to *Section 2, MAINTENANCE.*	Correct problem.
Component Tests OK		
Accessory Power Connector loose or broken wires	Refer to *J. Accessory Power Connector Test.*	Repair broken wire or connector.
Component Tests OK		
Accessory (Height of Cut) Switch is worn or failed.	Refer to *L. Height of Cut Switch Test.*	Replace height of cut switch.
Done		

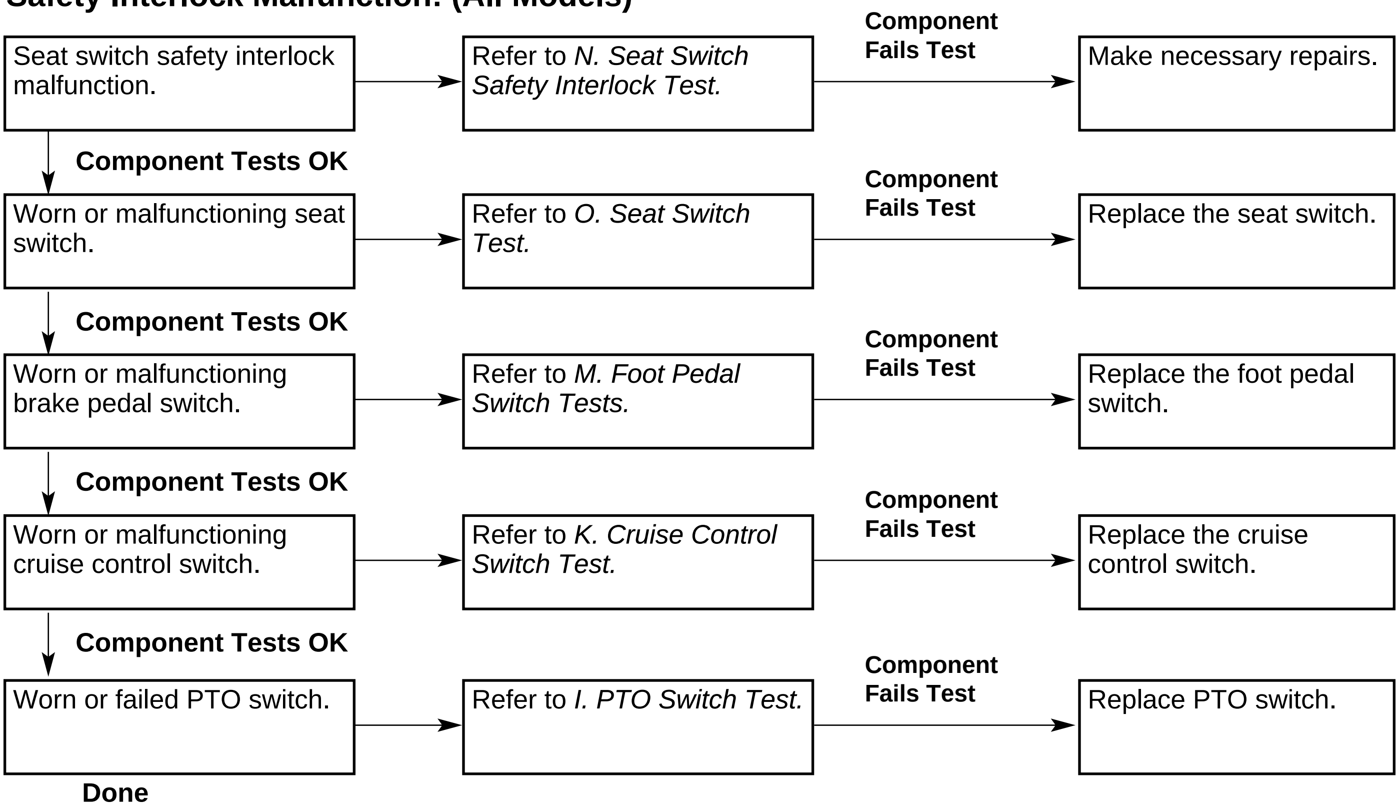
Incorrect Fuel Level Indication: (All Models)

Loose, broken, or dirty connectors or wiring.	Refer to *A. Check/Clean Wires and Connectors.*	**Component Fails Test**	Replace/repair damaged wires or connectors.
Component Tests OK			
Loose, broken, or dirty ground connection.	Refer to *B. Check/Clean Ground Cable.*	**Component Fails Test**	Replace/repair damaged ground connection.
Component Tests OK			
Malfunctioning fuel gauge.	Refer to *V. Fuel Level Signal Test.*	**Component Fails Test**	Repair wiring or instrument panel.
Component Tests OK			
Malfunctioning fuel level sensor.	Refer to *W. Fuel Level Sensor Test.*	**Component Fails Test**	Repair or replace fuel level sensor.
Done			

Headlights or Tail Lights don't operate: (All Models)

Burned-out bulb.	Refer to *Headlight or Tail Light Replacement* in this section.	**Component Fails Test**	Replace burned-out bulb.
Component Tests OK			
Loose, broken, or dirty ground connection	Refer to *B. Check/Clean Ground Cable.*	**Component Fails Test**	Replace/repair damaged ground connection.
Component Tests OK			
Battery connections dirty, loose, or worn battery.	Refer to *C. Battery Tests.*	**Component Fails Test**	Replace/repair battery cables or replace battery.
Component Tests OK			
Dead battery.	Refer to *C. Battery Tests.*	**Component Fails Test**	Charge or replace battery.
Component Tests OK			
Loose, broken, or dirty connectors or wiring.	Refer to *A. Check/Clean Wires and Connectors.*	**Component Fails Test**	Replace/repair damaged wires or connectors.
Component Tests OK			
Circuit breaker malfunction.	Refer to *P. Circuit Breaker Test.*	**Component Fails Test**	Replace circuit breaker.
Done			

Safety Interlock Malfunction: (All Models)



⚠ WARNING

Before beginning any test,

ALWAYS:

- **Disconnect the spark plug wire.**
- **Block the wheels.**

IN MOST CASES:

- **Engage the parking brake.**
- **Turn the PTO switch OFF.**
- **Turn the ignition switch OFF.**
- **Place the ground speed control lever in NEUTRAL (Peerless models only).**

If a test procedure requires a configuration other than the one listed above, instructions will be provided in that specific procedure.

Always reset the tractor to the configuration listed above unless told otherwise.

ELECTRICAL SYSTEM TESTING

The following tests should be used in conjunction with this sections troubleshooting flow charts to efficiently troubleshoot common electrical problems; however, if a specific component is suspect, these tests can be used independently of the flow chart and of each other.

Common Component Test

FUSES (EARLY DIESEL MODELS ONLY)

The electrical circuits for the early model tractors are protected by a fuse instead of a circuit breaker and fusible links. The fuse block is located on the firewall.

A blown fuse is easily identified by using an ohm meter to check for continuity.

Be sure to replace the blown fuse with the correct type.

If the replacement fuse immediately fails, don't replace it again until the cause of the problem is isolated and corrected. In most cases, the cause will be a short circuit in the wiring caused by a broken or deteriorated wire.

CIRCUIT BREAKERS (LATER MODELS)

All circuit breakers are located on the firewall. The circuit breaker resets itself automatically. If the circuit doesn't come back on, check it immediately.

GLOW PLUG RELAY (DIESEL TRACTOR MODELS)

The electrical system uses a relay to transmit the electrical power to the component. If the relay is defective, the component will not operate properly. The relay is located on the firewall.

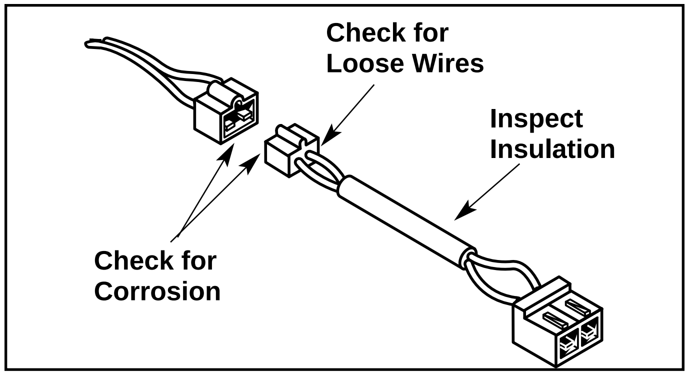


Figure 32. Typical Wire Harness

A. Check/Clean Wires and Connectors

1. Check all wires for cracked or worn insulation.
2. Check all connectors, terminals, and receptacles for loose wires or corrosion (Figure 32). Refer to the exploded view diagrams for wire harness locations.

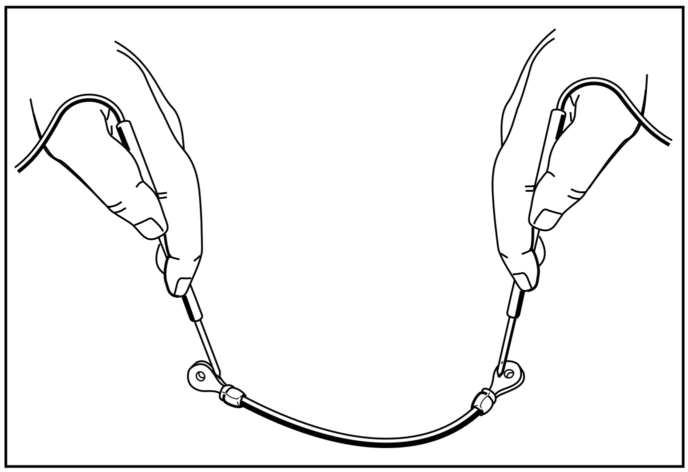


Figure 33. Testing Cable Continuity

B. Check/Clean Ground Cable

1. Disconnect and secure the negative battery cable (see Section 6, COMMON SERVICE PROCEDURES).
2. Disconnect the other end of the negative battery cable (ground cable) from the engine.
3. Clean the battery and cable terminals with a wire brush until the metal is shiny.
4. Using a VOM set to Ohm, test the continuity of the cable (Figure 33). The VOM should register no more than 2-3 ohm.
5. Clean the negative battery post and engine ground with a wire brush until the metal is shiny.
6. Reattach the negative cable to the engine block and then the negative battery terminal.

C. Battery Tests

GENERAL

If the battery is producing 12 volts and the battery cables have continuity, the rest of the cranking system can be systematically tested. However, a full test of the battery includes cleaning, testing battery charge (hydrometer test), and testing its ability to deliver current (heavy load test).

NOTE: Before testing, check the battery for any damage such as a loose post or cracks. Damaged batteries must be replaced.

C-1 HYDROMETER TEST

1. Remove the vent caps (A, Figure 34).
2. Check each cell using a hydrometer.
3. All cells should have a specific gravity of 1.27 or higher. If the cells vary by more than .050 points, charge the battery and recheck.

   If one or more cells read below 1.265, charge at 5 Amps, checking hourly. If the low cell or cells do not improve within three hours of charging, replace the battery.
4. Replace the cap when finished.

C-2 CHECK ELECTROLYTE LEVEL

1. Remove the battery vent cap (A, Figure 62) and make sure the breather holes are open.
2. Check that fluid is even with the bottom of the split rings (B, Figure 62). If not, fill with distilled water. Replace vent cap when done.

C-3 TEST BATTERY VOLTAGE

1. Test the battery voltage: set VOM to VDC.
2. Place one test probe of the VOM on the batteries positive post and one probe on the negative post (see Figure 35). Note and record the battery voltage as it will be referenced in later tests. It should be approximately 12 VDC.

C-4 HEAVY LOAD TEST

1. Follow the load tester manufacturer's instructions; connect the battery tester to the battery.
2. Discharge the battery under a fixed load at three times the ampere-hour rating for approximately 15 seconds, then read the terminal voltage.

C-5 CLEAN BATTERY

1. Disconnect the battery cables.
2. Remove the battery from the battery compartment.
3. Remove dirt and corrosion with a solution of one part baking soda and seven parts water.

⚠ WARNING

Be careful when handling the battery. Avoid spilling electrolyte. Keep flames and sparks away from the battery.

When removing or installing battery cables, disconnect the negative cable FIRST and reconnect it LAST. If not done in this order, the positive terminal can be shorted to the frame by a tool.

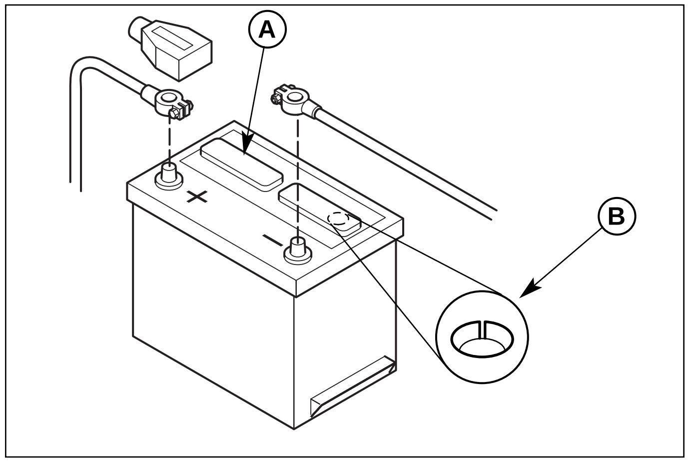


Figure 34. Check Battery Electrolyte
A. Battery Cap **B. Split Ring**

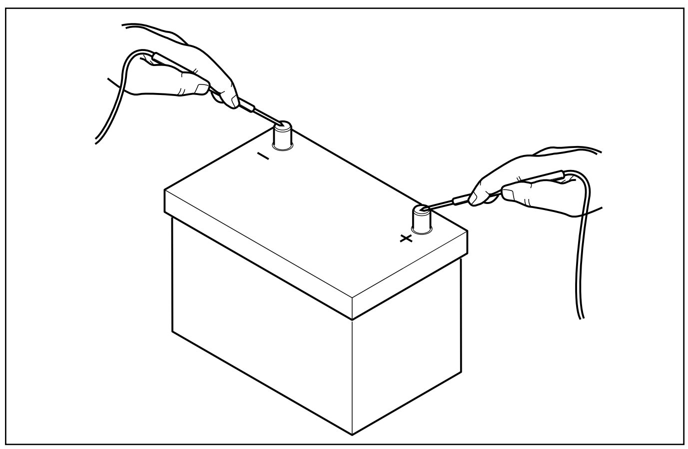


Figure 35. Check Battery Voltage

4. Clean the posts with a wire brush until the metal is shiny.
5. Reinstall battery and coat the terminals with petroleum jelly to prevent corrosion.

D. Isolated Battery Voltage Check

See Figure 36.

In some cases, a short in the wiring or another component could be causing a low level current draw on the battery. This would be indicated by a slow drain on the battery during times when the engine is off. The easiest way to check this is to check the voltage with the battery installed, and then with the battery uninstalled (isolated).

Then reconnect the battery terminals with an amp meter in series with the battery and terminal. There should be no current draw off the battery when all accessories are off and the ignition key switch is in the OFF position.

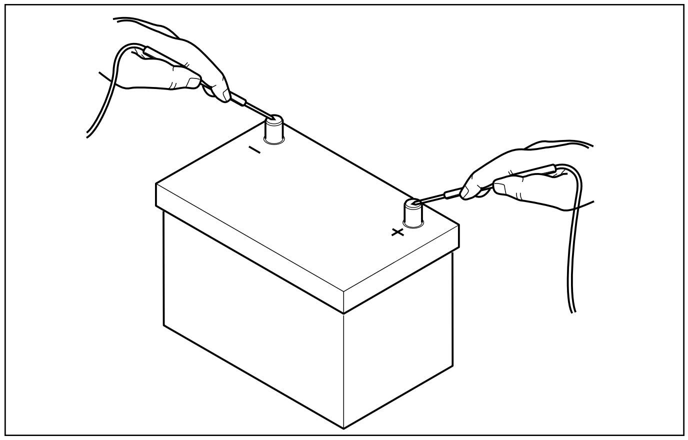


Figure 36. Check Battery Voltage

E. Charging Voltage Check

See Figure 37.

To determine if the charging system is functioning properly, check the battery voltage while the engine is running. The charging system produces a slightly higher voltage than the battery so that the battery will recharge and there is enough energy remaining to supply power to the electrical systems.

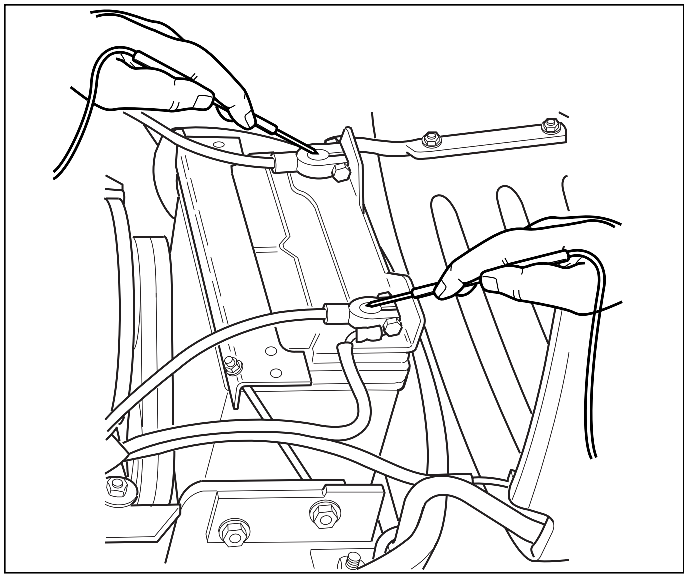


Figure 37. Check Charging Voltage

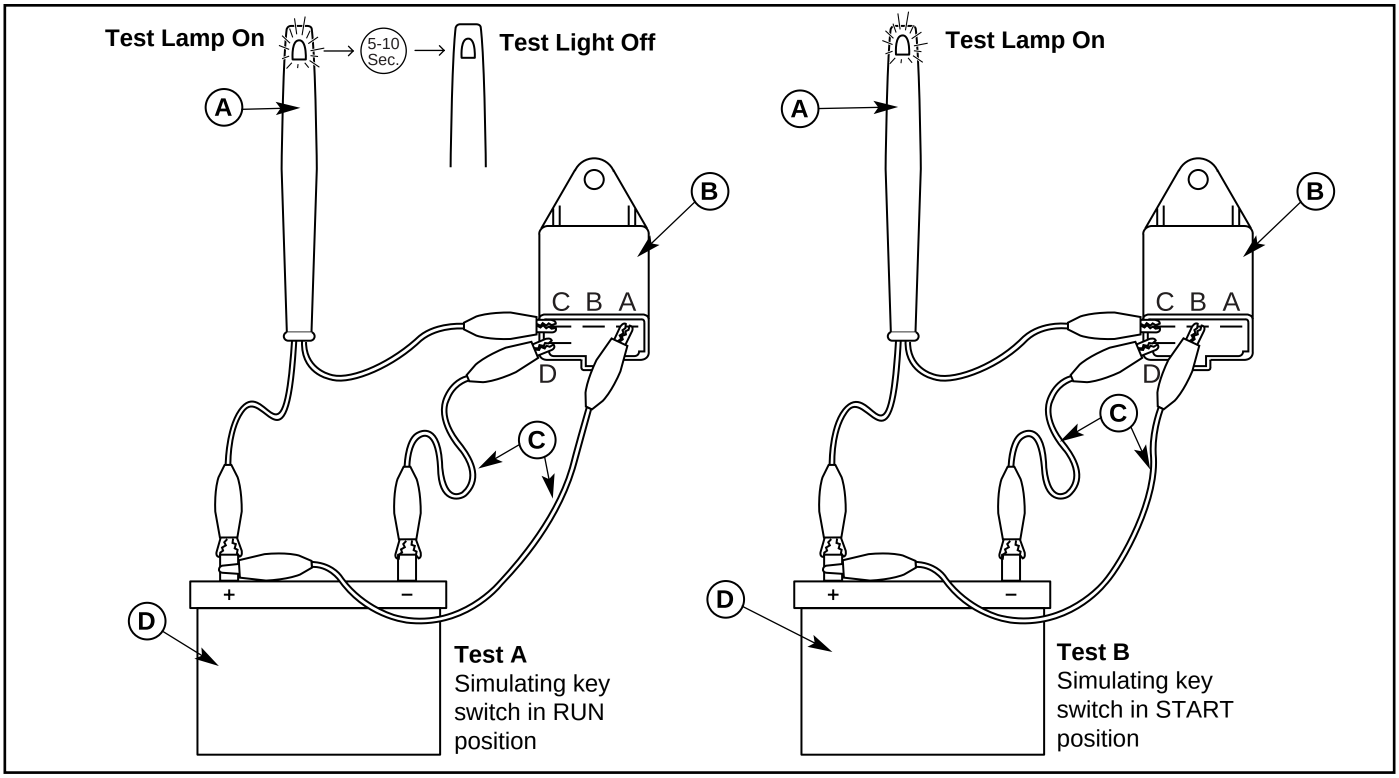


Figure 38. Testing Preheat Timer
A. 12 Volt DC Lamp/Tester
B. Preheat Timer
C. Test Jumpers/Wires with Alligator Clips
D. 12 Volt DC Battery (or Power Supply)

F. Preheat Timer Test

The preheat timer energizes the glow plug relay for five to ten seconds when the ignition key switch is initially placed into the RUN or START position.

Tools:

a. 12 volt dc test lamp (A, Figure 66).

b. 12 volt dc power supply or battery (D).

c. Two to four test jumpers/wires with alligator clips on the ends (C).

1. Connect one jumper from terminal D of the preheat timer (B) to the negative (-) terminal of the power supply or battery (D).
2. Use a test lamp (A) and connect one lead to terminal C of the preheat timer (B) and the other lead to the positive (+) terminal of the power supply or battery (D).

NOTE: The test lamp is simulating the coil of the preheat timer. The preheat timer is an electronic relay module and the actual test lamp may not be a large enough load for the module to turn on the test lamp. Be sure the lamp is a 12 volt dc lamp and not an electronic testing lamp or LED (light emitting diode) type of test lamp.

3. Connect one end of the jumper (C) to the positive (+) terminal of power supply or battery (D) and the other end to terminal A of the preheat timer (B).

   The test lamp should illuminate between five and ten seconds, then turn off. This test is simulating placing the ignition key switch into the RUN position.
4. Connect one end of the jumper to the positive (+) terminal of power supply or battery and the other end to terminal B of the preheat timer.

   The test lamp should illuminate and remain illuminated until the jumper is removed from terminal B of the preheat timer. This test is simulating placing the ignition key switch into the START position.

G. Glow Plug Relay Test

NOTE: Before testing the glow plug relay, the preheat timer should be tested first. The glow plug relay is connected to the glow plug and to the preheat timer.

Test equipment and tools:

a. DC voltage test meter with test probes (multimeter or 12 volt dc test lamp can also be used).
b. Ohm meter.
c. Test jumpers with alligator clips.
d. 12 volt dc power supply or 12 volt dc battery.

1. Connect the negative (-) test probe to ground or the negative (-) battery terminal.
2. Connect the positive (+) test probe to terminal 30 of the glow plug relay.
3. Turn the ignition key switch to the RUN position. The glow plug relay should energize for approximately five to ten seconds. If the glow plug relay does not energized, continue with the test.
4. Remove the glow plug relay from the tractor.
5. Connect the ohm meter to terminals 30 and 87 of the glow plug relay as shown in Figure 39.
6. Connect a jumper from terminal 85 of the glow plug relay to the negative (-) terminal of the battery or power supply.
7. Connect a jumper from terminal 86 of the glow plug relay to the positive (+) terminal of the battery or power supply.
   The relay should energize and continuity (0 Ohm) should be indicated between terminals 30 and 87 of the glow plug relay, if not, replace the relay. An audible “click” should be heard when the relay energizes. If the relay does energize, check the wiring and connectors.

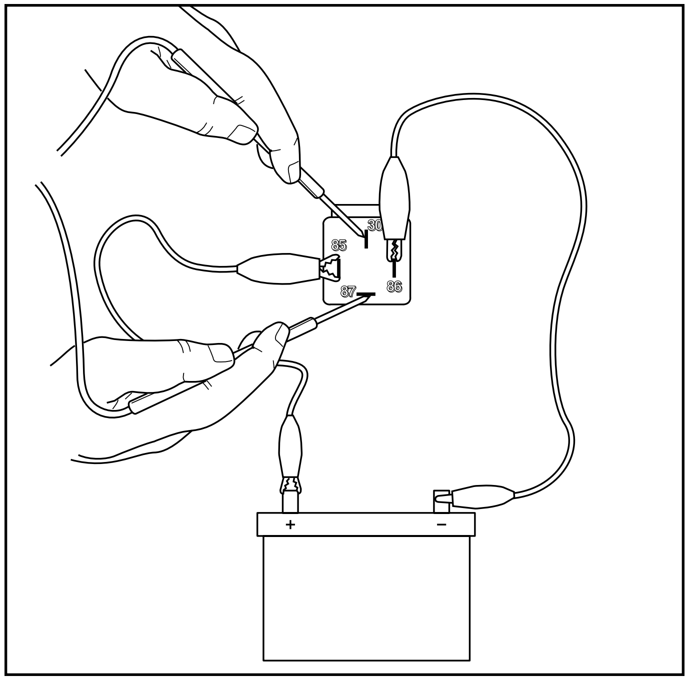


Figure 39. Testing Glow Plug Relay

H. Ignition Switch Tests

NOTE: Early models used the 5-pin steel body switch (Figure 40) and later models use the 6-pin steel switch (Figure 41).

To perform these tests, the ignition switch needs to be removed from the dashboard.

TEST START POSITION

NOTE: To perform this test, the ignition key switch may need to be placed in a vice to hold the switch.

1. Set VOM to Ohm.
2. Connect test leads to terminals B and L of the ignition key switch. The test meter should show no continuity (infinity/open if using an ohm meter).
3. Turn the ignition key switch to the START position.
4. The test meter should show continuity (zero ohm/short if using an ohm meter).
5. Release the ignition key switch. The test meter should return to showing no continuity (infinity/open if using an ohm meter).
6. Repeat steps 2 through 5 for each combination of terminals listed in the table for the “START” circuit of the appropriate figure. (Figure 40 for 5-pin steel body switches and Figure 41 for the 6-pin steel body switches.)
7. Check all other connection combinations for no continuity (open). The combinations tested in steps 2 through 5 should be the only combinations that have continuity; all other connection combinations should have no continuity.

TEST RUN POSITION

1. Set VOM to Ohm.
2. Connect test leads to terminals B and L. The test meter should show no continuity (infinity/open if using an ohm meter).
3. Turn the ignition key switch to the RUN position. The test meter should show continuity (zero ohm if using an ohm meter).
4. Repeat steps 2 and 3 for each combination of terminals listed in the table for the “RUN” circuit of the appropriate figure (Figure 40 for 5-pin steel body switches and Figure 41 for the 6-pin steel body switches).
5. Check all other connection combinations for no continuity (open). The combinations tested in steps 2 and 3 should be the only combinations that have continuity; all other connection combinations should have no continuity.

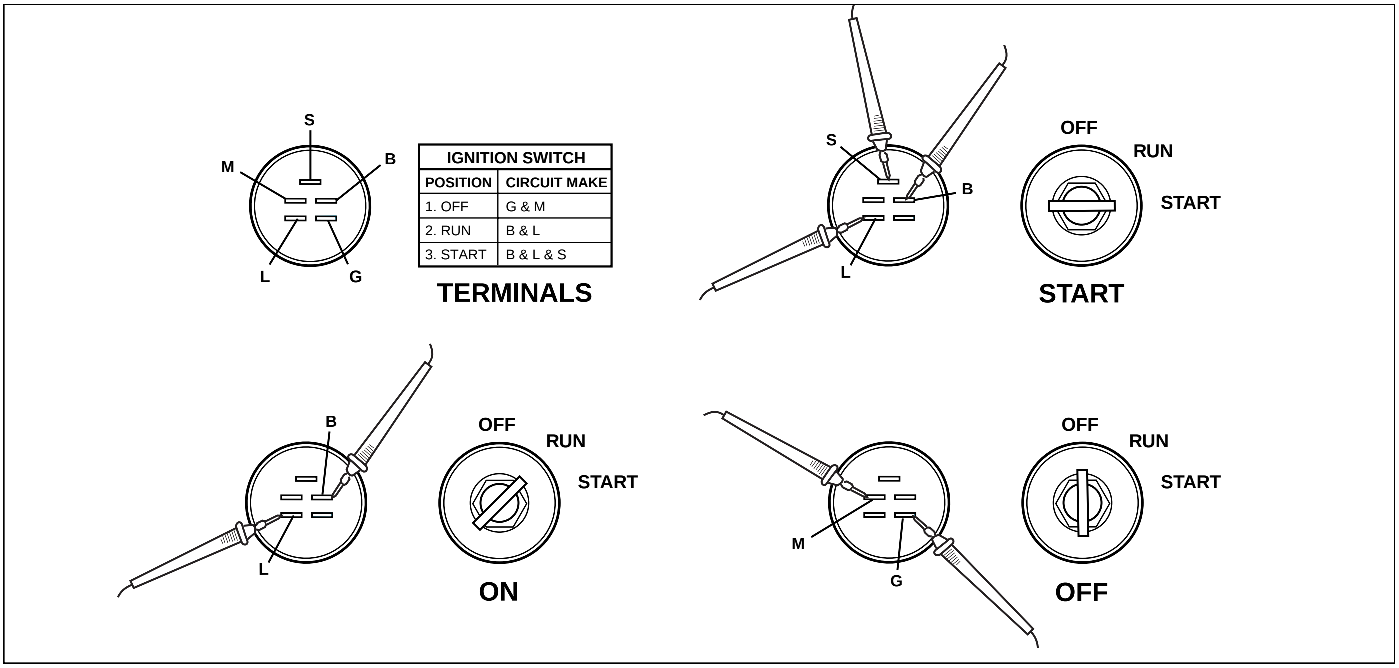


Figure 40. Ignition Switch Tests – 5-Pin Steel Body (Early Models)

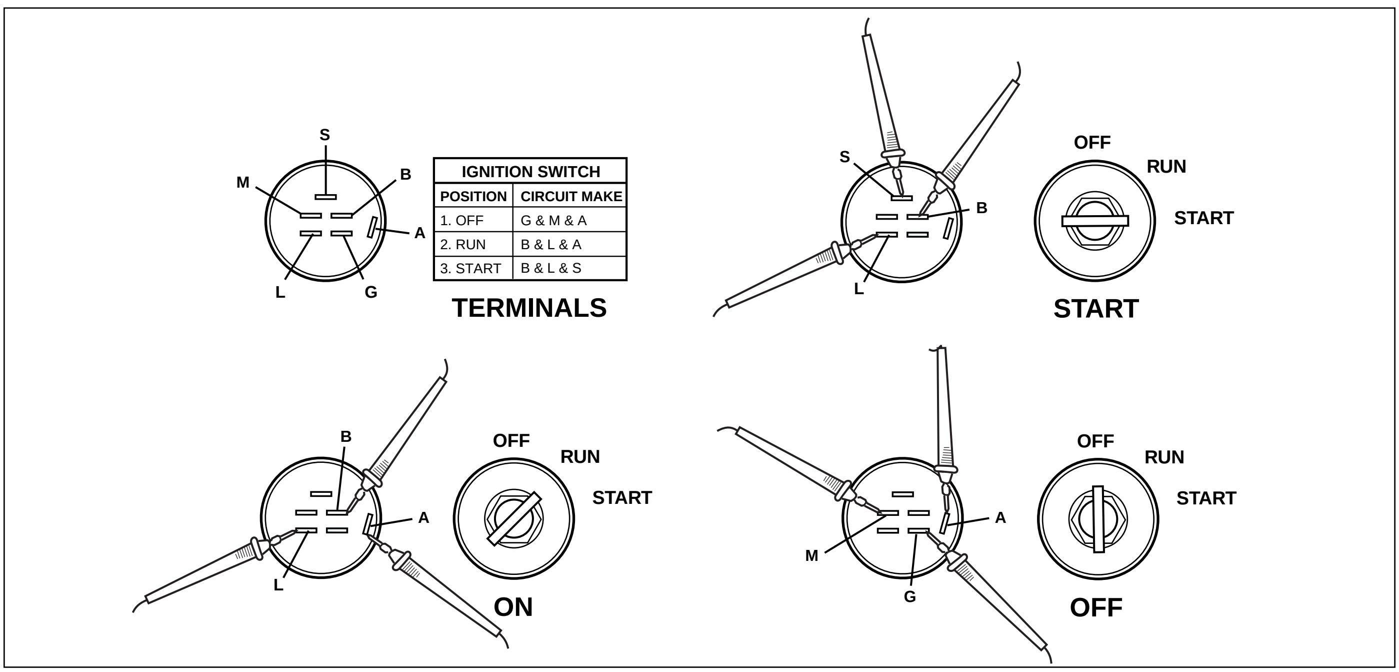


Figure 41. Ignition Switch Tests – 6-Pin Steel Body (Later Models)

TEST OFF POSITION

1. Set VOM to Ohm.
2. Turn the ignition key switch to the OFF position.
3. Connect test leads to G and M. The test meter should show continuity (zero ohm if using an ohm meter).
4. Turn the ignition key switch to the RUN position. The test meter should show <u>no</u> continuity (infinity/open if using an ohm meter).
5. Repeat steps 2 through 4 for each combination of terminals listed in the table for the “OFF” circuit of the appropriate figure (Figure 40 for 5-pin steel body switches and Figure 41 for the 6-pin steel body switches).
6. Check all other connection combinations for no continuity (open). The combinations tested in steps 2 through 4 should be the only combinations that have continuity; all other connection combinations should have no continuity.

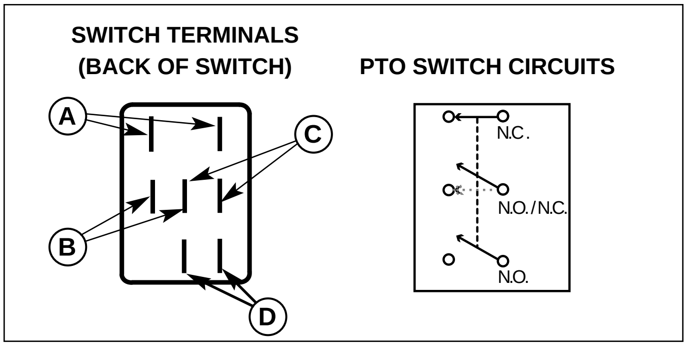


Figure 42. PTO Switch Terminals
A. Top N.C. Terminals (All Models)
B. Middle N.C. Terminals (Liquid-Cooled Models)
C. Middle N.O. Terminals (Air-Cooled Models)
D. Bottom N.O. Terminals (All Models)

I. PTO Switch Test

The PTO switch is used in the PTO circuit and both safety interlock circuits: cranking and safety shutoff. To accommodate these circuits, the PTO switch has four contacts actuated by the pull knob. The top and bottom contacts are common to all models covered in this manual. The middle N.O. (Normally Open) contacts are used by the air-cooled engine models and the middle N.C. (Normally Closed) contacts are used by the liquid-cooled engine models.

The N.C. contacts will be closed when the PTO switch is in the OFF position. Pulling up on the knob closes the contacts, pushing down on the knob will open the contacts.

The N.O. contacts will be open when the PTO switch is in the OFF position. Pulling up on the knob opens the contacts, pushing down on the knob will close the contacts these switches.

TEST PTO SWITCH

NOTE: You may want to remove the PTO switch from the control panel for testing. Refer to the PTO Switch Replacement procedures located in this section.

1. Pull the wire harness off the back of the switch.
2. Place the PTO switch in the OFF position, knob pulled up (Figure 43).
3. Set VOM to Ohm. Test the top, middle, and bottom rows of terminals for continuity (Figure 43.)
4. Place the PTO switch in the ON position, knob pushed down (Figure 44).
5. Set VOM to Ohm. Test the top, middle, and bottom rows of terminals for continuity (Figure 44).

Replace a switch that does not pass all tests.

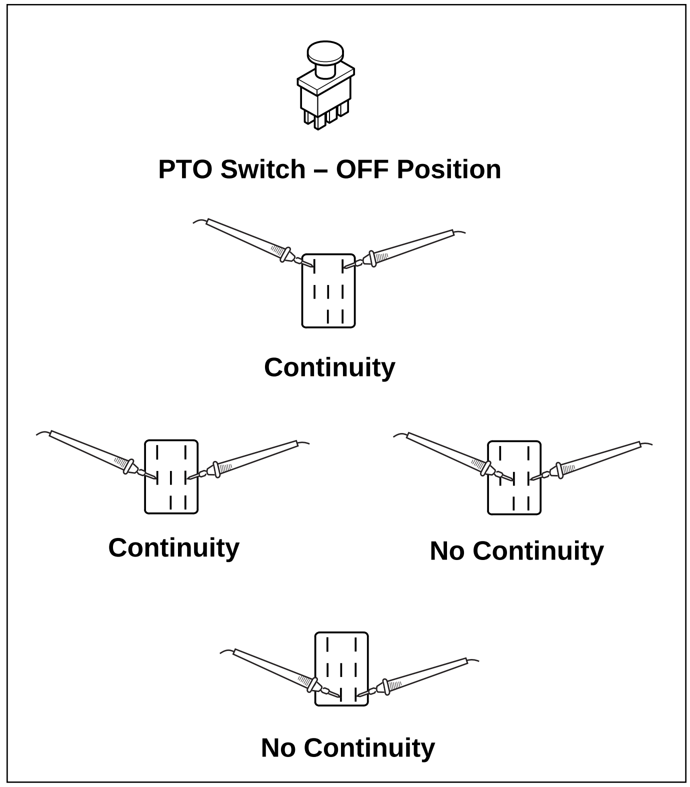


Figure 43. Test PTO Switch – OFF Position

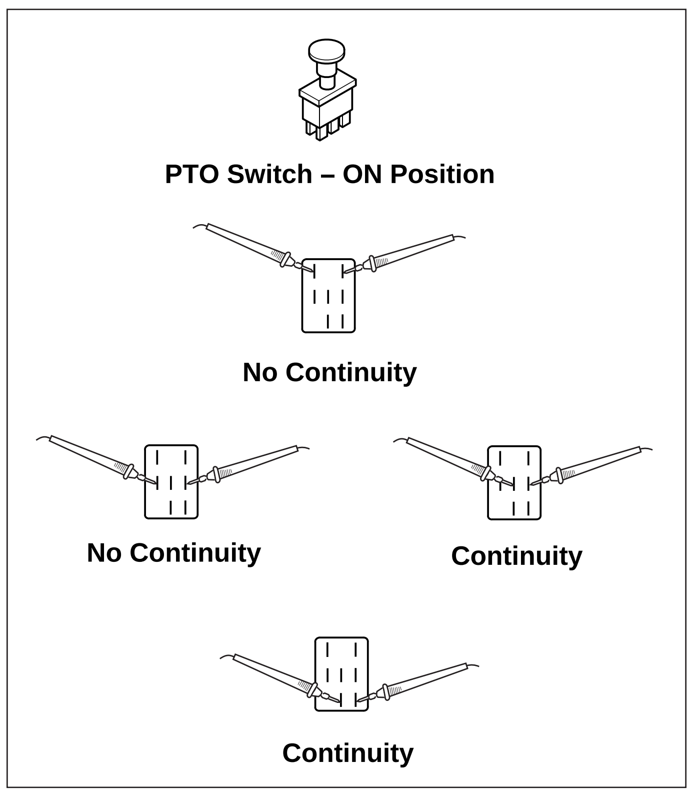


Figure 44. Test PTO Switch – ON Position

J. Accessory Power Connector Test

See Figure 46.

1. Disconnect any accessory connector from the accessory power plug.
2. Set VOM to DC Volts.
3. Connect the negative (-) test meter probe to the top pin (male) of the accessory power connector.
4. Connect the positive (+) test meter probe to the second pin (female) of the accessory power connector.
5. Press the height of cut switch to the up position. The connector should have 12 volts dc.
6. Connect the positive (+) test meter probe to the top pin (male) of the accessory power connector.
7. Connect the negative (-) test meter probe to the second pin (female) of the accessory power connector.
8. Press the height of cut switch to the down position. The connector should have 12 volts dc.

If either position of the switch did not function properly, begin further troubleshooting by checking the connectors between the accessory power connector and the switch and check the wiring. Then check the height of cut switch.

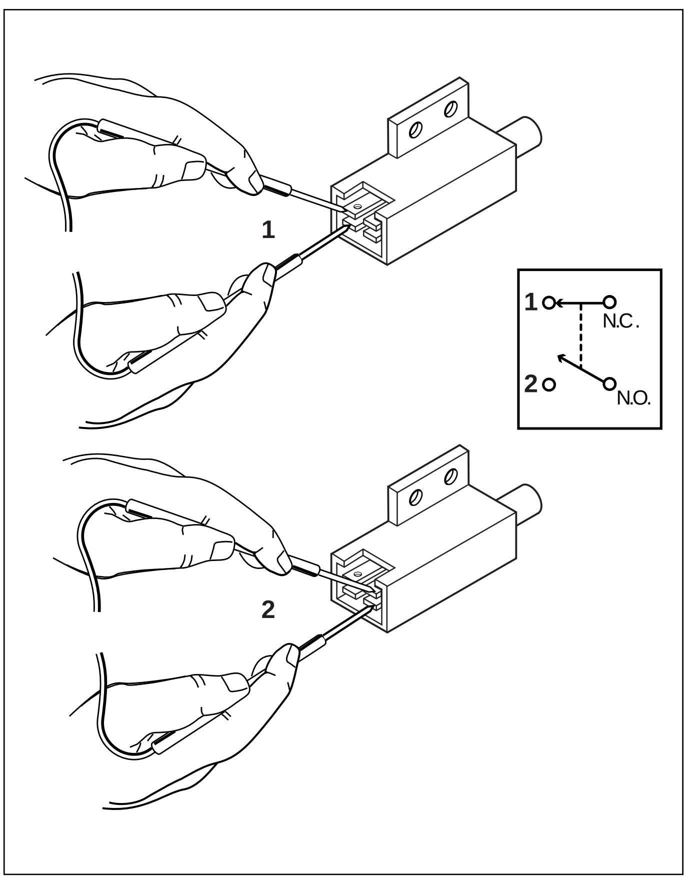


Figure 45. Cruise Control Switch

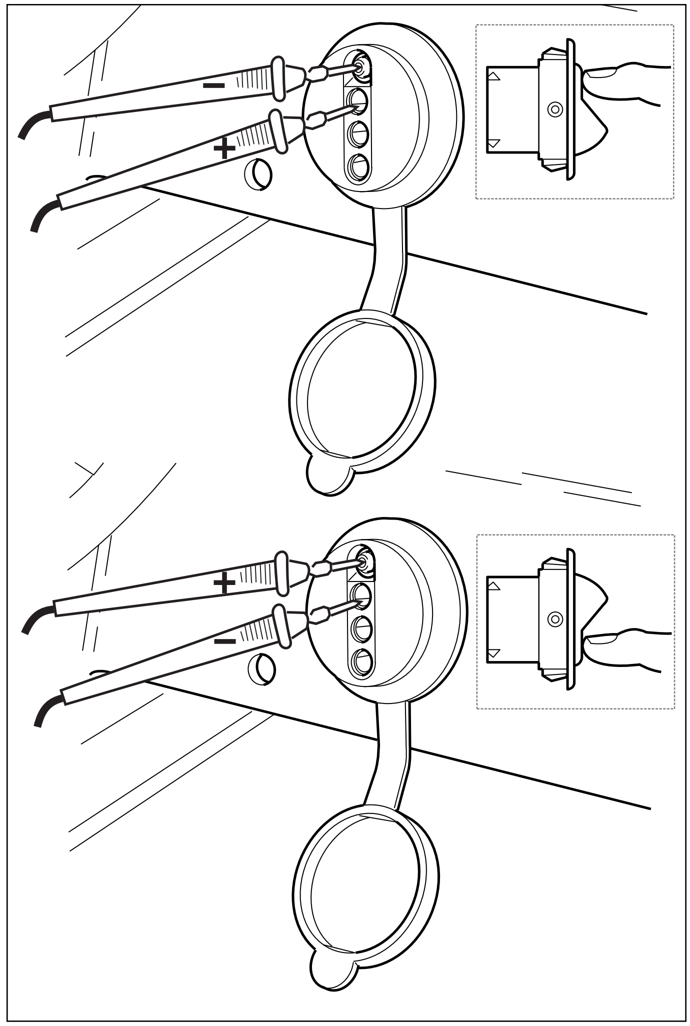


Figure 46. Testing Accessary Connector

K. Cruise Control Switch Test

The cruise control switch has a N.C. contact and closes when the cruse control is engaged. When the cruise control lever is in the disengaged position, the lever pushes in the plunger on the switch, opening the contacts.

SWITCH TESTS

NOTE: It may be easier to test the switch if the switch is removed. See Component Location and Replacement for switch removal procedures, earlier in this section.

1. Pull the wire harness off the back of the switch.
2. Set VOM to Ohm. With the cruise control lever in the engaged position (plunger not depressed) probe the switch terminals (see Figure 45). The VOM should show continuity (zero ohm).
3. Release the cruise control lever (disengage cruise control). Probe the switch terminals (see Figure 45). The VOM should show no continuity (open).
4. Replace a switch that does not pass all tests.

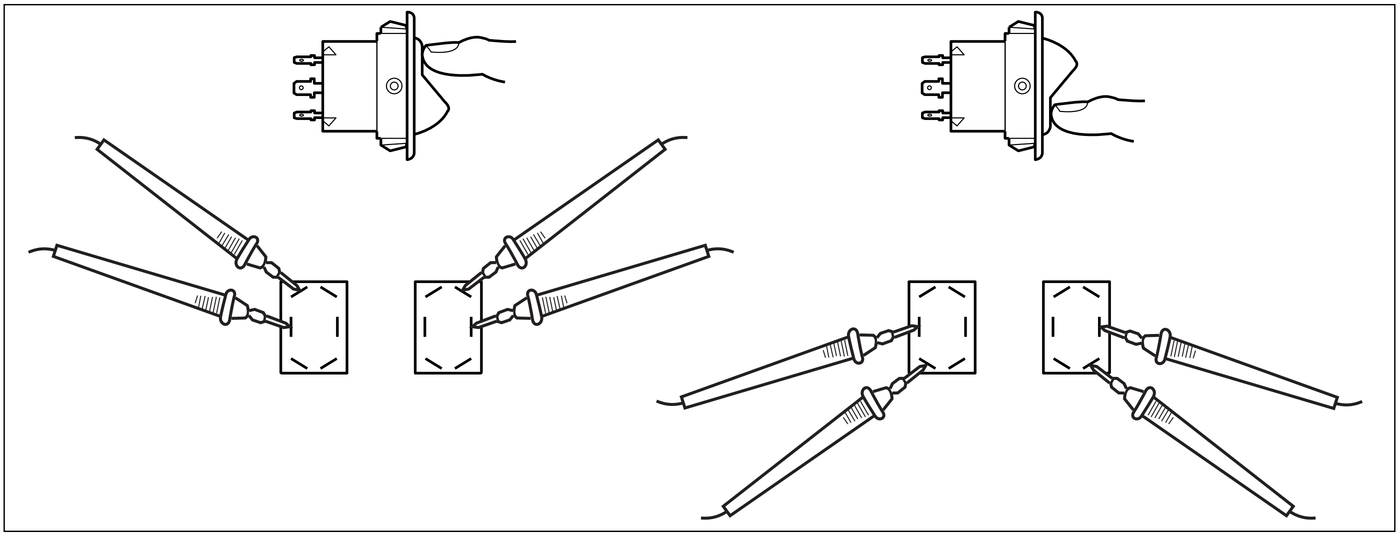


Figure 47. Testing Cut Height Switch

L. Height of Cut Switch Test

See Figure 47.

1. If necessary, remove the steering wheel and dashboard. (See Section 8, POWER STEERING SYSTEM SERVICE.)
2. Remove the connector from the height of cut switch.
3. Remove the height of cut switch from the control panel.
4. Set VOM to Ohm.
5. Press the switch to the up position and check the terminals on the back of the switch as shown in Figure 47. There should be continuity on the terminals shown when the switch is pressed.
6. Press the switch to the down position and check the terminals on the back of the switch as shown in Figure 47. There should be continuity on the terminals shown when the switch is pressed.

M. Brake Pedal Switch Tests

The foot pedal switch has four terminals for the two contacts. Air-cooled engine models use a N.C. and a N.O. contact as shown in A of Figure 48. Liquid-cooled engine models use two N.O. contacts as shown in B of Figure 48.

A N.O. contact is normally open, meaning that when the brake pedal is at rest (up, not depressed) the switch is open and will not conduct current. Depressing the brake pedal (or switch plunger) closes the switch. The opposite applies for the N.C. contact.

SWITCH TESTS

NOTE: It may be easier to test the switch if the switch is removed. See Component Location and Replacement for switch removal procedures, earlier in this section.

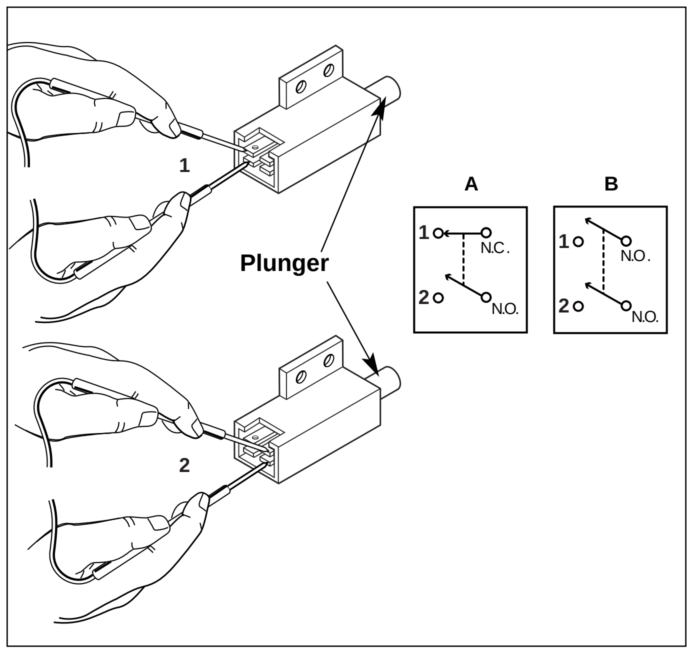


Figure 48. Brake Pedal Switch

1. Pull the wire harness off the back of the switch.
2. Set VOM to Ohm. With the brake pedal up (plunger not depressed) probe the switch terminals (see Figure 48). The VOM should show no continuity for N.O. contacts and continuity for N.C. contacts.
3. Depress the brake pedal and engage the parking brake.
4. With the brake pedal depressed (plunger depressed) Probe the switch terminals (see Figure 48). The VOM should show continuity for N.C. contacts and no continuity for N.O. contacts.
5. Replace a switch that does not pass all tests.

N. Seat Switch Safety Interlock Test

Check the seat switch (B, Figure 49) with the following tests.

Engine should shut off if:

A. Operator rises off seat with the brake pedal NOT depressed.

B. Operator rises off seat with electric clutch engaged.

C. Operator rises off seat with cruise control lever engaged.

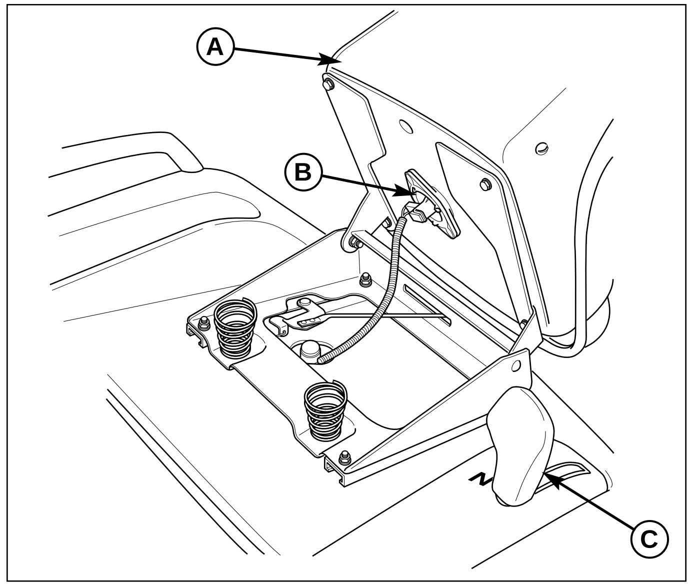


Figure 49. Seat Switch Safety System
A. Seat **C. Cruise Control Lever**
B. Seat Switch

O. Seat Switch Test

See Figure 50.

The liquid-cooled and diesel engine models have a N.O. (normally open) seat switch. When the seat is unoccupied, the switch is open and will not conduct current. Sitting in the seat closes the switch.

The air-cooled engine models have a N.C. (normally closed) seat switch. When the seat is unoccupied, the switch is closed and will conduct current. Sitting in the seat opens the switch.

1. Tilt the seat forward and pull the wire harness off the back of the switch.
2. Set VOM to Ohm. With the switch at rest (no operator pushing down on the seat) probe the switch terminals. The VOM should show no continuity (open) for liquid-cooled engine models and continuity (zero ohm) for air-cooled engine models.
3. Press down in the middle of the seat to activate the switch.
4. Probe the switch terminals. The VOM should show continuity (zero ohm) for liquid-cooled engine models and no continuity (open) for air-cooled engine models.
5. Replace a switch that does not pass all tests.

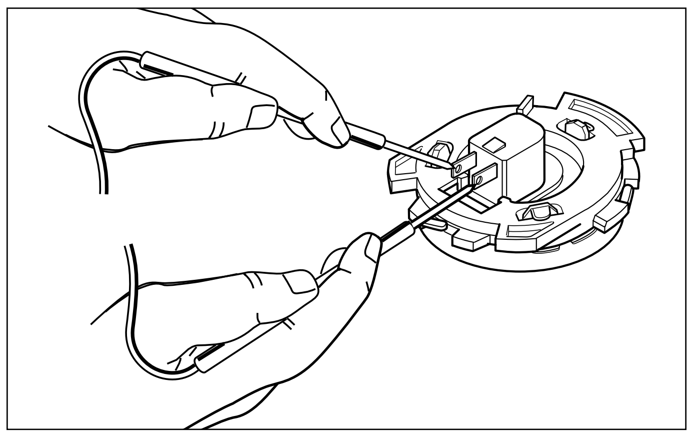


Figure 50. Test Seat Switch

P. Circuit Breaker Test

See Figure 51.

The circuit breaker is connected to one of the small solenoid posts along with the positive battery cable.

1. Set the VOM to VDC.
2. With the negative probe, touch ground.
3. Touch the positive probe to one post of the circuit breaker, and then the other. Both posts should have close to full battery voltage going to them. If not, replace the breaker.
4. Set VOM to Ohm.
5. Disconnect the circuit breaker leads and probe both circuit breaker terminals. If the VOM reads 5 ohm or more, replace the circuit breaker.

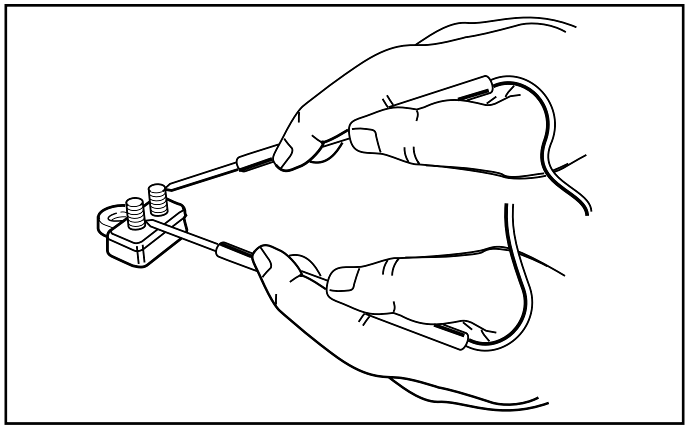


Figure 51. Testing Circuit Breaker

Q. PTO Clutch

Refer to Section 16, PTO CLUTCH SERVICE, for compete PTO clutch testing information and replacement procedures.

R. Headlight Switch Test

1. If needed, remove the steering wheel and dashboard. (See Section 8, POWER STEERING SYSTEM SERVICE.)
2. Set the VOM to Ohm.
3. With the switch in the OFF position, probe both terminals (Figure 52). The VOM should read no continuity.
4. Turn the switch to ON. The VOM should read continuity.

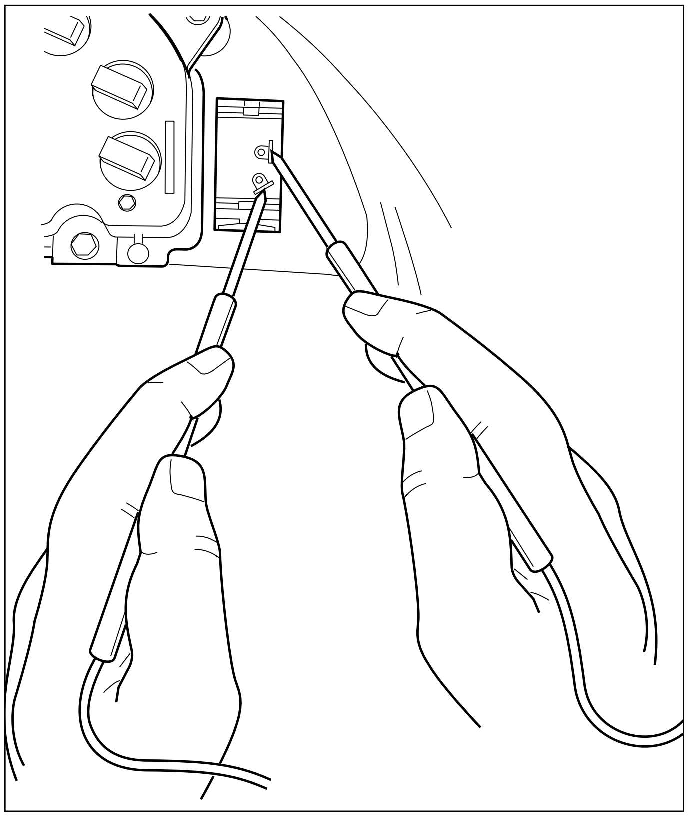


Figure 52. Testing Driving Light Switch

S. Fuel Solenoid Test

Refer to the engine manufacturer's operators manual for information relating to engine components.

1.Turn the ignition switch from OFF to RUN. There should be an audible "click" as the shut-off solenoid opens.

If there is no "click" use a VOM set to VDC. Test the voltage between the solenoid lead and ground. With the ignition switch in the RUN position, the lead should have 12 volts. If not, check the ignition switch and wiring.

If the solenoid is receiving 12 VDC and is not opening, replace the solenoid.

T. Voltage Regulator

The voltage regulator is part of the engine, refer to the engine manufacturer's operators manual for information relating to engine components. On some alternators the voltage regulator is built in.

U. Alternator

Refer to the engine manufacturer's operators manual for information relating to engine components.

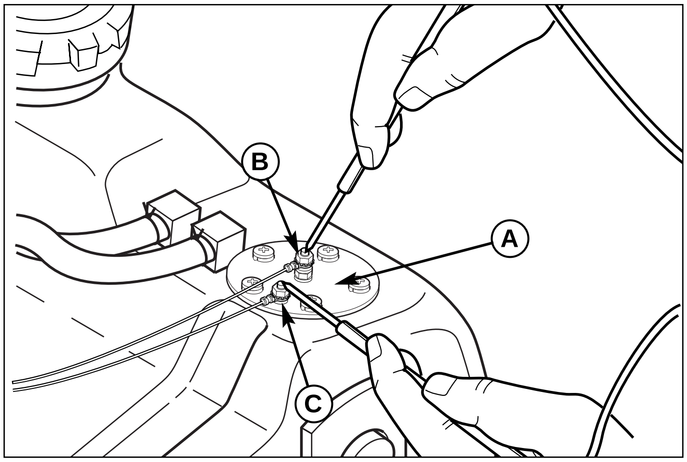


Figure 53. Fuel Level Sensor Volt Test
A. Sensor
B. Signal Terminal
C. Ground Terminal

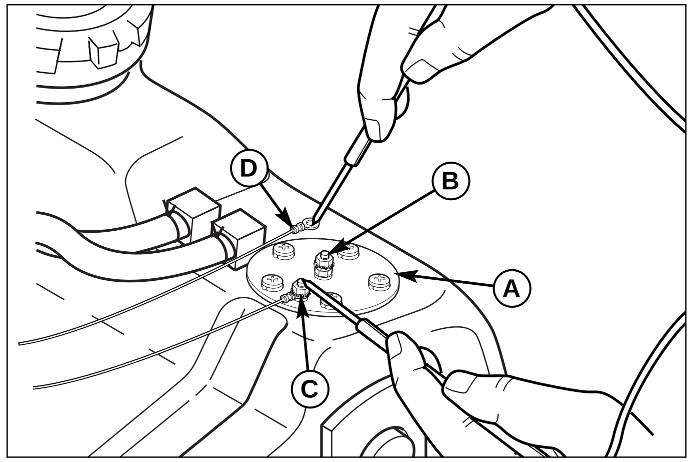


Figure 54. Fuel Level Sensor Signal Test
A. Sensor
B. Signal Terminal
C. Ground Terminal
D. Signal Wire

V. Fuel Level Signal Test

This test should be done before you fill the fuel tank, when the tank is near empty. If it is full, empty the tank before proceeding with this test.

1. Remove seat deck (refer to Section 15, SEAT DECK SERVICE).
2. Set the volt meter to dc volts.
3. Connect the black negative (-) test probe to the ground terminal (C, Figure 53) and the red positive (+) test probe to the signal terminal (B) to measure the voltage drop across the sensor.
4. The dc voltage level read on the volt meter when the tank is empty should be about 1 to 4 volts dc.
5. Slowly begin filling the fuel tank with the proper fuel while watching the voltage level. As the fuel tank is filled, the voltage level should increase.
6. If the voltage does not change or is at or near zero volts dc, remove the signal wire (D, Figure 54) from the fuel level sensor, which is the center wire and terminal (B).
7. Connect the black negative (-) test probe to ground terminal (C) or the negative (-) battery post and the red positive (+) test probe to the signal wire (D).
8. The volt meter should read approximately 12 volts dc. If the voltage is near zero or below 11 volts dc, replace the instrument panel. If the voltage is ok, proceed to the Fuel Level Sensor Ohm Test.

W. Fuel Level Sensor Test

1. Remove seat deck (refer to Section 15, SEAT DECK SERVICE).

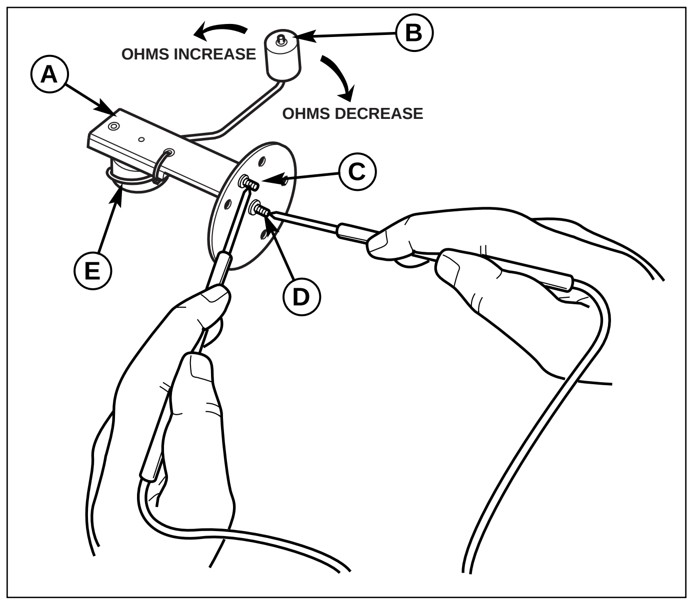


Figure 55. Fuel Level Sensor Ohm Test
A. Sensor Frame
B. Float
C. Ground Terminal
D. Signal Terminal
E. Variable Resistor

2. Remove the fuel level sensor assembly.
3. Using an ohm meter, measure the resistance across the ground terminal (C, Figure 55) and signal terminal (D).
4. Move the float (B) up and down, the resistance should change as you move the float. The range is from 30 ohm when the float is in the full position to 300 ohm when the float is in the empty position.

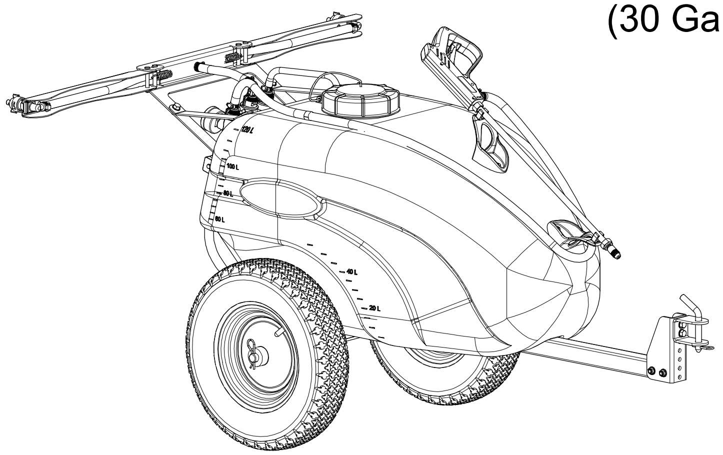
Notes

7 - 46

OWNER'S MANUAL

Model: LG-30-TRL (5302317)

(30 Gallon Lawn & Garden Trailer Sprayer)



Technical Specifications

- 30 Gal. Corrosion-Resistant Polyethylene Tank
- 12 Volt Diaphragm Pump, 2.4 GPM - 60 PSI
- 15 Ft. Handgun Hose
- 25 Ft. max. vertical throw, 40 Ft. horizontal throw
- 2-Nozzle Break-Away Boom Assembly (80" Spray Coverage)
- Corrosion-Resistant Nylon Nozzles
- Check Valve Strainers, 50 Mesh, 5 PSI
- Easy access drainage port (Complete Drain Out)
- Front forward gun and hose wrap for easier access from transport vehicle
  - Heavy Duty 16" tires
  - Wide Axle
  - Streamlined tank design for compact storage and shorter turning radius

Caution: Always check the vehicle load rating before using the sprayer. The loaded weight of this sprayer and boom assembly is approx.: 320 lbs. when the tank is full.

General Information

Thank you for purchasing this product. The purpose of this manual is to assist you in operating and maintaining your lawn & garden Trailer sprayer.

WARNING: To reduce the risk of injury, the user must read and understand the operator's manual before using this product.

WARNING: Cancer and Reproductive Harm
www.P65Warnings.ca.gov

NOTE: Maximum Speed - 5 MPH
Refer to vehicle's manual for towing instructions

BEFORE RETURNING THIS PRODUCT FOR ANY REASON, PLEASE CALL

1-800-831-0027

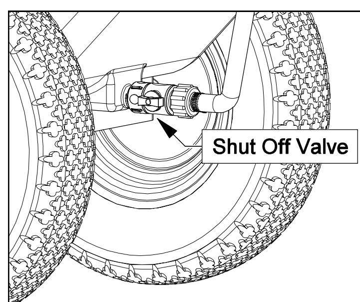
MONDAY-FRIDAY, 8:00 AM TO 5:00 PM CST

If you should have a question or experience a problem with your Fimco Industries Product: Visit our website @ www.fimcoindustries.com or call the Toll free number above. Our technical support representatives will be happy to help you. In most cases a customer service rep. can resolve the problem over the phone.

To obtain prompt, efficient service, always remember to give the following information....
• Correct Part Description and/or part number
• Model number and Serial Number
Part descriptions and numbers can be obtained from the illustrated parts list section(s) of this manual.

Assembly Instructions

- Make sure the contents of the sprayers carton match the items shown on page 2 of the manual.
- Follow the steps on pages 3 & 4 to properly assemble the sprayer.



IMPORTANT:

This sprayer comes with an On/Off (shut-off) valve located at the inlet location of the tank, towards the underside. You must make sure the valve is in the "open" position before using your sprayer.

Retain a copy of your receipt for your unit, as it will be required to validate any warranty service.

Warranted against manufacturer or workmanship defects from date of purchase with copy of receipt:

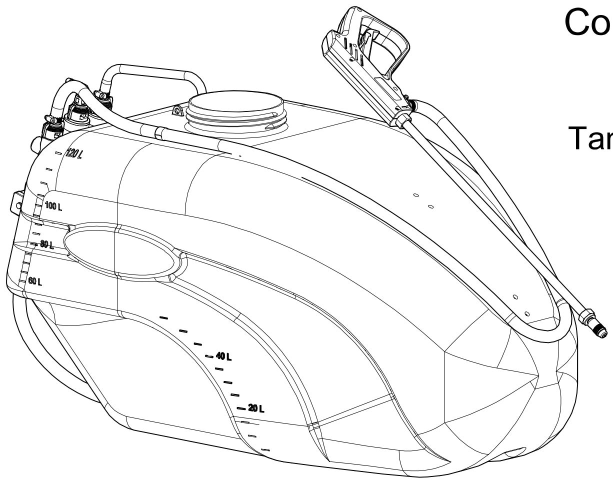
Homeowner Usage: Sprayer-One Year and Pump-Two Years.

Commercial Usage: Sprayer and Pump-90 Days.

FIMCO INDUSTRIES

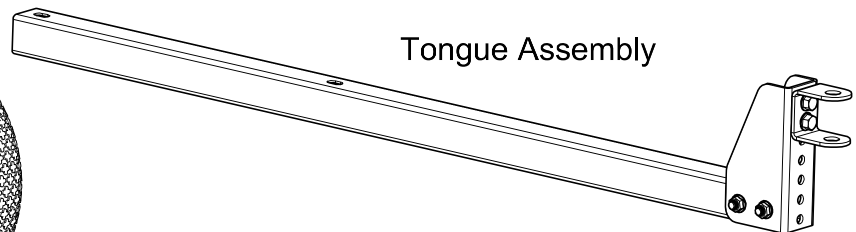
www.fimcoindustries.com
1000 FIMCO Lane, P.O. Box 1700, North Sioux City, SD 57049
Toll Free Phone: 800-831-0027 : Toll Free Fax: 800-494-0440
[5194822 (02/20)]

Contents of your sprayer's carton (LG-30-TRL)

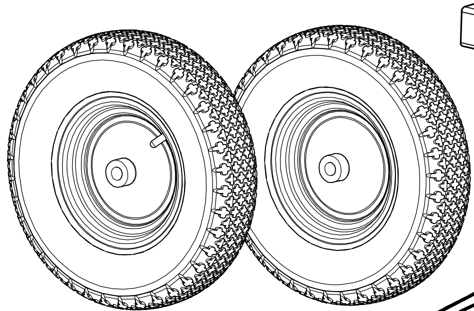


Tank/Plumbing Pre-Assembly

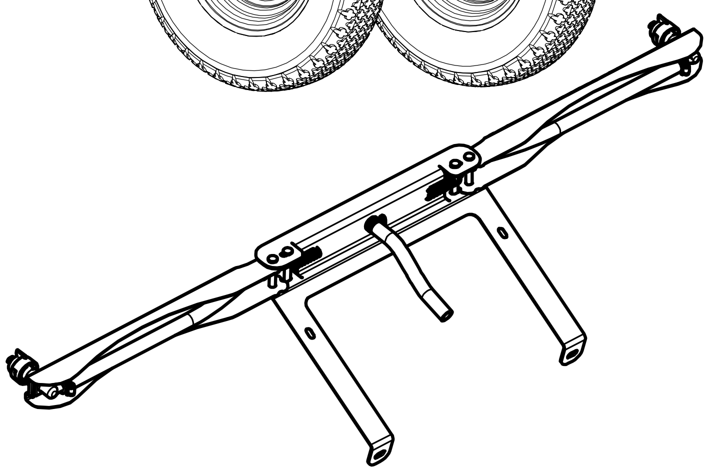
Owner's Manual



Tongue Assembly

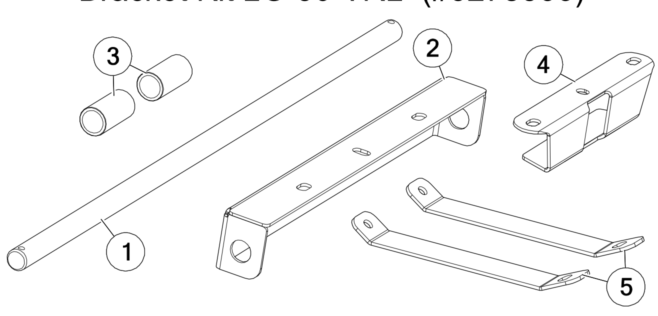


Tires



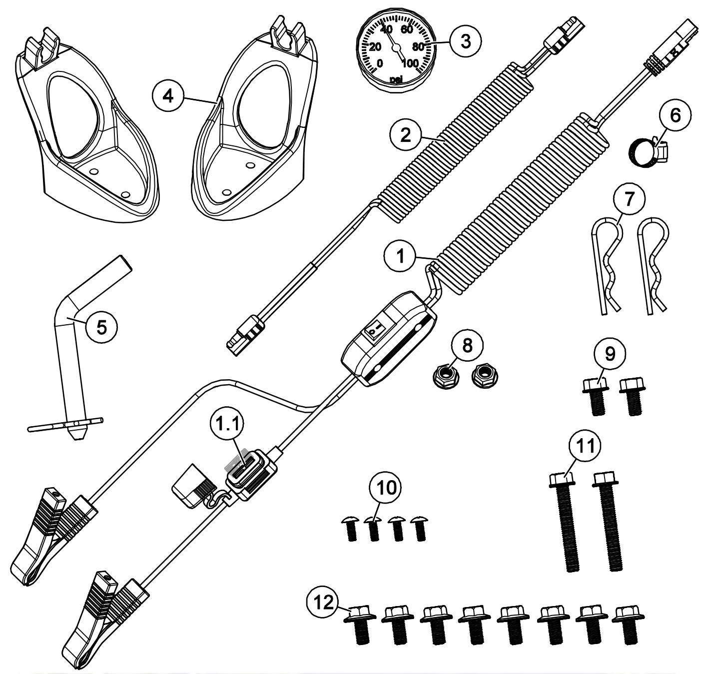
Breakaway Boom

Bracket Kit LG-30-TRL (#5278366)



Ref. #	Part #	Description	Qty
1	5101351	Wide Axle, 3/4" x 25.8125"	1
2	5095371	Axle Mount (LG-30-TRL)	1
3	5127226	3/4" X 2" Axle Spacer	2
4	5095373	Tank Support (LG-30-TRL)	1
5	5037868	Boom Top Strap	2

Contents of Parts Bag (#5278364)



Ref. #	Part #	Description	Qty
1	5278114	Lead Wire Assembly w/15A Fuse (96" Long)	1
1.1	5157238	15 Amp Regular Blade Fuse	1
2	5273212	5 Ft. Extension Cable	1
3	5167097	2" Dry 100# Back Mount Gauge	1
4	5133276	30 Gallon Hose Wrap	2
5	5101202	Bent Clevis Pin (1/2" Dia.) w/Clip	1
6	5051144	Hose Clamp, 3/8"	1
7	5101065	#211 Hitch Pin Clip (Zinc Plated)	2
8	5006307	5/16-18nc Hex Flanged Whiz Nut Gr. 5	2
9	5034634	H.H.C.S. Flanged 5/16"-18nc x 5/8" Long	2
10	5117234	#10-24 x 1/2" Phillips Truss Head Machine Screw	4
11	5034641	H.H.C.S. Flanged 5/16"-18nc x 2 1/4" Long	2
12	5034531	5/16"-18 x 5/8" Flange Lock Screw	8

Your tank comes pre-assembled with the pump, manifold, bypass, intake assembly, lid w/lanyard, handgun, handgun hose, handgun hose quick connect and loom clamp already attached.

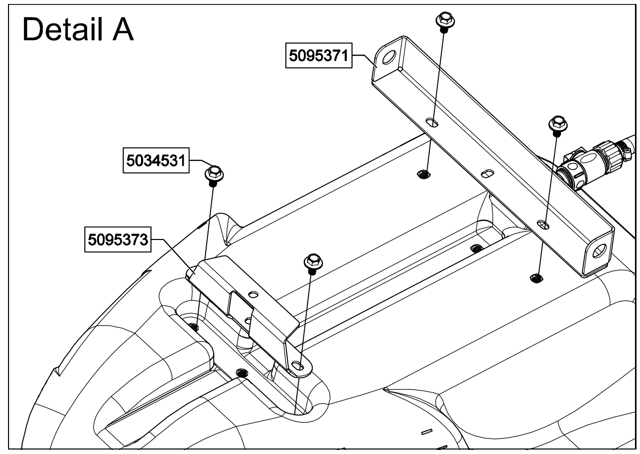
To assemble the tongue and frame to the tank. Locate the (4) 5/16” x 5/8” Flange Lock Screws, (2) 5/16” x 2-1/4” Flanged bolts, tank support, axle support and the preassembled tongue .

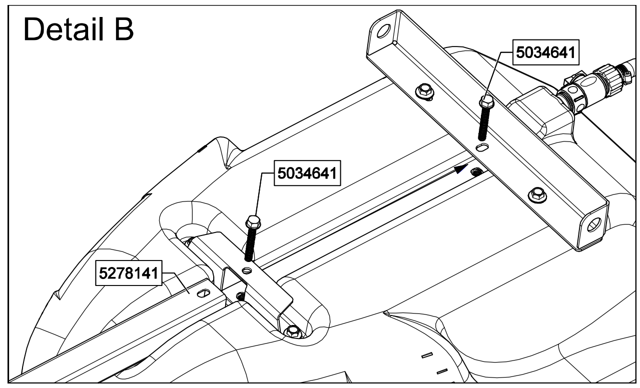
Turn the tank upside down.

Detail A: Loosely attach the tank support and axle support with (4) lock screws.
Just start the bolts, do not tighten on either support.

Detail B: Slide the tongue assembly into place and using the (2) flanged bolts, attach to the tank and tighten. Do Not Overtighten.

Then tighten the (4) lock screws. Do Not Overtighten.





Locate the axle, spacers and (2) wheels from the carton.

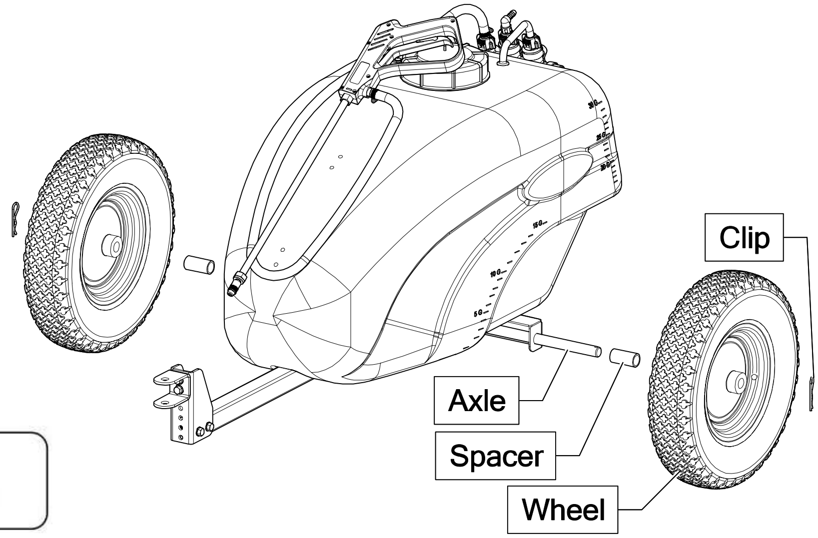
Remove the (2) Hair Pin Clips from the parts bag.

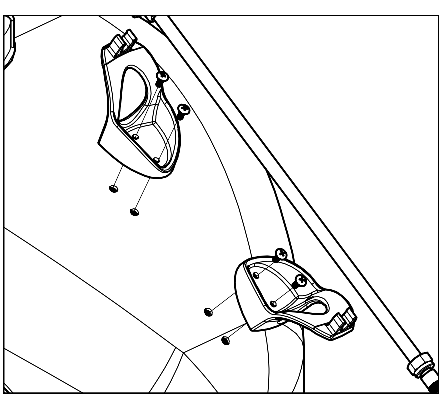
Slide the axle through the hole in one side of the axle mount and through the corresponding hole on the other side. Then slide the spacers onto the axle.

Slide the wheels over the axle, making sure the valve stems are facing outward.

Retain the wheels on the axle with the hair pin clips. Place the pins through the holes at the end of the axle.

NOTE: Maximum Speed - 5 MPH
Refer to vehicle’s manual for towing instructions





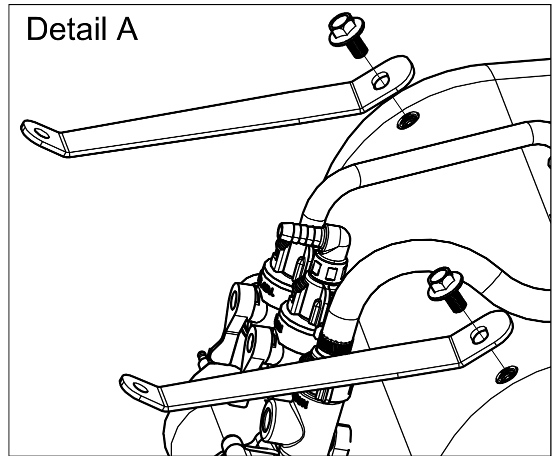
• A phillips head screwdriver is required for this step

Turn the trailer right side up.
Locate the (4) #10 x 1/2” Screws and the (2) Hose Wraps from the parts bag.

Place a screw through the holes in the hose wrap and bring it up to the tank. Use the phillips head screwdriver to secure the holders in place. Tighten so the holders are secure. **Do Not Over-Tighten**

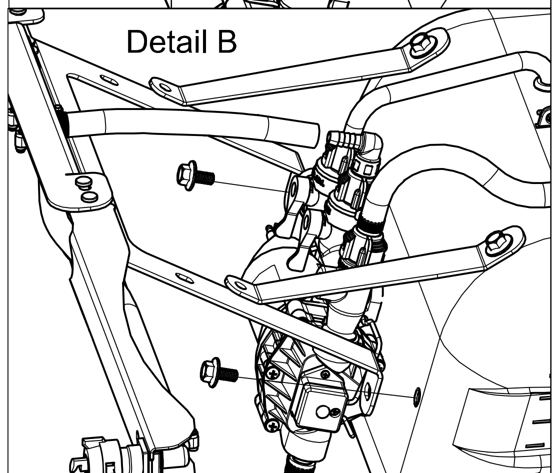
Wrap the hose and clip in the handgun. Do not use excessive force when placing the handgun into the clips, as this could cause breakage.

Break-Away Boom Assembly is preassembled. Follow the directions below to mount to your tank.



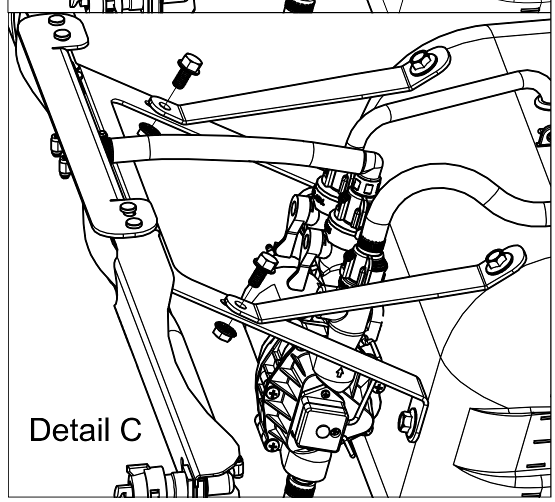
Detail A:
Locate the (2) Boom Top Straps and then in the parts bag, locate (2) 5/16-18 x 5/8" Flanged Lock Screws.

Attach the Boom Top Straps to the tank, using the two screws.
DO NOT TIGHTEN



Detail B:
Locate the Boom Assembly and then in the parts bag, locate (2) 5/16-18 x 5/8" Flanged Lock Screws.

Attach the Boom Assembly to the tank, using the two screws.
DO NOT TIGHTEN

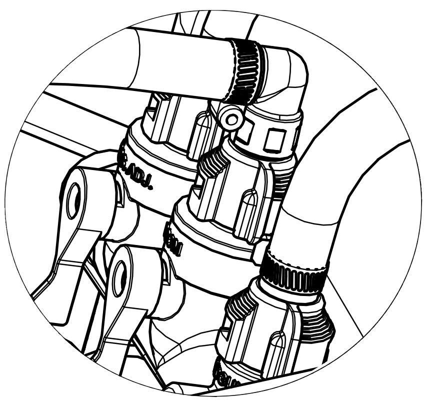


Detail C:
Locate in the parts bag (2) 5/16-18 x 5/8" Flanged Bolts and (2) Whiz Nuts.

Attach the Boom Top Straps to the Boom Assembly using the two bolts and whiz nuts.

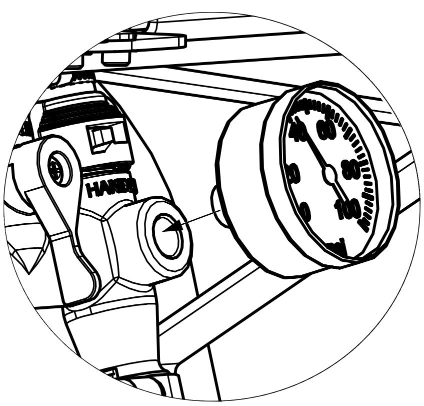
**** Tighten all Bolts from Details A, B & C ****
**** DO NOT OVERTIGHTEN ****

After the boom is installed, attach the 8" Feeder Hose to the 90° HB Elbow on the manifold.

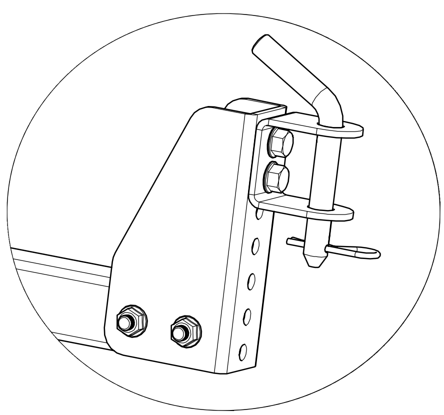


The boom is now installed.

Final Steps:



Locate the Pressure Gauge in the parts bag and thread into the open port on the manifold.

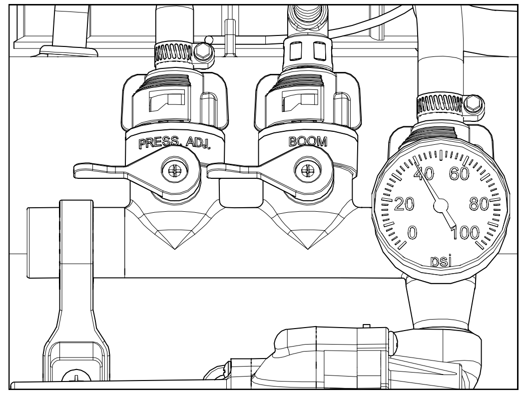


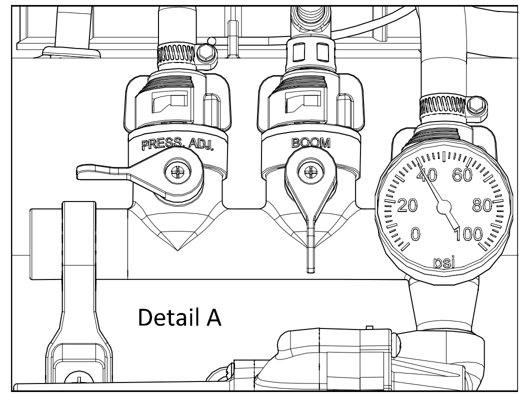
Locate the Bent Clevis Pin in the parts bag and place in the hole on the hitch.

*** The Sprayer should now be ready for use ***

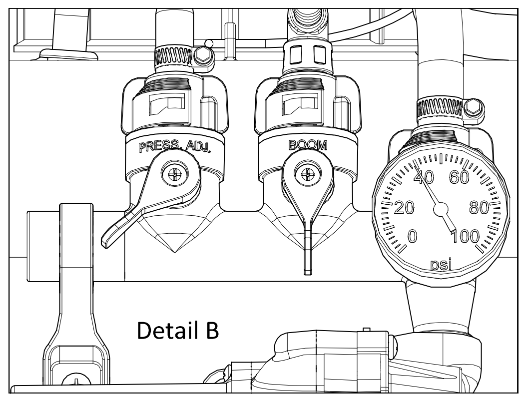
IMPORTANT: <u>Remove tank lid and be sure the tank is clean and free of any foreign material. Rinse tank out of any tank residue before filling with water to test.</u>

Manifold Valves CLOSED





Detail A



Detail B

Testing the Sprayer

NOTE:
It is VERY important for you to test your sprayer with plain water before actual spraying is attempted. This will enable you to check the sprayer for leaks without the possibility of losing any expensive chemicals.

Fill the tank about 1/2 full with plain water and drive to the starting place for spraying.

When you are ready to spray, turn the boom valve to the "on" position (Detail A). This will start solution spraying from the tips of the boom. The pressure will decrease slightly when the boom is spraying.
Adjust the pressure by turning the "ON/OFF" valve lever on the bypass line valve (Detail B). Make sure your pattern is sufficient. You may down-pressure the system by 'bypassing' solution back into the tank. This is achieved by opening the bypass valve. Regulating pressure is done in this manner.

Read the operating instructions and initially begin spraying by closing the 'Pressure Adjust' valve and opening the boom line valve (Detail A). This will enable the air in the line to be eliminated (purged) through all the tips, while building pressure. When everything tests all right (no leaks and good pressure), add the desired chemicals to the mixture and water combination and start your spraying operation. Adjust the pressure and spray as you did in the testing procedure.
Conditions of weather and terrain must be considered when setting the sprayer. Do not spray on windy days. Protective clothing must be worn in some cases.

Be sure to read the chemical label(s) before application!

Operation

The pumping system draws solution from the tank, through the strainer and to the pump. The pump forces the solution under pressure to the handgun or boom nozzles.

Connect the lead wire to a fully charged 12 volt battery. You may use either a stand-alone battery or the battery on your towing vehicle. Connect to the positive (red) terminal first, then connect to the negative (black) terminal. Then connect the end of the lead wire to the end of the pump. When disconnecting, disconnect the end of the pump wire from the lead wire, then disconnect the negative (black) connection and finally the positive (red) connection. The lead wire has an On/Off switch to activate the pump. "-" is on and "O" is off.

Fill the tank part way with water and then add the desired amount of chemical to be sprayed. Finish filling tank to proper level. Turn the pump on and by depressing the "-" side of the rocker switch. The pump is equipped with a pressure switch that is pre-set at the factory to shut the pump off when all discharges are closed.

The pump will turn back on when one of the following actions occurs:

- ♦ Handgun lever is squeezed to spray the handgun.
- ♦ Boom valve is opened to broadcast spray with the boom.
- ♦ Bypass valve is opened to re-circulate solution back into the tank.

When spraying with either the boom or the handgun, pressure may be reduced by slowly opening the bypass valve until desired pressure is achieved. Opening the valve decreases pressure, closing the valve increases pressure. When spraying with the boom, the proper method to set the pressure is to open the boom valve completely and if a lower pressure is desired, then slowly open the bypass valve until that pressure is obtained.

For the safest and most efficient chemical application, you will need to calibrate your sprayer using the tip and speed charts. Once you have determined the proper speed and pressure settings, you will need to consult your chemical label for the amount of chemical to be added to the tank. Read the entire label. Use only according to label directions.

Calibration

Chemical labels may show application rates in gallons per acre, gallons per 1000 square feet or gallons per 100 square feet. You will note that the tip chart shows 3 of these rating systems. Once you know how much you are going to spray, then determine (from the tip chart) the spraying pressure (PSI), and the spraying speed (MPH).

Determining the proper speed of the pulling vehicle can be done by marking off 100, 200 & 300 feet. The speed chart indicates the number of seconds it takes to travel the distances. Set the throttle and with a running start, travel the distances. Adjust the throttle until you travel the distances in the number of seconds indicated by the speed chart. Once you have reached the throttle setting needed, mark the throttle location so you can stop and go again, returning to the same speed.

Add water and proper amount of chemical to the tank and drive to the starting place for spraying.

Speed Chart

	Time Required in seconds		
Speed in M.P.H. (Miles Per Hour)	100 Ft.	200 Ft.	300 Ft.
1.0	68 sec.	136 sec.	205 sec.
2.0	34	68	102
3.0	23	45	68
4.0	17	34	51
5.0	14	27	41
6.0	11	23	34
7.0	9.7	19	29
8.0	8.5	17	26
9.0	7.6	15	23
10.0	6.8	14	20

Tip Chart for TKT-VP3, TF-VP3 & 30DT3.0 Tips

Tip No. (Color)	Pressure (psi)	Capacity (GPM)	Gallons Per Acre - Based on Water				
			1 MPH	2 MPH	3 MPH	4 MPH	5 MPH
3 (Gray)	10	.30	44	22	14.9	11.1	8.9
	20	.42	63	31.5	20.9	15.7	12.6
	30	.52	76	38	26	19.3	15.4
	40	.60	90	45	30	22	17.8
Tip No. (Color)	Pressure (psi)	Capacity (GPM)	Gallons Per 1000 Sq. Ft. - Based on Water				
			1 MPH	2 MPH	3 MPH	4 MPH	5 MPH
3 (Gray)	10	.30	1.01	.5	.34	.254	.204
	20	.42	1.4	.72	.48	.36	.29
	30	.52	1.74	.87	.596	.44	.35
	40	.60	2.06	1.00	.688	.50	.408
Tip No. (Color)	Pressure (psi)	Capacity (GPM)	Gallons Per 100 Sq. Ft. - Based on Water				
			1 MPH	2 MPH	3 MPH	4 MPH	5 MPH
3 (Gray)	10	.30	.10	.05	.034	.025	.02
	20	.42	.14	.072	.048	.036	.029
	30	.52	.174	.087	.059	.044	.035
	40	.60	.206	.10	.068	.05	.04

Using the Boom Nozzles

Four things must be considered before spraying with the boom.

1. How much chemical must be mixed in the tank.
2. Rate of spray (gallons per acre to be sprayed).
3. What pressure (p.s.i.) will be used.
4. Speed traveled (mph) while spraying.

* Refer to the chemical label to determine your chemical mixture
* See the tip chart to determine the pressure to be used. The chart will also show the speed used when spraying.
* Start the pump and open the valve to the boom nozzles.
* Check the spray pattern. Usually you can see the coverage better on a solid concrete surface, such as a driveway.

Maintenance During/After Spraying

Periodically check the strainer and clean the screen on your intake line.

Proper care and maintenance will prolong the life of your sprayer.

NOTE: Maximum Speed - 5 MPH
Refer to vehicle's manual for towing instructions

After use, drain the tank and store or dispose of chemical properly. Fill the sprayer half way with clean water. Start the pump and allow the water to pump through the entire plumbing system and nozzles. Drain and then refill half full, add the recommended amount of a good quality tank cleaner, such as FIMCO Tank Neutralizer and Cleaner. (If no tank cleaner is available, you may substitute dish soap for this step, about 1-2 oz. per gallon). Turn pump on and circulate through system for 15 minutes and then spray out through boom and handgun nozzles. Refill sprayer half way with clean water and repeat. Follow the chemical manufacturer's disposal instructions of all wash or rinsing water.
If boom or handgun nozzles need cleaning, remove them from the sprayer and soak in warm soapy water. Clean with a soft bristled brush or toothpick if necessary. Never use a metal object. Even the slightest damage can change the flow rate and spray distribution. Water rinse and dry the tips before storing.

WARNING: Some chemicals will damage the pump valves if allowed to soak untreated for a length of time! ALWAYS flush the pump as instructed after each use. DO NOT allow chemicals to sit in the pump for extended times of idleness. Follow the chemical manufacturer's instructions on disposal of all waste water from the sprayer.

Winter Storage

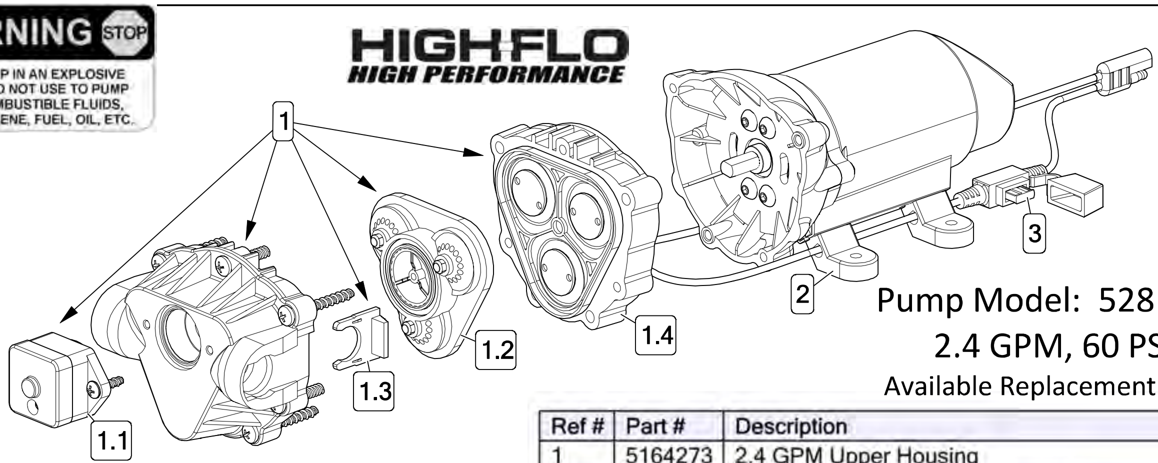
Prepare the sprayer for end-of-season storage by running RV antifreeze through the system. This will keep internal parts lubricated, protect against corrosion and keep the unit from freezing. *Note: RV antifreeze is non-toxic and biodegradable and generally safer for the environment than automotive antifreeze.*
Before storing your sprayer for winter or long term storage, thoroughly clean and drain it as much as possible. Then pour enough pink RV antifreeze into the tank so that when the pump is turned on you can pump the antifreeze throughout the entire plumbing system, including the bypass. Make sure to operate the boom and handgun until you see pink fluid spraying from the nozzles. Leave any remaining antifreeze in the tank. Before your next usage, rinse the antifreeze from the sprayer with clean water.
It is nearly impossible to drain all of the water from the sprayer and any trapped water can freeze in cold weather and damage parts of the sprayer. Pumping the antifreeze through the system will displace the water and help prevent this damage.

Removing from storage: drain the antifreeze. Fill the tank with fresh water and run through the system. Dispose of antifreeze and flush water properly.

WARNING

DO NOT USE PUMP IN AN EXPLOSIVE ENVIRONMENT. DO NOT USE TO PUMP FLAMMABLE/COMBUSTIBLE FLUIDS, GASOLINE, KEROSENE, FUEL, OIL, ETC.

HIGHFLO
HIGH PERFORMANCE



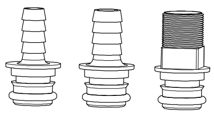
Pump Model: 5281371
2.4 GPM, 60 PSI

Available Replacement Parts

Ref #	Part #	Description	Qty
1	5164273	2.4 GPM Upper Housing	1
1.1	5157202	60 PSI Pressure Swtich Assembly	1
1.2	5143544	Check Valve Assembly	1
1.3	5051162	Pump Slide Clips (Pkg/2)	1
1.4	5063270	2.4 GPM Diaphragm /Piston/Cam/Bearing Kit	1
2	5095202	Pump Mount Feet (4 Pack)	1
3	5164274	10 Amp 'Mini Blade' Fuse	1

Replacement Pump: 5151087

Includes:



1/2" MNPT Port Kit Fitting #5168832
1/2" Hose Barb Port Kit Fitting #5168833
3/8" Hose Barb Port Kit Fitting #5168836

DO

- Clean and rinse your pump after each use with Fimco Tank Neutralizer
- Winterize your pump or sprayer by rinsing, draining and running RV Antifreeze through it before storing for the winter.
- Use clean water for your spray mixture
- Store inside a building when not in use.

DON'T

- Use to pump bleach.
- Use to pump petroleum products such as diesel fuel, gasoline or kerosene
- Leave your pump sit with spray mixture in it for extended periods
- Use dirty or unfiltered water for spraying

CAUTION

PRESSURE SWITCH OPERATION
Pressure switch is pre-set at the factory. Improper adjustment of the pressure switch, may cause severe overload or premature failure. If the pump is subjected to rapid cycling during normal operation, or infrequent periods, damage may occur.

Troubleshooting the Pump:

Motor does not run:
- Check for loose wiring connection(s).
- Make sure the 'ON/OFF' switch in the lead wire assembly is in the 'ON' position. "I" is the 'ON' position and 'O' is the 'OFF' position.
- Check for defective pressure switch. Make sure you are connected to a good 12 volt power source. Make sure any on/off switches are in the 'on' position. Remove the cap to the pressure switch. Pull both red wires off of their terminals, and touch the two ends together. If your pump runs when you do this, your pressure switch will need to be replaced.
- Check the fuse.
- Check for low voltage at the power supply.

Pump does not prime:
- Check for air leaks in supply line.
- Check for debris in the check valve assembly.
- Check for defective check valve.
- Check for clogged strainer/filter.
- Check for cracks in the pump housing.
- Check for empty product supply.

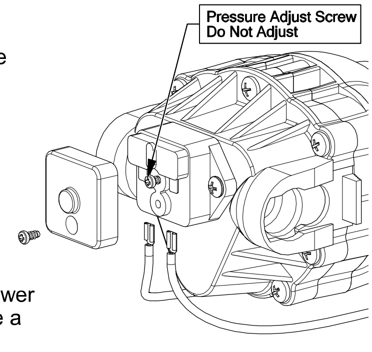
Low Pressure/Low Flow:
- Check for leaks in the discharge line.
- Check for restriction in the discharge line.
- Check for debris in nozzle orifice.
- Check for clogged strainer.
- Check for proper voltage—try another 12-volt battery.

Pulsating flow (surging):
- Low flow may cause pump to surge.
- Spray wand is adjusted for a small or fine spray pattern.
- Slightly open bypass (if applicable) to overcome.
- If needed, pressure switch may need to be adjusted—adjust a quarter turn at a time clockwise until surging stops.
- Check for defective pressure switch.
- Check for leaks in the discharge line.
- Check for restriction in the discharge line.
- Check for debris in nozzle orifice.
- Discharge hose may be too long.
- Check for clogged strainer.

Motor continues to run after discharge is shut off:
- Check for empty product supply.
- Check for open bypass valve. (if equipped)
- Check for low voltage.
- Check for leak in discharge line.
- Check for defective pressure switch.
- System has leaks.

Fuse blows:
- Excessive voltage.
- Improper adjustment of pressure switch.
- Damaged or defective wiring harness.
- Defective pressure switch.

Checking the Pressure Switch:



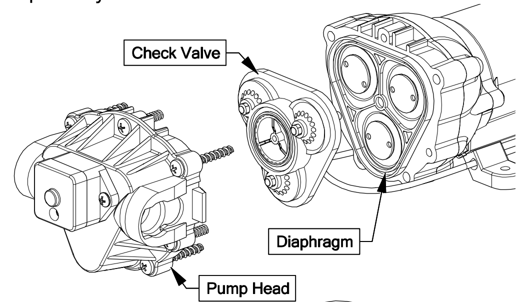
If your motor is not running and you've checked the following: for loose wiring connections, fuse, the switch on the lead wire was "ON" and made sure you were connected to a fully charged battery and everything is fine, but the motor won't run, then it's time to check to see if the pressure switch is bad.

- Remove the cover off the 1" square box (pressure switch) on the head of the pump, the cover is held on by one phillips-head screw. This will expose the two red wires.
- With the pump connected to a good 12 volt power source and everything on.
- Slip the two red wires off the terminals and touch them together.

If the motor runs, it means the pressure switch is bad and needs to be replaced.
If it still doesn't run, try bypassing the switch in the lead wire or using another lead wire. Even if a tester shows power to the pressure switch, it still could be the switch in the wire that is causing the problem. If still not responsive, use a voltmeter or electrical tester to make sure you are getting power to the head of the pump, as it could possibly be something in one of the wires or even the lead wire assembly may need to be replaced.

Warning: It is NOT recommended to run the pump this way, as the pump will continue to run and not shut off.

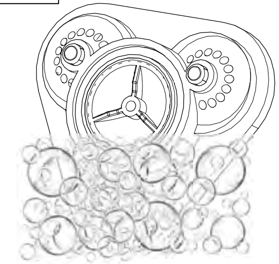
This could result in blown hoses when all discharges are closed.
Also, this could result in premature failure of the pump completely.



Cleaning the Check Valve:

If you're experiencing little to no pressure or the pump is not priming and you've checked your filter screen and it's clean, and you've gone through the other trouble shooting tips, you may need to clean the check valve.

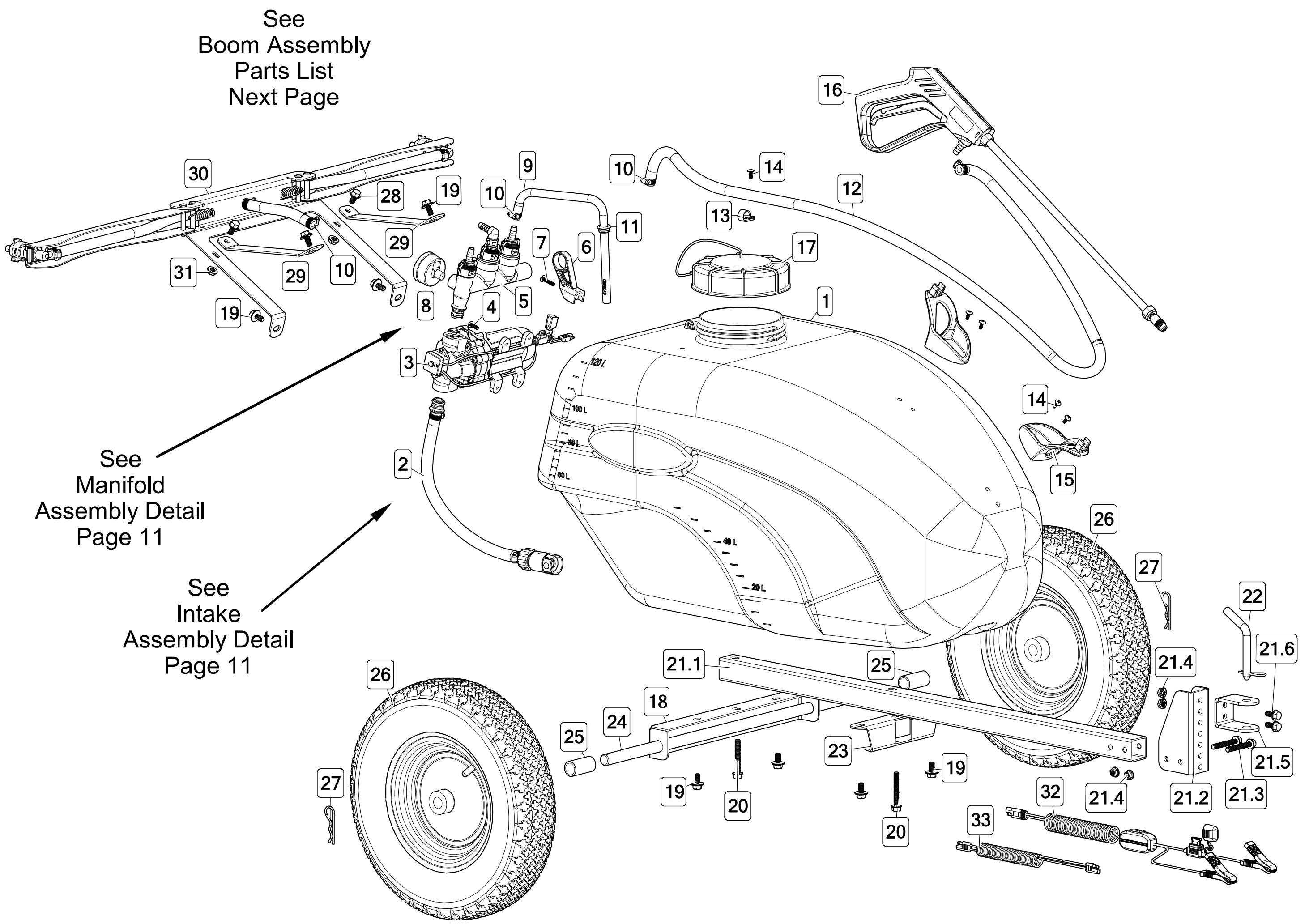
- Remove the head of the pump, which is held on by 7 screws.
- The first piece inside the head of the pump is called a check valve, it's the part responsible for building up pressure and pumping water/solution through the lines.
- Clean the check valve under hot, soapy water (such as a good grade dish soap).
- Give it a very light scrubbing with something like an old toothbrush, something with soft bristles.
- Then let it soak for about an hour or so in the hot soapy solution and replace in the pump and reassemble the pump.



Most times this will restore most, if not all of the prime of a pump.
If you're still having issues with pressure after this step, it would be recommended to replace this part.

Troubleshooting

Pump will not run:	Check for loose wiring
	Make sure the ON/OFF switch is on
	Check the fuse
	Check for defective pressure switch
Low Pressure/Low Flow:	Check for a clogged strainer
	Check for proper voltage Try another 12-Volt battery
	Check for worn or dirty check valve
Pump surges:	Low flow may cause pump to surge
	Spray wand is adjusted for a small or fine spray pattern
	Slightly open bypass (if applicable) to overcome
	If needed, pressure switch may need to be adjusted Quarter turn at a time clockwise until surging stops
Pump continues to run:	Bypass is not completely closed
	System has leaks
	Check for worn or dirty check valve
Fuse blows:	Excessive voltage
	Improper adjustment of pressure switch
	Damaged or defective wiring harness
	Defective pressure switch

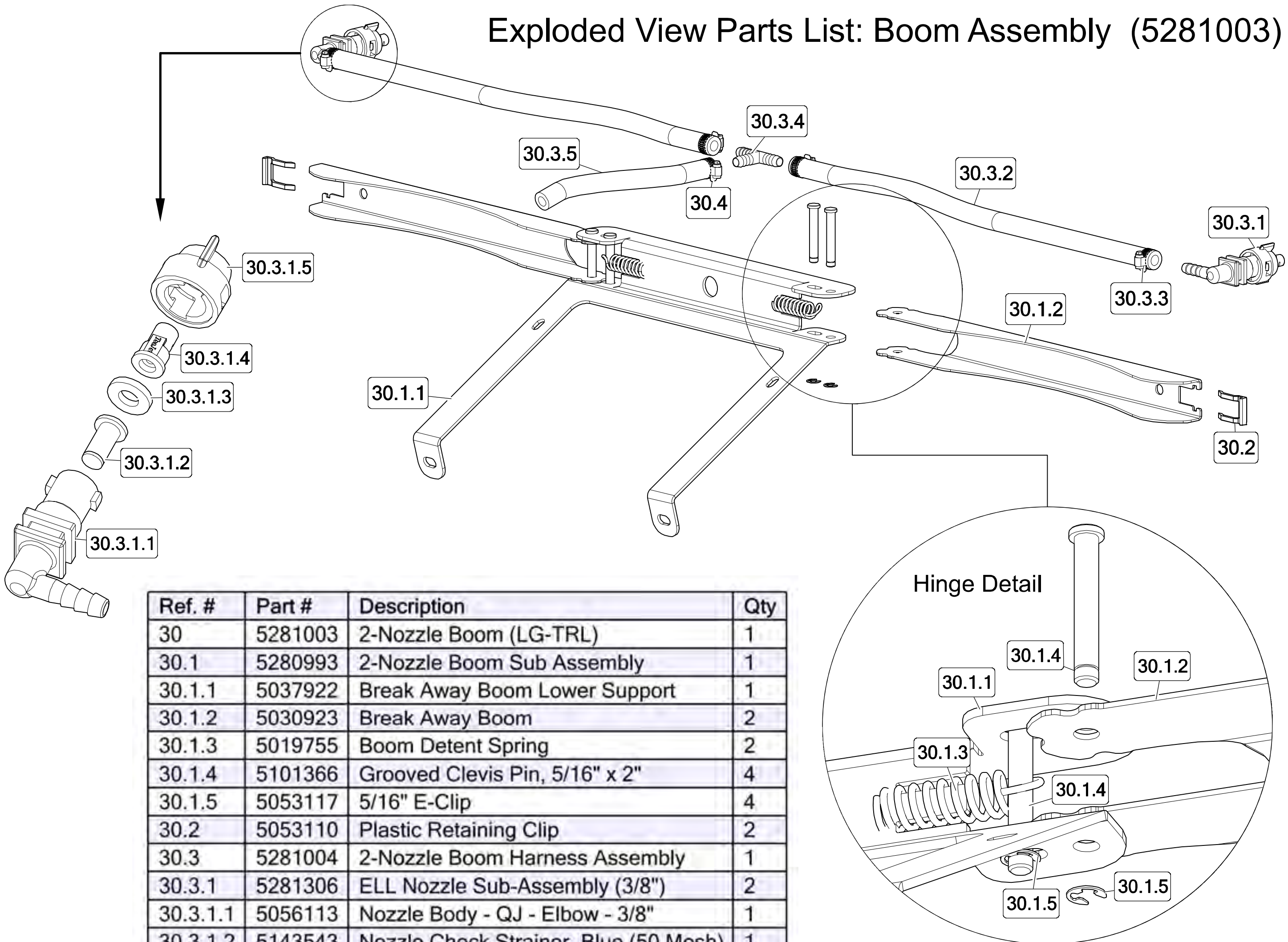


Exploded View/Parts List: LG-30-TRL (5302317)

Ref. #	Part #	Description	Qty
1	5169321	30 Gallon Trailer Tank	1
2	5278143	Intake Assembly	1
3	5281371	2.4 GPM High Performance Pump	1
4	5117167	#10-24 x 5/8" PH Truss Head Mach. Screw, Gr. 2	3
5	5281537	Quick Connect Manifold Assembly	1
6	5143422	Quick Connect Manifold - Support Bracket	1
7	5117168	#10-24 x 1" PH Truss Head Mach. Screw, Gr. 2	1
8	5167097	2" Dry 100# Back Mount Gauge	1
9	5100960	Formed Bypass Tube	1
10	5051144	Hose Clamp (3/8")	4
11	5075018	Grommet, 1/2" I.D.	1
12	5020524	Hose, 3/8"-1 Brd. x 15 Ft.	1
13	5051122	5/8" Black Nylon Loom Cable Clamp	1
14	5117234	#10-24 x 1/2" Phillips Round Head Mach. Screw	5
15	5133276	Hose Wrap	2
16	5273959	Deluxe Pistol-Grip Handgun w/X-26 Tip	1
16.1	5018331	Brass Handgun Tip (X-26)	1
17	5058188	Tank Lid w/Lanyard	1
18	5095371	Axle Mount	1
19	5034531	5/16"-18 x 5/8" Flange Lock Screw	8
20	5034641	5/16"-18 x 2 1/4" Flng Hex Bolt, Gr. 5 (Full Thread)	2
21	5278141	Tongue Assembly (LG-30-TRL)	1

Ref. #	Part #	Description	Qty
21.1	5096112	Trailer Tongue	1
21.2	5038929	Hitch Bracket 1 1/2"	1
21.3	5034641	H.H.C.S. Flanged 5/16"-18nc x 2 1/4"	2
21.4	5006307	5/16-18nc Hex Flanged Whiz Nut Gr. 5	4
21.5	5038928	Hitch	1
21.6	5117323	5/16"-18nc x 3/4" Flng Hex Bolt	2
22	5101202	Bent Clevis Pin (1/2" Dia.)	1
23	5095373	Tank Support	1
24	5101351	Wide Trailer Axle (3/4" Dia. x 25 13/16")	1
25	5127226	3/4" x 2" Axle Spacer	2
26	5021090	Tire, 4.80/400 x 8 (2-Ply)	2
26.1	5031141	3/4" Wheel Ball Bearing	2
27	5101065	Hair Pin, #211 x 2.50	2
28	5034634	5/16"-18 x 5/8" Flng Hex Bolt, Gr. 5	2
29	5037868	Boom Top Strap	2
30	5281003	2-Nozzle Boom Assembly (LG-TRL)	1
31	5006307	5/16"-18 Serrated Flng Hex Nut, Gr. A	2
32	5278114	Lead Wire Assembly w/15A Fuse (96" Long)	1
32.1	5157238	15 Amp Regular Blade Fuse	1
33	5273212	5' Extension Cable	1

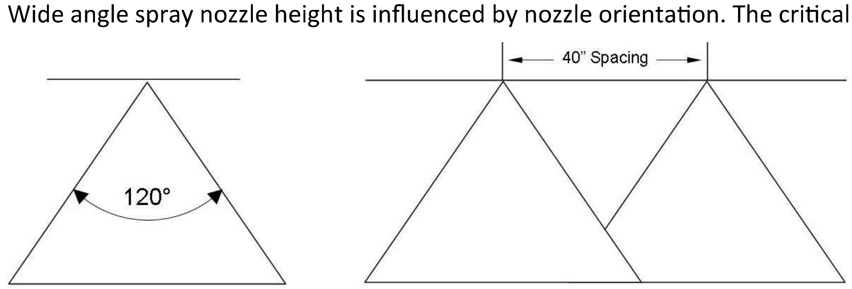
Exploded View Parts List: Boom Assembly (5281003)



Opposite side has typical setup

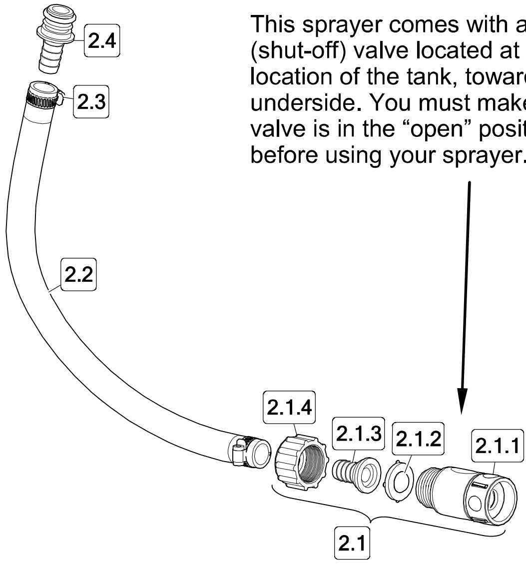
Ref. #	Part #	Description	Qty
30	5281003	2-Nozzle Boom (LG-TRL)	1
30.1	5280993	2-Nozzle Boom Sub Assembly	1
30.1.1	5037922	Break Away Boom Lower Support	1
30.1.2	5030923	Break Away Boom	2
30.1.3	5019755	Boom Detent Spring	2
30.1.4	5101366	Grooved Clevis Pin, 5/16" x 2"	4
30.1.5	5053117	5/16" E-Clip	4
30.2	5053110	Plastic Retaining Clip	2
30.3	5281004	2-Nozzle Boom Harness Assembly	1
30.3.1	5281306	ELL Nozzle Sub-Assembly (3/8")	2
30.3.1.1	5056113	Nozzle Body - QJ - Elbow - 3/8"	1
30.3.1.2	5143543	Nozzle Check Strainer, Blue (50 Mesh)	1
30.3.1.3	5016157	Seat Washer - EPDM - QJ Caps	1
30.3.1.4	5018274	Turbo FloodJet Tip (TF-VP3)	1
30.3.1.5	5046251	Quick Cap - Black	1
30.3.2	5020534	Hose, 3/8"-1 Brd. x 21"	2
30.3.3	5051144	Hose Clamp (3/8")	4
30.3.4	5086025	Poly Hose Tee, 3/8" HB	1
30.3.5	5020585	Hose, 3/8"-1 Brd. X 8"	1
30.4	5051144	Hose Clamp (3/8")	1

Based on the minimum overlap required to obtain uniform distribution with 120° tips and 40" spacing.
Suggested Minimum Spray Height: 18"-20" above what is being sprayed (to plant, not ground).
Optimum Spray Height: 39"
Wide angle spray nozzle height is influenced by nozzle orientation. The critical factor is to achieve a minimum 30% overlap.



- Excellent spray distribution for uniform coverage along the boom.
- Nozzle design incorporates a pre-orifice to produce larger droplets for less drift.

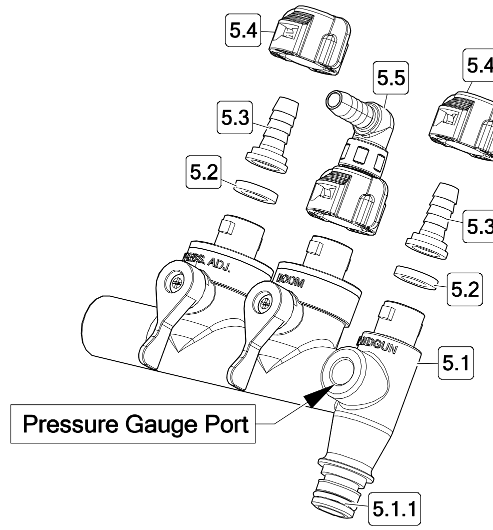
Intake Assembly 5278143



This sprayer comes with an On/Off (shut-off) valve located at the inlet location of the tank, towards the underside. You must make sure the valve is in the “open” position before using your sprayer.

Ref. #	Part #	Description	Qty
2	5278143	Intake Assembly	1
2.1	5282416	Intake Shutoff Subassembly	1
2.1.1	5143419	Swivel Shut-Off	1
2.1.2	5116242	Strainer, 1" Filter Washer	1
2.1.3	5149035	Poly Swivel, 1/2" Hose Barb	1
2.1.4	5006209	Poly Knurled Swivel Nut, 3/4" FGHT	1
2.2	5020566	HOSE 1/2" POLYSPRING X 12.75"	1
2.3	5051114	Hose Clamp (1/2")	2
2.4	5168833	Port Kit Fitting, 1/2" Hose Barb	1

Manifold Assembly 5281537



Ref. #	Part #	Description	Qty
5	5281537	Quick Connect Manifold Assembly	1
5.1	5302347	Quick Connect Manifold (Body ONLY)	1
5.1.1	5072514	O-Ring - Pump Port Connection	1
5.2	5143430	Flat Washer - Hose Barb Seal	2
5.3	5143431	QC Manifold - 3/8" Hose Straight Barb	2
5.4	5143429	Quick Connect Quarter Turn Cap	2
5.5	5302802	QC Manifold 3/8 Swivel 90° Elbow Assy	1

NOTES:

Warranty

LIMITED WARRANTY FOR NEW FIMCO, IND. EQUIPMENT

WHO MAY USE THIS LIMITED WARRANTY. This limited warranty (the "Limited Warranty") is provided by Fimco, Ind. to the original purchaser ("you") of the Equipment (as defined below) from Fimco, Ind. or one of Fimco, Ind.'s authorized dealers. This Limited Warranty does not apply to any subsequent owner or other transferee of the Equipment. THIS LIMITED WARRANTY GIVES YOU SPECIFIC LEGAL RIGHTS, AND YOU MAY ALSO HAVE OTHER RIGHTS WHICH VARY FROM STATE TO STATE.

WHAT THIS LIMITED WARRANTY COVERS AND FOR HOW LONG. Fimco, Ind. warrants that any new Equipment will be free from defects in material and workmanship for a period of **one (1) year** for sprayer and **two (2) years** for High-Flo High Performance pump (homeowner), **90 days** for sprayer and pump (commercial user), after delivery of the Equipment to you (the "Warranty Period"). The Warranty Period is not extended if Fimco, Ind. repairs or replaces the Equipment.

WHAT IS NOT COVERED BY THIS LIMITED WARRANTY. This Limited Warranty does not apply to: (1) used Equipment; (2) any Equipment that has been altered, changed, repaired or treated since its delivery to you, other than by Fimco, Ind. or its authorized dealers; (3) damage or depreciation due to normal wear and tear; (4) defects or damage due to failure to follow Fimco, Ind.'s operator's manual, specifications or other written instructions, or improper storage, operation, maintenance, application or installation of parts; (5) defects or damage due to misuse, accident or neglect, "acts of God" or other events beyond Fimco, Ind.'s reasonable control; (6) accessories, attachments, tools or parts that were not manufactured by Fimco, Ind., whether or not sold or operated with the Equipment; or (7) rubber parts, such as tires, hoses and grommets.

HOW TO OBTAIN WARRANTY SERVICE. To obtain warranty service under this Limited Warranty, you must (1) provide written notice to Fimco, Ind. of the defect during the Warranty Period and within **thirty (30)** days after the defect becomes apparent or the repair becomes necessary, at the following address: Fimco, Ind., 1000 Fimco Lane, North Sioux City, SD 57049; and (2) make the Equipment available to Fimco, Ind. or an authorized dealer within a reasonable period of time. For more information about this Limited Warranty, please call: **800-831-0027**.

WHAT REMEDIES ARE AVAILABLE UNDER THIS LIMITED WARRANTY. If the conditions set forth above are fulfilled and the Equipment or any part thereof is found to be defective, Fimco, Ind. shall, at its own cost, and at its option, either repair or replace the defective Equipment or part. Fimco, Ind. will pay for shipping and handling fees to return the repaired or replacement Equipment or part to you.

LIMITATION OF IMPLIED WARRANTIES AND OTHER REMEDIES. THE REMEDIES DESCRIBED ABOVE ARE YOUR SOLE AND EXCLUSIVE REMEDIES, AND FIMCO, IND.'S SOLE LIABILITY, FOR ANY BREACH OF THIS LIMITED WARRANTY. TO THE EXTENT APPLICABLE, ANY IMPLIED WARRANTIES, INCLUDING, WITHOUT LIMITATION, THE IMPLIED WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE, SHALL BE LIMITED IN DURATION TO THE WARRANTY PERIOD, AND THE REMEDIES AVAILABLE FOR BREACH THEREOF SHALL BE LIMITED TO THE REMEDIES AVAILABLE UNDER THIS EXPRESS LIMITED WARRANTY. SOME STATES DO NOT ALLOW LIMITATIONS ON HOW LONG AN IMPLIED WARRANTY LASTS, SO THE ABOVE LIMITATION MAY NOT APPLY TO YOU. IN NO EVENT SHALL FIMCO, IND.'S LIABILITY UNDER THIS LIMITED WARRANTY EXCEED THE ACTUAL AMOUNT PAID BY YOU FOR THE DEFECTIVE EQUIPMENT, NOR SHALL FIMCO, IND. BE LIABLE, UNDER ANY CIRCUMSTANCES, FOR ANY CONSEQUENTIAL, INCIDENTAL, SPECIAL OR PUNITIVE DAMAGES OR LOSSES, WHETHER DIRECT OR INDIRECT. SOME STATES DO NOT ALLOW THE EXCLUSION OR LIMITATION OF INCIDENTAL OR CONSEQUENTIAL DAMAGES, SO THE ABOVE LIMITATION OR EXCLUSION MAY NOT APPLY TO YOU.

CASE

Lesson 5.1 Diesel Components

Preface

Rudolf Diesel developed a compression ignition engine using fuel derived from hydrocarbons in the 1890s. The engine, and the fuel used as the power source, bears his name today. While diesel fuel has multiple applications, it is predominant in larger equipment, such as buses, tractors, construction equipment, and freight trucks. In addition, diesel fuel is more efficient than other hydrocarbon-based fuels and has a lower flashpoint.

There are several mechanical differences between diesel and gasoline engines. Most notable is that diesel engines use heat from compression to ignite the fuel. Additionally, diesel engines require a large volume of air to operate. Turbochargers use an exhaust turbine to drive a compressor, compressing air in the intake system. Diesel engines deliver fuel to each cylinder using a complex injection system featuring two pumps. The lift pump delivers fuel from a fuel tank to an injection pump. The injection pump pressurizes and meters fuel before injection into each cylinder.

During this lesson, students compare and contrast diesel and gasoline engines. Next, student groups model diesel intake and fuel systems. Next, students service a tractor by changing oil and fuel filters. Then, students create models of cooling systems. Finally, students determine the root cause of broken engine components.

Concepts	Performance Objectives
Students will know and understand	*Students will learn concepts by doing*
1. There are functional differences between diesel and gasoline engines.	• Identify similarities and differences between small gasoline and diesel engines. (Activity 5.1.1)
2. Mechanical diesel injection systems have several components with specific functions.	• Identify the high and low-pressure components of a fuel system. (Activity 5.1.2) • Flare and assemble a fuel line. (Activity 5.1.2) • Inspect a fuel injector for faults. (Activity 5.1.2)
3. Diesel engines have systems that clean and pressurize the air and clean the exhaust.	• Inspect and identify the components of a turbocharger and air filter. (Activity 5.1.3) • Measure the urea content in diesel exhaust fluid samples. (Activity 5.1.3)
4. Diesel engine systems have a variety of lubrication and liquid cooling systems.	• Change oil and oil filter using OEM specifications. (Activity 5.1.4) • Inspect a cooling system using industry equipment. (Activity 5.1.4 and Project 5.1.5) • Model a cooling system to cool the engine coolant. (Project 5.1.5)
5. Technicians use customer complaints combined with an inspection to determine the cause of engine failure.	• Determine the cause of broken engine components and complete a work repair order. (Project 5.1.6)

National AFNR Common Career Technical Core Standards Alignment

Career Ready Practices
1. Act as a responsible and contributing citizen and employee.
• CRP.01.01: Model personal responsibility in the workplace and community.
2. Apply appropriate academic and technical skills.
• CRP.02.01: Use strategic thinking to connect and apply academic learning, knowledge, and skills to solve problems in the workplace and community.
4. Communicate clearly, effectively and with reason.
• CRP.04.01: Speak using strategies that ensure clarity, logic, purpose and professionalism in formal and informal settings.
• CRP.04.02: Produce clear, reasoned and coherent written and visual communication in formal and informal settings.

Power, Structural and Technical (AG-PST)
1. Apply physical science principles and engineering applications related to mechanical equipment, structures, and biological systems to solve problems and improve performance in AFNR power, structural, and technical systems.
• AG-PST 1.1: Select energy sources for power generation.
2. Operate and maintain mechanical equipment related to AFNR power, structural, and technical systems.
• AG-PST 2.1: Maintain machinery and equipment by performing scheduled service routines.
3. Service and repair mechanical equipment and power systems used in AFNR power, structural and technical systems.
• AG-PST 3.1: Service and repair the components of internal combustion engines using procedures for troubleshooting and evaluating performance.

Next Generation Science Standards Alignment

Disciplinary Core Ideas	
Engineering, Technology, and the Application of Science	
ETS1: Engineering Design	
ETS1.B: Developing Possible Solutions	• When evaluating solutions, it is important to take into account a range of constraints including cost, safety, reliability and aesthetics and to consider social, cultural and environmental impacts. • Both physical models and computers can be used in various ways to aid in the engineering design process. Computers are useful for a variety of purposes, such as running simulations to test different ways of solving a problem or to see which one is most efficient or economical; and in making a persuasive presentation to a client about how a given design will meet his or her needs.

Science and Engineering Practices	
Developing and Using Models	Modeling in 9–12 builds on K–8 experiences and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed world(s). • Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system.
Obtaining, Evaluating, and Communicating Information	Obtaining, evaluating, and communicating information in 9–12 builds on K–8 experiences and progresses to evaluating the validity and reliability of the claims, methods, and designs. • Communicate scientific and/or technical information or ideas (e.g. about phenomena and/or the process of development and the design and performance of a proposed process or system) in multiple formats (including orally, graphically, textually, and mathematically).

Crosscutting Concepts	
Systems and System Models	A system is an organized group of related objects or components; models can be used for understanding and predicting the behavior of systems.
	• Systems can be designed to do specific tasks. • When investigating or describing a system, the boundaries and initial conditions of the system need to be defined and their inputs and outputs analyzed and described using models. • Models (e.g., physical, mathematical, computer models) can be used to simulate systems and interactions—including energy, matter, and information flows—within and between systems at different scales.

	• Models can be used to predict the behavior of a system, but these predictions have limited precision and reliability due to the assumptions and approximations inherent in models.
Energy and Matter: Flows, Cycles, and Conservation	Tracking energy and matter flows, into, out of, and within systems helps one understand their system's behavior.
	• The total amount of energy and matter in closed systems is conserved. • Energy cannot be created or destroyed—only moves between one place and another place, between objects and/or fields, or between systems.

Common Core State Standards for High School Mathematics

CCSS: Conceptual Category – Statistics and Probability	
Interpreting Categorical and Quantitative Data	*Summarize, represent, and interpret data on a single count or measurement variable. *Summarize, represent, and interpret data on two categorical and quantitative variables. *Interpret linear models.

Common Core State Standards for English Language Arts

CCSS: English Language Arts Standards » Science & Technical Subjects » Grade 11-12	
Key Ideas and Details	• **RST.11-12.3 –** Follow precisely a complex multistep procedure when carrying out experiments, taking measurements, or performing technical tasks; analyze the specific results based on explanations in the text.
Craft and Structure	• **RST.11-12.4 –** Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to grades 11-12 texts and topics.
Range of Reading and Level of Text Complexity	• **RST.11-12.10 –** By the end of grade 12, read and comprehend science/technical texts in the grades 11-CCR text complexity band independently and proficiently.

CCSS: English Language Arts Standards » Writing » Grade 11-12	
Research to Build and Present Knowledge	• **WHST.11-12.7 –** Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation.

Essential Questions

1. How are the subsystems of a diesel and gasoline engine different?
2. What components of each engine system are similar, and which are specialized?
3. How do diesel fuel system components work together?
4. What skills do technicians need to service a fuel system?
5. What faults can impact a diesel intake system?
6. How does the wastegate impact air intake?
7. How does an injection pump with a fixed speed regulate the fuel injection?

Key Terms

Air cleaner
Atomization
Bleed
Bleed screws
Camshaft
Combustion
Compression event
Compressor
Cooling fins
Cooling system
Crankshaft
Crude oil

Diesel exhaust fluid (DEF)	**Diesel**	**Engine**
Exhaust	**Exhaust event**	**Exhaust system**
Flashpoint	**Fuel injector**	**Fuel system**
Gasoline	**Glow plug**	**Hydrocarbon**
Ignition system	**Impeller**	**Injection pump**
Intake manifold	**Lift pump**	**Oil filter**
Piston	**Radiator**	**Refractometer**
Return line	**Thermostat**	**Turbine**
Turbocharger	**Valve**	**Wastegate**
Water jacket	**Water pump**	

Day-to-Day Plans
Time: 13 days

*Refer to the Teacher Resources section for specific information on teaching this lesson, in particular **Lesson 5.1 Teacher Notes**, **Lesson 5.1 Glossary**, **Lesson 5.1 Materials**, and other support documents.*

Day 1 – 2:

- Present **Concepts**, **Performance Objectives**, **Essential Questions**, and **Key Terms** to provide a lesson overview.
- Provide students with a copy of **Activity 5.1.1 Functional Differences**.
- Students work in pairs to complete *Activity 5.1.1 Functional Differences.*

Day 3:

- Provide students with a copy of **Activity 5.1.2 Fuel Delivery**.
- Designate student groups to start on Parts One and Two or Parts Three and Four.
- Students complete their assigned parts in *Activity 5.1.2 Fuel Delivery*.

Day 4:

- Student groups rotate and complete *Activity 5.1.2 Fuel Delivery*.

Day 5:

- Provide students with a copy of **Activity 5.1.3 Lubrication and Cooling**.
- Provide students with tractors and OEM specifications for changing oil.
- Students change the oil in a tractor to complete Part One of *Activity 5.1.3 Lubrication and Cooling*.

Day 6:

- Students complete Parts Two and Three of *Activity 5.1.3 Lubrication and Cooling*.

Day 7:

- Provide students with a copy of **Project 5.1.4 Cool Inspection** and **Project 5.1.4 Evaluation Rubric**.
- Students work in groups to complete Part One of *Project 5.1.4 Cool Inspection*.
- Students start Part Two of *Project 5.1.4 Cool Inspection*.

Day 8:

- Students complete Part Two of *Project 5.1.4 Cool Inspection*.

- Evaluate student *Project 5.1.4 Evaluation Rubric*.

Days 9 – 10:

- Provide students with a copy of **Activity 5.1.5 Clean Air.**
- Students work in groups to complete *Activity 5.1.5 Clean Air*.

Day 11 – 12:

- Provide students with a copy of **Project 5.1.6 Engine Failure**, **Work/Repair Order Template**, and **Work/Repair Order Evaluation Rubric**.
- Students submit a *Work/Repair Order* for assessment.
- Assess student work with *Work/Repair Order Evaluation Rubric*.

Day 13:

- Distribute **Lesson 5.1 Check for Understanding**.
- Students complete *Lesson 5.1 Check for Understanding* and submit it for evaluation.
- Use **Lesson 5.1 Check for Understanding Key** to evaluate student assessments.

Instructional Resources

Student Support Documents

Lesson 5.1 Glossary

Activity 5.1.1 Functional Differences

Activity 5.1.2 Fuel Delivery

Activity 5.1.3 Lubrication and Cooling

Project 5.1.4 Cool Inspection

Activity 5.1.5 Clean Air

Project 5.1.6 Engine Failure

Teacher Resources

Lesson 5.1 Diesel Components PDF

Lesson 5.1 Teacher Notes

Lesson 5.1 Materials

Lesson 5.1 Check for Understanding

Answer Keys and Assessment Rubrics

Lesson 5.1 Check for Understanding Answer Key

Project 5.1.4 Evaluation Rubric

Work Repair Order Evaluation Rubric

Student Templates

Work/Repair Order Template

Reference Sources

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Herren, R. V., & Donahue, R. L. (2000). *Delmar's agriscience dictionary with searchable CD-ROM*. Albany, NY: Delmar.

Hooper, M. (2019). *DIY Radiator Pressure Test – How to Test Your Radiator for Leaks.* **https://www.eeuroparts.com/blog/how-to-pressure-test-a-radiator-with-a-bike-pump/**

It Still Runs (n.d). *How Do Diesel Fuel Shut-Off Solenoids Work?* **https://itstillruns.com/diesel-fuel-shutoff-solenoids-work-5016171.html**

John Deere Pub. (2003). *Engines: a service, testing, and maintenance guide for engine systems in off-road vehicles, trucks and buses* (Ser. Fundamental of Service).

Mack, J. P., Daniels, J. A., DeHart, M. A., & Norman, A. *Diesel Engine Technology: Fundamentals, Service, Repair* (Ninth Edition ed.). Tinley Park, IL: The Goodheart-Wilcox Company, Inc.

FFA Connections

This lesson provides conceptual and procedural knowledge related to the following FFA awards, activities and educational resources.

- Agricultural Proficiency
  - **Agricultural Mechanics Repair and Maintenance –Placement**
  - **Agricultural Mechanics Repair and Maintenance –Entrepreneurship**
  - **Agriscience Research – Integrated Systems**
- Agriscience Fair
  - **Power, Structural and Technical Systems**
- Career Development Events
  - **Agricultural Technology & Mechanical Systems**
- Educational Resources
  - **All About Engines**
  - **SAE Idea Cards-Power, Structural and Technical Systems**
  - **Power, Structural and Technical System Careers**
  - **Power, Structural and Technical Systems Career Focus Area Resources**
  - Power, Structural and Technical Careers **(Word)**

Skills and knowledge from this lesson support the development and implementation of service-learning projects concerning diesel components.

- **Service-Learning and Living to Serve Grants**
  - Service-learning projects focused on diesel and gas engines
  - Project ideas include hosting a spring tune up event or used oil recycling event.
  - Living to Serve Grants provide funding to FFA chapters to support service-learning and community service projects.

For more information, visit the **National FFA Organization** website.

SAE for All

Foundational SAE

All students in an agricultural education program are expected to have a Foundational SAE. Students completing the APP and extensions listed below will meet the Foundational SAE qualification for the *Advanced(Grades 11-12) level*. Students should place all documented evidence in the *FFA/SAE* section of their *Agriscience Notebook* along with the *SAE for All Foundational Checksheet*.

- Employability Skills for College and Career Readiness
  - Project 5.1.6 Engine Failure

Immersion SAE

Students interested in this lesson’s topics should explore the following related Immersion SAEs. An immersion SAE is optional and replaces the agricultural literacy component of the Foundational SAE.

- **Immersion SAE Learning Guides**

For more information on the guiding principles for implementing SAE programs, visit the **SAE for All: Evolving Essentials** site.

Critical Thinking and Application Extensions

Explanation

1. Students will develop a maintenance plan for a diesel engine.

Application

2. Students will construct a model of a turbocharger and explain how it works.

Lesson 5.1 Teacher Notes

Lesson 5.1 Diesel Components

In preparation for teaching this lesson, review Concepts, Performance Objectives, Essential Questions, and Key Terms. Also, review all activity and project directions, expectations, and work students will complete.

During this lesson, students compare and contrast diesel and gasoline engines. Next, student groups model diesel intake and fuel systems. Then students service a tractor by changing the oil and fuel filters. Finally, students create models of cooling systems. Finally, students apply this knowledge to determine the root cause of broken engine components.

Activities, Projects, and Problems

Activity 5.1.1 Functional Differences

Students reflect upon prior knowledge of *Mechanical Systems in Agriculture* to compare the gasoline and diesel engine systems.

Teacher Preparation

1. Students watch a video from *The Power Porta*l for this activity. *The PowerPorta*l is an interactive website from Briggs and Stratton. Provide each student with a technician account for **The PowerPortal** (www.thepowerportal.com).
   - Log into *The Power Portal*.
   - Click on the **Power Channel** tab.
   - Click on **Technician Accounts** on the top menu bar.
   - Type the first name, last name, and email address of each student, as shown in Figure 1. Click **Submit**.
   - Continue submission for each student.
   - Provide each student with their account and password.

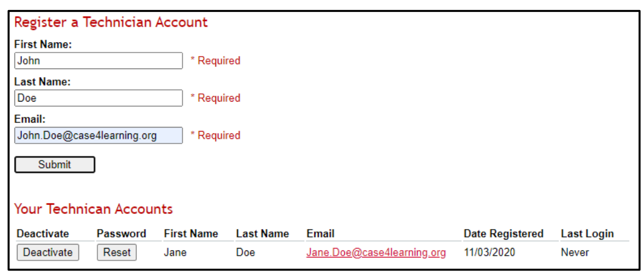


Figure 1. PowerPortal Technician Accounts

2. If you do not have student accounts, play the videos for the students at the following links.
   - **http://www.thepowerportal.com/nA/English/PowerChannel/Foundations/FourCycleTheory.htm**
   - **https://www.thepowerportal.com/nA/English/PowerChannel/Courses/DieselEngineTheory.htm**
3. Access the Engine Part Identification website to ensure the website functions on student devices.
   - **https://www.swtc.edu/Ag_Power/diesel_engines/part_id/real_engine/index.htm**
4. Choose a reading strategy used to cover the content of the Purpose. In Part One, students will utilize information from the table in the Purpose.

Student Performance

Students reflect upon their experience with small gasoline engines and contrast the differences with diesel subsystems. The Purpose includes information about the diesel subsystems. Next, students review engine parts using an online simulation of a cutaway diesel engine. Students list components found on small gasoline engines before defining engine components on the student observations page. Then, students match engine components to a subsystem.

Results and Evaluation

Potential answers to the student observations page are in Tables 1–3.

Table 1. ***Gas Engine Events***

Event	Inputs	Processes					Outputs
		Fuel Intake	Piston	Crankshaft	Ignition	Fuel Exhaust	
Intake	*Fuel Air*	*Intake Valve Open*	*Moving downward*	*Rotates 170 degrees*	*No spark*	*Exhaust Valve Closed*	*Air fuel mixture*
Compression	*Air fuel mixture*	*Intake Valve Closed*	*Moving upward*	*Rotates 180 degrees*	*No spark*	*Exhaust Valve Closed*	*Compressed air-fuel mixture Heat Compressed energy*
Ignition	*Compressed air-fuel mixture*	*Intake Valve Closed*	*Moving upward*	*10 degrees before top dead center*	*Spark*	*Exhaust Valve Closed*	*Explosive flame*
Power	*Explosive flame*	*Intake Valve Closed*	*Moving downward*	*Rotates 180 degrees*	*No spark*	*Exhaust Valve Closed*	*Hot expansive gasses*
Exhaust	*Hot expansive gases*	*Intake Valve Closed*	*Moving upward*	*Rotates 180 degrees*	*No spark*	*Exhaust Valve Open*	*Gasses leave the engine*

Table 2. ***Diesel Engine Events***

Event	Inputs	Processes					Outputs
		Fuel Intake	Piston	Crankshaft	Ignition	Fuel Exhaust	
Intake	*Fuel Air*	*Fuel Injected Air compressed*	*Moving downward*	*Rotates 170 degrees*		*Exhaust Valve Closed*	*Air fuel mixture*
Compression	*Air fuel mixture*		*Moving upward*	*Rotates 180 degrees*		*Exhaust Valve Closed*	*Compressed air-fuel mixture Heat Compressed energy*
Ignition	*Compressed air-fuel mixture*		*Moving upward*	*10 degrees before top dead center*	*Fuel Ignited by compression*	*Exhaust Valve Closed*	*Explosive flame*
Power	*Explosive flame*		*Moving downward*	*Rotates 180 degrees*		*Exhaust Valve Closed*	*Hot expansive gasses*
Exhaust	*Hot expansive gases*		*Moving upward*	*Rotates 180 degrees*		*Exhaust Valve Open*	*Gasses leave the engine*

Table 3. ***Potential Responses for Student Observations Page***

Subsystem	Small Gasoline Engine Operation	Diesel Operation

Cooling	Air Cooled	Liquid and Air Cooled
Ignition	Spark Plugs	Ignites from the heat of compression stroke
Fuel and Exhaust	Carburetor delivers air/fuel mixture	Fuel is injected using a pump Exhaust is treated with DEF
Intake	Carburetor delivers air/fuel mixture	Air is distributed evenly with an exhaust manifold

Parts Found in Both Small Gasoline and Large Diesel Engines		
Camshaft Crankshaft Connecting Rod Cylinder Rocker Arm	Oil Pressure Regulator Piston Push Rods Timing Gears	Valve Valve Cover Valve Spring Wrist Pin

Part	Function	Part	Function
Air intake	An inlet air path through the head to the cylinder.	Intake Side of Turbo Charger	Compressor wheel used on intake system to force air into the cylinder during the intake
Dampener Pulley	Reduces torsional stress in the crankshaft.	Oil Filter Manifold	Serves as a mounting base for the lubrication filter.
Exhaust Manifold	A device that connects all exhaust ports to one outlet.	Oil Gallery	Carries oil throughout the engine.
Idler Pulley	A pulley on a shaft presses against a guide belt to guide or tighten it.	Oil Line	Turbocharger oil drain line that returns oil from the turbocharger to the crankcase.
Injection Lines	Schedule 80 high-pressure lines that carry fuel under pressure from the injection pump to the injection nozzles.	Oil Pan	The lower section of the crankcase is used as an oil-lubricating reservoir on an internal combustion engine.
Injection Pump	A high-variable pressure pump delivers fuel to the combustion chamber.	Turbo Charger	A gas-driven turbine is used to force air into the combustion chamber.
Injection Pump Drive Gear	Gear in the timing gear set that drives the injection pump.	Water Jacket	The enclosure directs the cooling water flow around the parts to be cooled.
Intake Manifold	A port or component that brings air into the cylinder. Also, a connecting casting between the air filter and turbocharger.	Water Pump Pulley	The pulley drives the water pump.
Intake Pipe	Connects the turbocharger to the manifold.		

Activity 5.1.2 Fuel Delivery

Student pairs rotate through three stations during this activity, each with specific skills and tasks. Student pairs identify fuel system components on a diesel tractor at the first station. They use a flaring bar to double-flare two fuel line sections and join them with a union during the second station. Finally, they use a fuel injection pressure tester at the third station to analyze spray patterns of faulted fuel injectors.

Teacher Preparation

1. Prepare the following three stations for student pairs to rotate through and complete. Prep each station with enough tools for three student pairs. See the station material lists below.

Table 4. ***Station Preparation***

Station 1	Station 2	Station 3
• Diesel tractor with exposed fuel injection system • (3) Tractor user manuals	• (3) Metric wrench sets • Fuel line (12” per pair)	• (3) Fuel injector pressor tester • (3) Wrench, 17mm • (3) Wrench, 14mm • Diesel fuel, 1 gallon • Transmission fluid, 1 quart

2. Cut a 12″ section of fuel line for each student pair using a fuel line cutter.
3. Review the use of the fuel injection pressure tester. Use the flaring tool and fittings to adjust the fuel line to fit your fuel injectors. Fuel injectors should be faulted and secured through local equipment dealerships.
    - Store the fuel injection pressure tester with diesel fuel mixed with automatic transmission fluid within the pump and lines to prevent corrosion.

Student Performance

Part One

Student pairs identify and sketch a fuel injection system for a tractor.

Part Two

Students construct a fuel line connection using a double flaring tool kit. First, students cut a 12″ section of ¼″ steel fuel line into two 2″ sections. Then, students double flare the end of each piece using a flaring bar, ¼″ die, and a flaring cone, as shown in Figure 3. Students fasten the lines together with a steel compression union.

Part Three

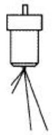
Students test a used fuel mechanical injector using a fuel injection pressure tester. Students add automatic transmission fluid (any type) to the diesel fuel before use. The fuel is filtered using a fine-tipped paint strainer. Students pressurize the pump and inspect the injector spray and pressure.

Results and Evaluation

Table 5 summarizes potential faults for Part Three referenced within **Diesel Engine Fuel Injector Service**.

Table 5. ***Potential Injector Faults***

Spray Pattern	Fault	Maintenance Suggestions
	**Normal**	**N/A**

	**Stream**	**Check for dirt on the valve seat, clean or replace the nozzle, and clean fuel filter(s)**
	**Spike**	**Clean or replace the nozzle. Inspect and clean the injection port.**
	**Spray**	**Clean or replace the nozzle, inspect carbon build-up in the cylinder or intake manifold, and clean as necessary**
	**Slanted**	**Clean carbon build-up and inspect the seat.**

Activity 5.1.3 Lubrication and Cooling

Students service a tractor by changing and analyzing the oil and oil filter. Next, students inspect three samples of engine coolant and a thermostat.

Teacher Preparation

1. Provide tractors or other equipment that need an oil change and obtain an engine service manual for each model represented. Reference the service manual for fuel filter types and procedures. Notify students of any changes to the Procedure to meet OEM specifications.
2. Obtain the OEM recommended oil and oil filters for each tractor.
3. Cut 2′ of nylon string for each group.
4. Gather a worn thermostat for each student group. Record the ratings of each thermostat to provide to students.
5. Mix three samples of engine coolant in 250ml beakers.
    - Use coolant that is not premixed. The label should read concentrate.
    - Mix the proportions listed in Table 6 in each beaker.
    - Test each sample using a refractometer using the steps in Part Two.
    - Compare your results to the results in Table 6.

Table 6. ***Antifreeze Samples***

Sample	Water	Coolant	Freezing Point (°)
A	50ml	50ml	**-37°C (-34°F)**
B	60ml	40ml	**-23°C (-10°F)**
C	40ml	60ml	**-53°C (-63°F)**

Student Performance

Part One

Students change the oil in a tractor and inspect the oil for contaminants. Students rub the oil between their fingers, similar to determining soil texture. A gritty presence indicates excessive wear on the engine.

Part Two

Students test a thermostat to determine if it opens as designed. For example, a thermostat with a 170-190°F rating should start to open at 170°F and be fully open at 190°F. Students will suspend a thermostat in a beaker of water over a hotplate to determine the rating. Then, using a temperature probe, students record the temperature of the water when the thermostat changes position. Replace a thermostat that does not meet its rating.

Part Three
Students calibrate a refractometer used for antifreeze. Next, students obtain premixed samples of antifreeze coolant in small 3oz cups. Students place 1ml of each coolant on the daylight plate and read the freezing point of each mixture.

Results and Evaluation
Table 7 includes the anticipated results of the antifreeze freezing points. Table 5 provides potential responses to analysis questions.

Table 7. *Analysis Questions and Potential Responses*

Q1	Was the full-to-open rating consistent with the thermostat test? How do you know?	*Answers will vary. Students will know if the ratings match the results on the student observations page. For example, a thermostat with a rating of 170-190°F will release the ribbon at 170°F and fully extend at 190°F.*
Q2	What defects did your thermostat have? Should it be replaced?	*Answers will vary. Thermostats should be replaced if it does not meet the rating criteria. For example, a thermostat with a rating of 170-190°F should start to open at 170°F and be fully open at 190°F.*

Project 5.1.4 Cool Inspection

Students inspect two water pumps and a radiator. Next, students construct and test a model coolant system.

Teacher Preparation
1. Create three stations for Part One. Place the following components at separate stations.
    - Belt-driven water pump
    - Gear-driven water pump
    - Radiator
2. Prepare the radiator station.
    - Place two flashlights at the station for class use.
    - Obtain a container that is large enough to submerge the radiator completely. A livestock tank or storage tub will work, depending on the size of the radiator. If a water tank is unavailable, students can cover the entire system with soapy water and look for bubbles.
    - Read **DIY Radiator Pressure Test**. Then, assemble the radiator as instructed to be pressurized with a bicycle pump.
3. Cut a six-foot section of tubing for each student group. The tubing should be 4mm or ¼″ I.D.

Student Performance
Part One
Students rotate through three stations, inspecting water pumps and the radiator. During the radiator inspection, students pressurize the system and look for evidence of leaks. If bubbles appear in the water or the pressure of the bicycle pump drops, a leak is present.

Part Two

Students construct a base model of a coolant system using a pump, flask, and hotplate. The hotplate simulates the heat of the engine cylinder. Next, students prime the pump and bleed air from the system before proceeding to Part Three.

Part Three
Student groups modify the cooling system to cool the coolant present in the model water jacket. After constructing the model, students warm the hot plate until the water reaches 140-150°F. Next, students use an IR thermometer to monitor heat while the system is closed. After the water reaches this threshold, the students activate the pump. They collect measurements for four minutes. A well-designed system should cool the coolant for over four minutes. Finally, student groups present the components and efficiency of their system to the class.

Results and Evaluation
Evaluate student models, data, and class presentations using the **Project 5.1.4 Evaluation Rubric**.

Activity 5.1.5 Clean Air

Students examine an air filter, turbocharger, and DEF samples.

Teacher Preparation
1. Prepare four diesel exhaust fluid and water samples in 16 oz cups.
    - 250ml of DEF with no distilled water added, Labeled *A*
    - 230ml DEF with 20ml distilled water added, Labeled *B*
    - 200ml DEF with 50ml distilled water added, Labeled *C*
    - 250ml distilled water labeled *Distilled Water*
2. Prepare the following three stations with materials.

Table 8. ***Station Preparation***

Station 1	Station 2	Station 3
• (3) Used oil bath air cleaners	• (3) Turbochargers • (3) Wrench sets	• Cup A • Cup B • Cup C • Distilled water • (3) Refractometer kits

Student Performance
Assign an equal number of student pairs to each station. Students disassemble and inspect a used air filter during Part One (Station 1). While completing Part Two (Station 2), students tear down and label the parts of a turbocharger. During Part Three (Station 3), students use a refractometer to identify DEF with the correct amount of urea.

Results and Evaluation
Students record observations and answer questions on the student observations page. Table 9 includes potential responses to analysis questions.

Table 9. ***Analysis Questions and Potential Responses***

Q1	How does the wastegate valve influence the speed of the turbocharger?	*The wastegate controls the amount of exhaust available to the turbine, controlling the speed.*
Q2	How does the turbocharger's speed influence the air pressure in the intake manifold?	*A faster turbocharger turbine will intake a higher volume of air. Since the intake manifold volume is fixed, the air will become compressed and increase in pressure.*
Q3	What is the role of compressed air in the intake manifold?	*Compressed air delivers a higher air volume to the cylinder for increased power.*

Project 5.1.6 Engine Failure

Students identify diesel engine components, identify what is damaged, and determine the cause of the damage.

Teacher Preparation

Label ten cards 1 through 10. Then prepare the following ten stations for students to observe. Place the corresponding card by each station. Be prepared to assign each station to a student during Part Two.

Table 10. ***Station Materials and Causes***

Station Number	Materials	Cause	Correction
1	Dirty air filter	**The air filter is clogged, causing an incorrect air-fuel mixture.**	**Replace or clean the air filter.**
2	Leaky injector attached to an injector pressure tester	**The injector adds too much fuel to the combustion chamber, causing an incorrect air-fuel mixture.**	**Replace the fuel injector.**
3	Piston with a broken ring and seized bearing	**The seized bearing caused the**	**Rebuild the engine with new bearings, pistons, rings, and connecting rods.**
4	Turbocharger with broken fin or seized bearing	**The turbocharger is not sending enough air to the combustion chamber.**	**Replace or fix the turbocharger.**
5	Broken thermostat, temperature sensor, beaker, nylon ribbon, and a hot plate or damaged radiator	**The thermostat is not releasing the coolant to cool the engine, or the radiator is not cooling the coolant.**	**Replace the thermostat or fix/clean the radiator.**
6	Dirty oil or clogged oil filter	**The oil is not flowing through the engine because the filter is clogged.**	**Change the oil and replace the oil filter.**
7	Faulty solenoid and digital multimeter	**The solenoid is not allowing a high current to turn the starter motor.**	**Replace the solenoid.**
8	Dirty fuel filter	**The fuel system is not allowing enough fuel to enter the combustion chamber.**	**Clean or replace the fuel filter and fuel.**
9	Refractometer and container with coolant that is more than 50% water	**The coolant was mixed incorrectly and cannot cool the engine.**	**Drain the coolant and replace it with the correct mixture.**
10	Refractometer and container with DEF that is more than 32.5% water	**The DEF needs to be primed to move through the system and be the correct percentage**	**Prime the DEF so it flows through the system. Replace the DEF if it has the incorrect urea percentage.**

Provide each student pair with a copy of an engine troubleshooting guide. Use the weblinks below for example guides. *Diesel Technology 7th Edition*, from Goodheart-Willcox, has a troubleshooting guide appendix.

- **Turbocharger Troubleshooting**
- **Diesel Engine Troubleshooting Guide 2022**

Student Performance
Student pairs use engine components and information from customer complaints and troubleshooting guides to identify the cause and correction of failed engines. Next, students individually complete a **Work/Repair Order Template** for one of the customer complaints assigned to them.

Results and Evaluation
Use Table 9 to evaluate the cause and correction identified by each student. Note that there may be more than one correct answer. Use the **Work/Repair Order Evaluation Rubric** to assess student work/repair orders.

Assessment

Lesson 5.1 Check for Understanding

Lesson 5.1 Check for Understanding is included for you to use as an assessment tool for this lesson. Use **Lesson 5.1 Check for Understanding Answer Key** for evaluation purposes.

Name____ CASE

Activity 5.1.1 Functional Differences

Purpose

The maintenance and repair of diesel engines are vital to the agricultural industry. Diesel engines account for over two-thirds of all farm equipment. During past agricultural courses, you learned about the function of a small gasoline engine. There are several similarities between diesel and gasoline engines. Both engines convert fuel's potential energy into mechanical energy through internal combustion.

Fossil fuels are all produced from the same crude oil base. Crude oil consists of hydrocarbons and natural gasses heated during the refinement process, separating gas vapor from the oil. Various hydrocarbons with varying densities develop with additional heat and separate in a fractioning column. Refinement produces several fuels, such as gasoline, kerosene, and diesel. Each fuel will vaporize and be able to ignite. For example, gasoline fuels have a flashpoint of -49°F. On the other hand, diesel fuels are less volatile, with a flashpoint between 125-180°F.

Due to the higher flashpoint, diesel ignition only uses the heat created during the compression stroke to ignite. Some diesel engines have glow plugs that heat fuel when the engine starts to help the diesel reach the flashpoint, reducing cranking time. Figure 1 shows an electrified glow plug. As current passes through the glow plug, electrical resistance produces heat, emitting light. In addition, a diesel engine's cooling, fuel delivery, and air intake also differ from gasoline engines.

Figure 1. Electrified Glow Plug

Therefore, technicians working on agricultural equipment should be knowledgeable about diesel function, maintenance, and repair. Table 1 summarizes the basic functions of the diesel cooling, ignition, fuel and exhaust, and intake systems.

Table 1. *Diesel Subsystems*

Subsystem	Description
Cooling	Diesel engines use both air-cooled and liquid-cooled systems. Air-cooled systems use cooling fins to dissipate heat from the engine cylinder. Liquid-cooled systems use a mixture of water and antifreeze to cool the engine. The water pump forces the liquid through a water jacket around the cylinders. The warmed coolant is cooled as it travels through a radiator.
Ignition	The diesel ignition system does not use a spark plug. Rather, the diesel fuel ignites from the heat created by the compression stroke.
Fuel and Exhaust	Injectors regulate the amount of fuel delivered to the combustion chamber. The exhaust system injects DEF into the exhaust to meet EPA emission standards.
Intake	The basic components of an air intake system include the air cleaner and intake manifold. After the air is clean, the intake manifold evenly distributes the air across each cylinder.

How are the subsystems of a diesel and gasoline engine different? What components of each engine system are similar, and which are specialized?

Materials

Per pair of students:

- Device with internet access
- (4) Highlighters, assorted colors
- *PowerPortal* account

Per student:

- *Agriscience Notebook*
- *Logbook*

Procedure

Compare the differences between subsystems in gasoline and diesel engines. Next, identify parts consistently found in gasoline and diesel engines. Then, define the function and subsystem of specialized diesel components.

Part One – Four-stroke operation

1. Log into *The PowerPortal* using the username and password provided by your teacher.
2. Observe the **Four-Stroke Gasoline Engine Video** (http://www.thepowerportal.com/nA/English/PowerChannel/Foundations/FourCycleTheory.htm) on *The PowerPortal*.
3. Complete Table 2 on *Activity 5.1.1 Student Observations* by recording the inputs, processes, and outputs that occur during each of the five events of the four-stroke gasoline engine.
4. Observe the **Diesel Engine Theory video** (https://www.thepowerportal.com/nA/English/PowerChannel/Courses/DieselEngineTheory.htm) on *The Power Portal*.
5. Complete Table 3 by recording the inputs, processes, and outputs that occur during each of the five events of the diesel engine.

Part Two – Diesel vs. Gasoline

Reflect upon your experience working with small gasoline engines. Identify how the cooling, ignition, fuel, exhaust, and intake systems operate. Record these operations in Table 4 of the student observations page. Use a device with internet access to review as needed. Next, review the *Purpose* to find operational differences within the subsystems. Record these differences in Table 4.

Part Three – Parts Function

1. Go to **Engine Part Identification** (https://www.swtc.edu/Ag_Power/diesel_engines/part_id/real_engine/index.htm) on your computer.
2. Scroll over each part to learn more about each engine component and its function.
3. Identify the parts found in a diesel engine and a small gasoline engine.
4. List the parts in Table 5.
5. Scroll through the engine to find the diesel parts listed in Table 6.
6. Record the function of each part.

Part Four – Parts Function

1. Review the specialized diesel subsystems listed in Table 4.
2. Highlight each subsystem in a different color.
3. Review the diesel engine parts listed in Table 6. Highlight each part to match the subsystem colors in Table 4.

Conclusion

1. What are the functional differences between diesel and gasoline engines?

2. How does the diesel engine spark without a spark plug?

Name____

Activity 5.1.1 Student Observations

Table 2. ***Gas Engine Events***

Event	Chemical Inputs	Component Processes					Chemical Outputs
		Intake Valve	Piston	Crankshaft	Ignition	Exhaust Valve	
Intake							
Compression							
Ignition							
Power							
Exhaust							

Table 3. ***Diesel Engine Events***

Event	Chemical Inputs	Component Processes					Chemical Outputs
		Intake Valve	Piston	Crankshaft	Ignition	Exhaust Valve	
Intake							
Compression							
Ignition							
Power							
Exhaust							

Table 4. ***Diesel vs. Gasoline***

Subsystem	Small Gasoline Engine Operation	Diesel Operation
Cooling		
Ignition		
Fuel and Exhaust		
Intake		

Table 5. ***Similar Parts***

Parts Found in Both Small Gasoline and Large Diesel Engines

Table 6. ***Diesel Part Identification***

Part	Function	Part	Function
Air intake		Intake Side of Turbo Charger	
Dampener Pulley		Oil Filter Manifold	
Exhaust Manifold		Oil Gallery	
Idler Pulley		Oil Line	
Injection Lines		Oil Pan	
Injection Pump		Turbo Charger	
Injection Pump Drive Gear		Water Jacket	
Intake Manifold		Water Pump Pulley	
Intake Pipe			

Name____

CASE

Activity 5.1.2 Fuel Delivery

Purpose

Diesel fuel systems use multiple components to deliver clean fuel to fuel injectors. Figure 2 shows the path diesel fuel takes through filters, a lift pump, an injection pump, and injection nozzles. The dashed lines in Figure 2 show fuel lines under low pressure, and the solid lines are lines under high pressure. Table 1 summarizes the components and their roles within a diesel fuel system.

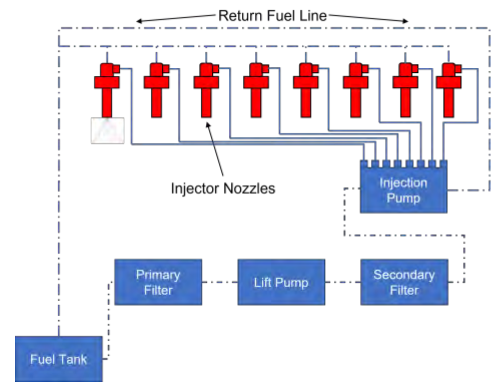


Figure 1. Diesel Fuel System

Filters are necessary to maintain high-quality fuel and prevent damage to interior engine components. Small debris in an engine can damage the fuel pump and injectors. In addition, diesel fuel absorbs water. Diesel systems are designed to condense and separate water in the fuel tank before entering the fuel lines.

Table 1. ***Fuel System***

Component	Role
Fuel lift pump	The pump transfers fuel from the fuel tank and pressures fuel to the injection pump.
Fuel filters	Fuel filters remove sediment and water from diesel fuel. Diesel systems may have more than one fuel filter. Primary filters protect the fuel lift pump. OEMs place secondary filters before the injection pump.
Injection pump	Injector pumps regulate and pressurize fuel before the injection into the cylinder. The crankshaft drives the injection pump with gears, chains, or a timing belt.
Injection nozzles	Fuel injectors deliver fuel into engine cylinders and control injection timing and atomization of fuel.
Return line	Diesel systems deliver excess fuel to serve as a coolant to the injectors. The excess fuel returns to the fuel tank for storage and dissipates any heat absorbed while cooling the injectors.
Fuel tank	The fuel tank stores fuel for use and cools unused fuel returned to the tank by the return line.
Fuel lines	Fuel lines carry fuel through system components under various pressures. Steel fuel lines carry fuel under high pressure, and hoses carry fuel under low pressure. Technicians flare steel fuel lines with a flaring tool to ensure proper connection.
Bleed screws	Diesel fuel lines need air removal before operation. Bleed screws are included in fuel lines for technicians to remove air from the system.

The fuel injection systems operate under pressure reaching over 1000 psi (pounds per square inch). Fuel leaks under this much pressure can puncture the skin. Therefore, technicians need to know how to work with a diesel system to avoid serious injuries.

Before removing a fuel injector, the technician will bleed the line to eliminate system pressure. After removing the fuel injector, they can test the injector for leaks, correct operational pressure, and spray patterns to ensure efficient engine operation.

How do the components of a diesel fuel system work together? What skills do technicians need to service a fuel system?

Materials

Per class:

- Automatic transmission fluid, quart
- (3) Bosch diesel fuel injector
- Diesel fuel, gallon
- (3) Diesel fuel injector pressure tester
- (3) Double flaring tool kit
- (3) Steel line cutter
- (6) Face shield
- (3) Metric wrench set
- Shop towels
- Tractor with diesel engine
- (3) Tractor user manuals

Per pair of students:

- Steel fuel line compression union
- Fuel line, steel, 12″ x ¼″

Per student:

- *Agriscience Notebook*
- Face shield
- Green highlighter
- Nitrile gloves
- Pen
- Pink highlighter
- Safety glasses
- Safety goggles

Procedure

Work in pairs to complete each part at a separate lab station. Your teacher will assign which part to complete first and when to rotate. Pairs starting with Part One will identify fuel system components. Those starting with Part Two will construct a fuel line. The students starting with Part Three will test a fuel injector.

Part One – Fuel System Identification (Station 1)

1. Put on safety glasses and tie back long hair.
2. Ensure the tractor is off and the engine is cool.
3. Locate the following fuel components. Sketch them in Figure 6 on *Activity 5.1.2 Student Observations*.
    - Fuel tank
    - Primary filter
    - Lifter pump
    - Secondary filter
    - Bleed screws
    - Injector pump
    - Fuel injector
    - Fuel shutoff valve
4. Use a green highlighter to mark the components under low pressure in Figure 6.
5. Use a pink highlighter to mark the components under high pressure in Figure 6.

Part Two – Fuel Line Connection (Station 2)

1. Put on safety glasses and tie back long hair.
2. Obtain 12″ of fuel line, line cutter, and a double flaring tool case from your teacher.
3. Remove 6″ of the fuel line using a line cutter from the tool case.
4. Remove the burs from all fuel line ends using the deburring tool on the line cutter and a metal file.
5. Inspect the flaring bar and clean it as needed with a shop towel.
6. Place the fuel line in the ¼″ section of the flaring bar with about ¼″ exposed from the chamfered side, as shown in Figure 2.
    - First, tighten the clamp closest to the line.
    - Second, tighten the clamp furthest to the line.
7. Place the ¼″ die next to the exposed line.

Figure 2. Fuel Line and Flaring Bar

8. Loosen the flaring bar and move the line until it is even with the die, as shown in Figure 2.
9. Retighten the clamp.
10. Place the die inside the line and place the flaring cone tool over the die, as shown in Figure 3.
11. Tighten the flaring cone tool until it is hand-tight.
12. Loosen the flaring cone tool and remove the die.
    - At this stage, the line has been single flared.
    - Diesel lines require a double flare.
13. Reposition the flaring cone tool over the line and retighten it until it is hand-tight.
14. Repeat Steps 6–13 with the second line.
15. Obtain a ¼″ steel fuel line compression union from your teacher.
16. Connect the two double flared connections with the compression union, as shown in Figure 4.

Figure 3. Setting Fuel Line Length

Figure 4. Exploded View of Compression Union and Fuel Line

17. Tighten the flare nuts with two wrenches.
18. Use masking tape and a permanent marker to label the connection with your name and turn it in for inspection as instructed by your teacher.

Part Three – Injector Test (Station 3)

1. Put on nitrile gloves, safety goggles, and a face shield.
2. Obtain a fuel injector from your teacher.
3. Pour 200ml of diesel fuel and 50ml of automatic transmission fluid into the tester's plastic fuel tank.
4. Gently swirl the solution in the fuel tank to mix.
5. Attach the fuel injector to the plastic lid of the fuel tank.
6. Attach the lid to the top of the plastic fuel tank.
7. Tighten the fuel injector to the end of the flared line with 14mm and 17mm wrenches.

Figure 5. Fuel Injection Pressure Tester

8. Lead the exhaust line to a window or an outside entrance to exhaust fumes.
    - The fuel injection pressure tester should be ready, as shown in Figure 5.
9. Attach the fuel line to the pressure tester.
    - Ensure the fuel filter is at the bottom of the plastic fuel tank.
10. Bleed air from the fuel line.
    - Slightly loosen the relief valve ¼ turn.
    - Pump the pressure tester pump until diesel fuel bleeds out the fitting.
    - Retighten the fitting.

11. Pump the pressure tester at a rate of one pump per second until the nozzle sprays diesel fuel.
12. Draw the spray pattern in Table 2. Repump fuel through the nozzle as needed to identify the pattern.
13. Repump the tester and record the pressure at which the nozzle injects fuel.
14. Slightly loosen the relief valve ¼ turn to relieve the pressure.
15. Pump the pressure tester pump and hold the pressure at 300 psi.
    - Inspect the injector tip for dripping.
    - Record your observations in Table 2.
16. Pump the pressure tester pump and hold the pressure within 100 psi of injecting fuel.
    - Record the starting pressure in the internal seal observations row of Table 2.
    - Wait 5 seconds.
    - Record the ending pressure in Table 2.
    - Calculate the percent decrease in pressure and record it in Table 2.
        - Decreases greater than 25% indicate an internal leak.
17. Relieve the pressure from the tester and tear down the injector tester.
    - **Caution:** Ensure there is no pressure in the system before disassembly.
18. Identify potential faults with the spray pattern using the **Diesel Engine Fuel Injector Service** article (http://www.dieselmotors.info/fuel-systems/diesel-engine-fuel-injector-service.html).
19. Record any faults and maintenance suggestions in Table 2.
20. Drain the fuel and store the tester as instructed by your teacher.

Conclusion

1. Why do diesel systems use more than one fuel filter?

2. What are the safety hazards found in a diesel fuel system?

3. What are the characteristics of a functional fuel injector?

Name____

Activity 5.1.2 Student Observations

Figure 6. Fuel System Sketch

Table 2. ***Injector Faults***

Spray Pattern Drawing				
Pressure at fuel injection				
Injector Tip Observations				
Internal Seal Observations	**Starting Pressure**	**Ending Pressure**	**Difference**	**Percent Change**
Potential faults				
Maintenance suggestions				

Name____

CASE

Activity 5.1.3 Lubrication and Cooling

Purpose

Diesel engines produce heat from friction, combustion, and compression. Excess heat in an engine will lead to seized parts and diminished service life. Heat, or thermal energy, can be transferred but not destroyed. Engineers designed diesel engines to transfer heat energy away from the engine using lubrication, air-cooling, and liquid-cooling. Routine maintenance and inspection of lubrication and cooling system will extend the engine's service life.

Oil cools, cleans, and lubricates the engine. Any moving part requires lubrication to reduce friction and remove heat. Small gasoline engines splash oil from the sump onto moving parts to dissipate heat. Modern diesel engines use a force-feed lubrication system to pump oil from the oil pan sump and throughout the engine. An oil cooler cools the oil before flowing through the system. Oil transfers contaminants in the engine to an oil filter. Figure 1 shows a cutaway model of an oil filter using paper to remove small contaminants. Technicians perform routine maintenance on oil pumps and change the oil on diesel engines.

Figure 1. Oil Filter

Air-cooled engines quickly transfer thermal energy from the combustion chamber to outside the engine. Figure 2 shows how cooling fins increase the surface area around the cylinder to transfer heat. Blower motors further cool the engine by moving heat to the atmosphere.

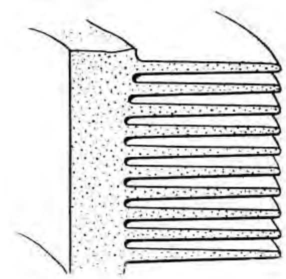


Figure 2. Cooling Fins

Liquid-cooled engines use a mixture of ethylene glycol (antifreeze) and water. The water pump moves coolant from the radiator to pockets around the cylinders called water jackets, as shown in Figure 3. The terms water pump and water jackets are names from older diesel models that only used water as engine coolant. Technicians use a refractometer to inspect the freezing point of coolants, as shown in Figure 4.

Figure 3. Water Jackets

Coolant circulates through the engine and water pump at temperatures below 170-190°F. As temperatures rise above that level, a thermostat opens a path for coolant to enter the radiator. The radiator cools the coolant using cooling fins and outside air before recirculating it to the water pump. Diesel engines require thermostats of various ratings. For example, a 170-190°F thermostat has a start-to-open rating of 170°F and a close-to-open rating of 190°F. The start-to-open rating is the temperate at which the thermostat slightly opens the path for coolant to enter the radiator. The thermostat is fully open when the coolant reaches the full-to-open rating.

Figure 4. Refractometer

How do technicians inspect lubrication and cooling systems?

Materials

Per group of four students:

Part One

- Cups, 3 oz
- Device with timer
- Engine oil
- Funnel
- OEM specifications for tractor
- Oil drip pan
- Oil filter
- Oil filter wrench
- Permanent marker
- Socket set, 6 pt, $^3/_8$″ drive
- Socket wrench, $^3/_8$″ drive
- Torque wrench $^3/_8$″ drive
- Tractor

Part Two

- (3) Cups, 3 oz
- Permanent marker
- Pipet, 1ml
- Refractometer kit

Part Three

- Beaker, 600ml
- Device with internet access
- Hot plate
- Needle nose pliers
- Nylon string, 2′
- Ring stand
- Ring, 10 cm
- Thermometer
- Thermostat, used
- Water

Per class:

- (3) Engine coolant samples
- Distilled water
- Shop towels

Per student:

- *Agriscience Notebook*
- *Logbook*
- Nitrile gloves
- Pen
- Safety glasses

Procedure

Your teacher will provide your group with a tractor. First, change the oil in the diesel engine according to the OEM specifications and analyze the oil for contaminants. Next, Use a refractometer to analyze the engine coolant. Then, inspect a thermostat to ensure the working condition.

Part One – Change and Inspect Oil

1. Check the OEM specifications for the lubrication system. Record in Table 1 of *Activity 5.1.3 Student Data*.
2. Operate the engine until the engine temperature reaches 140°F (60°C).
    - Oil contaminants settle to the bottom when the engine is not running. Operating the engine will suspend the contaminants.
3. Turn off the engine.
4. Put on nitrile gloves and safety glasses.
5. Place an oil drain pan under the oil drain plug to catch oil. Remove the oil drain plug using a six-point socket wrench.
6. Clean the area around the oil filter head to prevent debris from entering the engine.
7. After the oil has drained into the drain pan, remove the filter using an oil filter wrench.
8. Place the oil filter on the oil drain pan to drain the oil.

Figure 5. Oil Filter Head

9. Inspect the filter head, as shown in Figure 5.
10. Clean the gasket surface of the filter head using a shop towel.
    - Check for an O-ring that may be clinging to the filter head. Remove if present.
11. If recommended by the OEM, fill the replacement filter with clean lubricating oil as directed.
12. Place your finger in clean oil and apply a light film to the gasket sealing surface.
13. Install the new filter to the filter head and hand-tighten.
14. Install the drain plug and use a torque wrench to tighten it to specifications.
15. Fill the engine oil to OEM specifications.
16. Idle the engine for two minutes and check for leaks at the oil filter and drain plug.
17. Turn off the engine and check the engine oil level at the dipstick. Add oil if necessary.
18. Mark a 3 oz cup as *used oil* and another as *new oil*.
19. Fill each cup halfway with the corresponding oil.
20. Inspect the oil color, viscosity, and the presence of contaminants. Record observations in Table 2.
    - Swirl the oil between your thumb and finger to feel for contaminants.
    - Check the oil drain pan for signs of any potential shavings.
21. Recycle the engine oil as directed by your teacher.

Part Two – Thermostat

1. Obtain a thermostat from your teacher. Record the start-to-open and full-to-open ratings in Table 4, if available. If only a part number is available, research the ratings using a device with internet access.
2. Inspect the thermostat seal for any damage or debris. Record any faults in Table 4.
3. Fill a 600ml beaker with approximately 450ml of water.
4. Place the beaker on a hot plate.
5. Prepare the thermostat as shown in Figure 6.
    - Manually open the thermostat with a slotted screwdriver and insert the two-foot nylon string.
6. Place the thermometer into the beaker.
    - Hold the sensor, so it is not touching the glass.
7. Suspend the thermostat from a ring stand in the water, as shown in Figure 7.
    - Hold the sensor, so it is not touching the glass.
8. Turn the hot plate to high.
9. Observe the thermostat as the water approaches the start-to-open and full-to-open ratings.
10. Record the temperature of the water when the thermostat releases the nylon string in Table 4.
    - An operating thermostat should release the string at its full-to-open rating.

Figure 6. Thermostat Prep

Figure 7. Thermostat Suspension

11. Use a needle nose pliers to remove the thermostat from the water and inspect the inside of it for pitting and foreign objects. Record any defects in Table 4.
12. Answer *Part Three Analysis Questions*.

Part Three – Refractometer

1. Set up the refractometer for calibration.
    - Open the daylight plate, as shown in Figure 8.
    - Use a pipet to place three drops of distilled water onto the daylight plate.
    - Close the daylight plate. The water should spread evenly with no bubbles.
    - Set the refractometer aside for 30 seconds for the sample to adjust to ambient air temperature.

Figure 8. Open Daylight Plate

Figure 9. Uncalibrated Refractometer Scale

2. Calibrate the refractometer.
    - Hold the daylight plate towards the light and look through the eyepiece. Figure 9 shows the scale of an uncalibrated refractometer.
    - A calibrated refractometer will break between blue and white at the *waterline* mark. Adjust the top screw with the small screwdriver if needed until the refractometer calibrates.
    - Remove the water with the microfiber cloth found in the refractometer kit.
3. Obtain three 3 oz cups. Label the cups *A*, *B*, and *C* with a marker.
4. Place approximately 5ml of antifreeze solution into the appropriate cups, labeled *A*, *B*, and *C*.
5. Use a pipet to place three drops of sample *A* evenly onto the daylight plate.
6. Record the freezing temperature for ethylene antifreeze in Table 3.
7. Remove the antifreeze with the microfiber cloth found in the refractometer kit.
8. Repeat Steps 5–7 with samples *B* and *C*.
9. Circle the sample in Table 3 best suited for the farmer operating a tractor in -25°F weather.

Conclusion

1. What is the role of oil in a diesel engine?

2. What are the fundamental differences between air-cooled and liquid-cooled engines?

3. How do thermostats control how a diesel engine is cooled?

Name____

Activity 5.1.3 Student Data

Table 1. ***OEM Oil Specifications***

Specification	Data	Specification	Data
Drain Plug Size		Oil Type	
Drain Plug Torque		Oil Capacity	
Frequency of Oil Change		Oil Filter	

Table 2. ***Oil Analysis***

Specification	New Oil	Used Oil
Color		
Viscosity		
Contaminants		

Table 3. ***Thermostat Inspection***

Specification	Data
Start-to-open rating	
Full-to-open rating	
Thermostat lip seal damage	
Temperature at string release (full-to-open)	
Internal inspection	

Part Two Analysis Questions

Q1 Was the full-to-open rating consistent with the thermostat test? How do you know?

Q2 What defects did your thermostat have? Should it be replaced?

Table 4. ***Coolant Freeze Points***

Coolant	Freeze Point
Sample A	
Sample B	
Sample C	

Name____ **CASE**

Project 5.1.4 Cool Inspection

Purpose

Agricultural equipment is often operated for long hours and in high heat situations. Overheating engines create harvest delays, costing the operator time and money. When an engine overheats, there are several things a technician needs to inspect and *Technician Questions* they should ask themselves.

Technician Questions

- Does the radiator have coolant?
- Is the water pump circulating coolant?
- Is the serpentine belt turning the water pump?
- Is the thermostat opening at the correct temperature?
- Is the radiator cooling the coolant?
- Are the coolant hoses clogged or leaking?

A water pump is the heart of the cooling system. Heat will build up and damage the engine when the water pump fails to circulate coolant. Most water pumps are self-lubricated and use sealed bearings. The pumps move fluid through the cooling system at a quick rate. Some water pumps have a flow rate of 125 gallons per minute. Two types of water pumps are used in diesel engines: belt and gear driven.

The purpose of radiators is to dissipate the heat collected by the coolant. Warm coolant bypasses the thermostat, enters the radiator's top through a hose, and then travels through tubes surrounded by metal fins to air-cool the coolant. Depending on OEM design, the tubes will either move vertically or horizontally through the radiator. Faulty radiators include leaks, bent components, or debris. A radiator is tested for leaks under pressure in a water tank. The presence of bubbles indicates a leak. Technicians may suspect a leak if white mineral deposits are on the radiator's surface. Debris in the radiator will restrict the dissipation of heat. Never open a radiator while an engine is hot.

Materials

Per group of four students:

- Battery, 12V
- Device with timer
- Erlenmeyer flask, 1L
- Hot plate
- IR thermometer
- Lap tape
- Permanent marker
- Plastic cup, 16 oz
- (2) Plastic splice $^1/_8$″
- Plastic tubing, 1′ x $^1/_8$″ I.D. – 6 feet
- Positive displacement pump, 12V
- Rubber stopper, two holes, size 6
- Scissors
- Supplies and tools to construct radiator
- (2) Wire with alligator clips

Per class:

- Bicycle pump
- (2) Flashlights
- Radiator, assembled for inspection
- Water pump, belt-driven
- Water pump, gear-driven
- Water tank

Per student:

- *Agriscience Notebook*
- *Logbook*
- Pen
- *Project 5.1.5 Evaluation Rubric*
- Safety glasses

Procedure

Your group will inspect water pumps and radiators as you rotate through the stations. Then create a model cooling system that air cools liquid.

Part One – Cooling System Inspection

Station One – Water Pump Inspection
Your teacher has provided a gear-driven and a belt-driven water pump for inspection. Inspect both water pumps using the student observation sheet. Record inspections for the gear-driven pump in Table 1 and the belt-driven in Table 2. As you inspect the water pump, look for leaks in the pump housing, damaged seals and bearings, and bent vanes. List the parts needing replacement in your *Logbook*. Technicians should install new seals and gaskets when reassembling a water pump.

Station Two – Radiator Inspection
Inspect the radiator provided by your teacher. Use a flashlight to inspect for bent fins, debris in the radiator, evidence of leaks, or cracked hoses. Record the inspections in Table 3.

Your teacher has closed the radiator system to add compressed air. After inspecting the external components for evidence of leaks, pump the bicycle pump attached to the radiator to 15-18 PSI. Check the hoses and radiator for evidence of leaks. Brush on the soap-water mixture in suspected areas. Draw a picture of the radiator in Table 3 and document the locations of leaks.

Part Two – Model Coolant System

Figure 1. Model Cooling System

1. Cut the six-foot section of the tubing into a one-foot and a five-foot sections.
2. Fill the Erlenmeyer flask 90% full of water.
3. Construct the model cooling system shown in Figure 1.
   - The one-foot tubing is labeled A in the figure.
4. Connect the tubing using $^{1}/_{8}$″ plastic splices.
5. Connect the pump to a 12V battery using wires with alligator clips. Disconnect one wire after verifying the operation.
6. Place the Erlenmeyer flask on a hot plate.
7. Obtain an IR thermometer from your teacher.
   -
8. Label the components representing the listed parts of a cooling system with lab tape and a permanent marker. Then, sketch your model and label the components in your *Logbook*.
   - Water pump
   - Water jacket
   - Engine cylinder
   - Coolant hoses
   - Thermostat
9. Fill a 16 oz plastic cup full of water.
10. Disconnect the tubing connection on the longer tube and place both ends in the water, as shown in Figure 2.

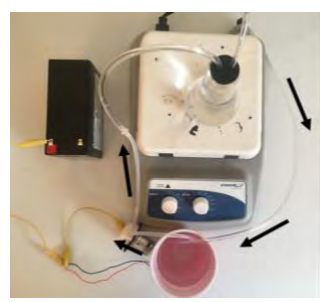


Figure 2. Bleeding the Model

11. Activate the water pump to siphon water through the hoses. Continue until all the air has bled out of the system.
    - The water should flow along the directional path shown in Figure 5. If not, switch the leads on the pump.
    - Add more water to the cup as needed.
    - Repair any leaks as needed.
12. Turn off the pump.

Part Three – Modify the Coolant System

Turn on the hot plate and heat the water to 140-150°F. Collect measurements using the IR thermometer. Modify the coolant system to dissipate the heated coolant in the water jacket. Once you have designed and constructed your modifications, collect the temperature of the coolant in the water jacket. Record the temperature in Table 4. Next, turn on the pump and collect readings in one-minute intervals for four minutes. After four minutes, turn off the pump and hot plate.

Create a presentation to demonstrate to your class the components and efficiency of your cooling system. Include data from Table 4 to showcase heat dissipation from the water jacket. Your teacher will use the *Project 5.1.5 Evaluation Rubric* to evaluate the model and presentation.

Conclusion

1. What is the role of the water jacket in a diesel cooling system?

2. List three potential faults that could cause an engine to overheat

.

Name____

Project 5.1.4 Student Observations

Table 1. ***Gear Driven Pump Inspection***

Component	Check if Operational	Faults	Recommended Repairs
Pump housing			
Impeller vanes			
Seals			
Bearings			

Table 2. ***Belt Driven Pump Inspection***

Component	Check if Operational	Faults	Recommended Repairs
Pump housing			
Impeller vanes			
Seals			
Bearings			

Table 3. ***Radiator Inspection***

Component	Check if Operational	Faults	Recommended Repairs
Fins			
Debris			
Tubes			
Hoses			
Leaks			
Location of leaks			

Table 4. ***Model Diesel Cooling System***

Time	Temperature
Beginning Temperature	
1 minute	
2 minutes	
3 minutes	
4 minutes	

Name____

CASE

Project 5.1.4 Evaluation Rubric

Areas with Room for Improvement	Criteria	Areas that Meet or Exceed Expectations
	Model The model cools the coolant simulating components found in a diesel cooling system. Examples include, but are not limited to, radiator, cooling fan, and cooling fins. The cooling system dissipates heat from the coolant before reentering the water jacket.	
	Data The data collected is documented on the student observations page and highlighted during the presentation.	
	Presentation The presentation showcases the components of a cooling system simulated on the model. The data presented showcases the efficiency of the system.	
	Professionalism All students participated in the presentation and model construction. Students use safe practices while constructing the model.	

Name____

CASE

Activity 5.1.5 Clean Air

Purpose

Diesel engines require a large volume of clean air to operate correctly. During previous agricultural courses, you learned that small gasoline engines require a fuel-to-air ratio of 14.7 to 1. Large diesel engines require 8,500 gallons of air for every gallon of diesel fuel. OEMs design diesel engines with an intake system that evenly distributes clean air to each cylinder.

Contaminants in the air degrade engine performance and service life. Airborne contaminants, such as dust and moisture, are plentiful in agricultural and construction applications. Air filters and air cleaners remove these contaminants before entering the intake system. For example, oil bath air cleaners are common in tractors. Figure 1 shows air moving through an air cleaner's oil bath and filter element to remove contaminants.

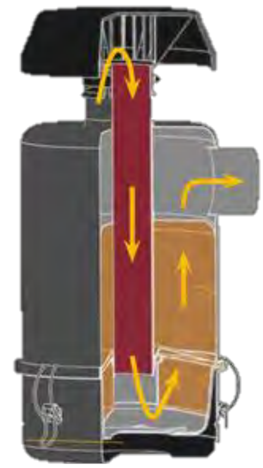


Figure 1 Oil Bath Air Cleaner

After the air is filtered, turbochargers increase the power output of an engine by forcing compressed air into a combustion chamber. Figure 2 shows a sectional view of a turbocharger. A turbine connected to the exhaust manifold drives a turbocharger. As exhaust moves the turbine, the compressor on the intake side of the turbocharger rotates. The compressor pulls in and compresses air en route to the intake manifold. A wastegate on the exhaust side controls the speed of the turbine. Diesel systems use a wastegate to control the volume of air compressed by the turbocharger.

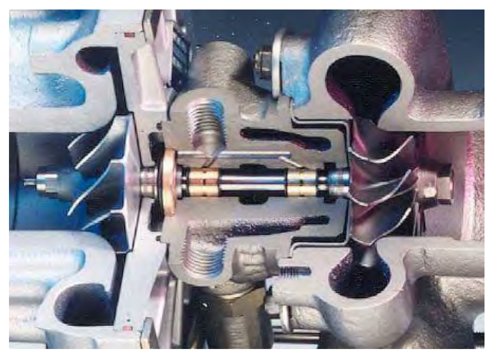


Figure 2. Turbocharger

Intake manifolds are on the engine's side, opposite the exhaust manifold. Figure 3 shows a used intake manifold from a tractor. The intake manifold equally distributes air from the intake system to each cylinder. Likewise, the exhaust manifold distributes exhaust from each cylinder to the turbocharger and exhaust system.

Figure 3. Intake Manifold

The engine must clean the exhaust as well. The Environmental Protection Agency (EPA) requires new diesel engines to have exhaust treatment systems that reduce air pollutants.

Diesel exhaust fluid (DEF) is a mixture of urea and water injected into a diesel engine's exhaust stream. DEF breaks down NO_x gasses into nitrogen and water. For DEF to work correctly, it must be 32.5% urea. A technician can use a refractometer to determine urea percentages of DEF.

How does a technician ensure clean air enters into and exhausts from a diesel engine?

Materials

Per class:

- (3) Air filters
- (3) Box wrench sets
- (3) DEF samples
- Distilled water
- Refractometer
- (3) Turbochargers

Per group of four students:

- Colored pencils
- (4) Cups, 3 oz
- Plastic pipet, 1ml

Per student:

- *Agriscience Notebook*
- Pen
- Permanent marker
- Safety glasses

Procedure

Put on safety glasses and tie back long hair. Work in a group and rotate through stations as instructed by your teacher. At stations, one and two, disassemble and inspect an air filter and turbocharger. During station three, use a refractometer to determine the quality of DEF samples.

Station One – Air Filter

1. Disassemble the air filter.
2. Sketch the air filter in Figure 5 of *Activity 5.1.5 Student Observations*.
3. Inspect the element for contaminants.
4. Record the contaminants and note their location on your sketch
5. Inspect the gasket for cracking and wear.
6. Sketch the gasket in Figure 6.
    - Note locations on the gasket where the seal may be poor.
7. Reassemble the air filter for the next group.

Station Two – Turbocharger

1. Disassemble the turbocharger using the tools provided and draw the components in Figure 7 of the observations sheet.
    - Compressor wheel
    - Turbine wheel
    - Shaft
    - Bearing
    - Compressor housing
    - Wastegate valve
2. Use a red colored pencil to label the exhaust components.
3. Label the intake components in blue.
4. Reassemble the turbocharger.
5. Answer *Station Two Analysis Questions*.

Station Three – DEF Evaluation

1. Set up the refractometer for calibration.
    - Open the daylight plate
    - Use a pipet to place three drops of distilled water onto the daylight plate.
    - Close the daylight plate. The water should spread evenly with no bubbles.
2. Calibrate the refractometer.
    - Set the refractometer aside for 30 seconds for the sample to adjust to ambient air temperature.
    - Hold the daylight plate towards the light and look through the eyepiece. Figure 4 shows the scale of an uncalibrated refractometer.
    - A calibrated refractometer will break between blue and white at the *waterline* mark. Adjust the top screw with the small screwdriver if needed until the refractometer calibrates.
    - Remove the water with the microfiber cloth found in the refractometer kit.

Figure 4. Refractometer Scale

3. Obtain four 3 oz cups and label them *A*, *B*, *C*, and *distilled water* with a permanent marker.
4. Use a pipet to add 5 ml of distilled water to the *distilled water* cup.
5. Use a pipet to add 5 ml of each DEF solution into cups *A*, *B*, and *C*.
6. Use a pipet to place three drops of sample *A* onto the daylight plate.
7. Record the urea percentage in Table 1.
8. Remove the DEF with the microfiber cloth found in the refractometer kit.
9. Repeat Steps 6–8 with samples *B* and *C*.
10. Circle the sample in Table 1 with the correct urea percentage.

Conclusion

1. What controls the rate of compressed air entering the engine?

2. How can air contaminants affect engine operation?

3. How would DEF with a low urea percentage affect air quality?

Name____

Activity 5.1.5 Student Observations

Figure 5. Filter	**Figure 6. Gasket**

Figure 7. Turbocharger

Station Two Analysis Questions

Q1 How does the wastegate valve influence the speed of the turbocharger?

Q2 How does the turbocharger's speed influence the air pressure in the intake manifold?

Q3 What is the role of compressed air in the intake manifold?

Table 1. ***DEF Percentage***

Sample A	Sample B	Sample C

Name____

CASE

Project 5.1.6 Engine Failure

Purpose

Throughout this lesson, you have learned the differences between a diesel and a gasoline engine. Some of the most similar components are found within the engine block after fuel and air enter the combustion chamber and before the exhaust is released. What are those similar components?

All internal combustion engines have pistons, rings, connecting rods, crankshafts, valves, and bearings. The piston moves linearly inside a cylinder or sleeve. Rings surrounding the piston seal the combustion chamber creating compression while preventing oil from entering. The piston is attached to a connecting rod. The connecting rod moves the crankshaft converting the linear motion to rotary motion. Bearings between rotating and stationary components reduce friction and prevent components under high torque and speeds from breaking.

A technician will analyze the component and look for clues to determine the cause when a component breaks before replacing it. Common clues include noises, lack of power, and colored exhaust. Unburned diesel fuel in the combustion chamber will cause white exhaust; combustion issues such as low compression or lack of air will cause black exhaust. Blue exhaust indicates oil is entering the combustion chamber. How do technicians use troubleshooting charts during this failure analysis process?

Materials

Per student:

- *Agriscience Notebook*
- Device with internet access
- *Work/Repair Order Template*
- *Work/Repair Order Evaluation Rubric*

Per class:

- (10) *Customer Complaint Station*

Procedure

Work with a partner to observe damaged components associated with a customer complaint. Then use a troubleshooting chart to determine the cause and solution. Finally, complete the project by individually writing a work/repair order for one of the customer complaints.

Part One – Customer Complaints

Rotate through each station. Read each complaint associated with the example components. Then, use the equipment at each station to diagnose the problem. Record the station's complaint, cause, and correction in Table 1 on *Project 5.1.6 Student Observations*. Use the following resources to help identify the cause.

- **Turbocharger Troubleshooting** (https://seideldieselgroup.com/wp-content/uploads/2016/12/TurboTroubleshooting.pdf)
- **Diesel Engine Troubleshooting Guide 2022** (https://www.tlcautotruck.com/blog/diesel-engine-troubleshooting-guide/)

Station 1
Tori Atwater has a tractor that lacks power and has black exhaust. She used the tractor for tilling soil in a very dusty environment.

Station 2
Chris Johnsville's tractor has been using more fuel than usual. He has noticed that the exhaust is black in color.

Station 3
Van Danville has heard noises coming from inside the engine. He has also noticed a considerable power loss and blue smoke in the exhaust.

Station 4
Jenny Sturgis has heard noises coming from the turbocharger. The engine has lacked power and is producing black smoke.

Station 5
Brittani Hewitt has noticed that the engine's operating temperature has been higher than normal. He is concerned that the engine may overheat.

Station 6
Patrick Clark has a tractor with a light on signaling low oil pressure light. The oil level is the correct level.

Station 7
Kevin Port's tractor will not start. The battery is fully charged.

Station 8
Allen Roberts' tractor is running "rough" when he starts it. After the engine is warm, it continues to stall.

Station 9
Ashley Maple has noticed that the engine's operating temperature has been higher than normal. He is concerned that the engine may overheat.

Station 10
Josh Goldendale's tractor stopped running because it ran out of DEF. He added DEF to the tractor, but it still will not start.

Part Two – Work/Repair Order

Your teacher will assign you one of the stations from Part One. Complete a *Work/Repair Order Template* for your assigned station. Your teacher will use the *Work/Repair Order Evaluation Rubric* to assess your work.

Conclusion

1. How do technicians troubleshoot engine failure?

2. Why could there be more than one cause of an engine failure?

3. What clues does a technician use to determine the cause of engine failure?

Name____

Project 5.1.6 Student Observations

Table 1. ***Station Observations***

Station Number	Complaint	Cause	Correction
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			

Name____

CASE

Lesson 5.1 Check for Understanding

1. Match the engine component to the diesel subsystem.

A.	Cooling
B.	Intake
C.	Ignition
D.	Fuel
E.	Exhaust

______ Glow plugs

______ Turbocharger wastegate

______ Air cleaner

______ Injection pump

______ Oil filter

______ Turbocharger compressor

______ Lift pump

______ Thermostat

2. Which statement about diesel fuel is not true?
   a) Diesel fuel is produced through heating and refinement of crude oil
   b) Diesel fuel mixes with air in the fuel pump before entering the combustion chamber
   c) Diesel fuel has a lower flashpoint than gasoline
   d) Diesel ignition utilizes heat during the compression stroke

3. What is the function and purpose of a thermostat?

4. Draw and label a diagram representing the fuel flow through a diesel injection system. Include the components listed in your diagram.

Fuel injectors	Fuel tank	Injection pump	Lift pump
Primary fuel filter	Return fuel line	Secondary fuel filter	

5. Match the system most likely to cause each of the following problems

A.	Cooling system
B.	Fuel system
C.	Lubrication System
D.	Air intake system
E.	Exhaust system

______ The engine with a clean air filter has lost power.

______ Worn piston rings and sleeves caused by abrasive material.

______ Engine exhausts blue smoke with a loss of power.

______ Engine overheats while idling and not doing work.

______ The engine is low on DEF.

Name____

CASE

Lesson 5.1 Check for Understanding Answer Key

1. Match the engine component to the diesel subsystem.

A.	Cooling
B.	Intake
C.	Ignition
D.	Fuel
E.	Exhaust

__C__ Glow plugs
__E__ Turbocharger wastegate
__B__ Air cleaner
__D__ Injection pump
__A__ Oil filter
__B__ Turbocharger compressor
__D__ Lift pump
__A__ Thermostat

2. Which statement about diesel fuel is not true?

a) Diesel fuel is produced through heating and refinement of crude oil
b) Diesel fuel mixes with air in the fuel pump before entering the combustion chamber
c) Diesel fuel has a lower flashpoint than gasoline
d) Diesel ignition utilizes heat during the compression stroke

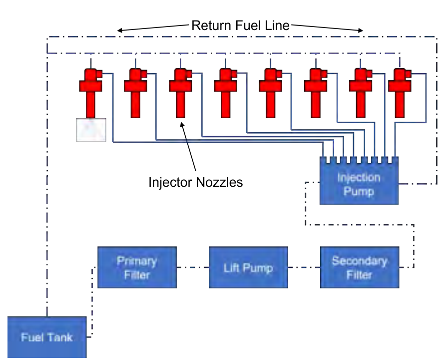
3. What is the function and purpose of a thermostat?

The thermostat reacts to the heat of the coolant. As the engine coolant cycling between the water pump and water jackets reaches a threshold, the thermostat opens a path for the coolant to the radiator.

4. Draw and label a diagram representing the fuel flow through a diesel injection system. Include the components listed in your diagram.

Fuel injectors	Fuel tank	Injection pump	Lift pump
Primary fuel filter	Return fuel line	Secondary fuel filter	

An example drawing is shown below. Students do not have to include multiple fuel injectors to demonstrate mastery of the concept.



5. Match the system most likely to cause each of the following problems

A.	Cooling system
B.	Fuel system
C.	Lubrication System
D.	Air intake system
E.	Exhaust system

__B__ The engine with a clean air filter has lost power.

__D__ Worn piston rings and sleeves caused by abrasive material.

__C__ Engine exhausts blue smoke with a loss of power.

__A__ Engine overheats while idling and not doing work.

__E__ The engine is low on DEF.

CASE

Lesson 5.2 Diesel and Electrical

Preface

Equipment systems utilize Controller Area Network (CAN bus) to increase communication efficiency between computers. Diesel equipment, much like passenger vehicles, are equipped with several microprocessors that communicate together without using a central computer. A CAN bus consists of Electronic Control Units (ECUs) that send and receive information through an 8-bit digital signal. All ECUs in a CAN bus receive the signal, but only designated ECUs will act upon it. For example, when the oil pressure transducer senses low pressure, an ECU will signal low oil pressure. Another ECU in the CAN bus called a BCM (body control module), activates an indicator light while other ECUs ignore the signal. ECUs generate signals over two wires, CAN_H (CAN high) and CAN_L (CAN low).

Students construct a model CAN bus system during this lesson and identify how changes in terminating resistance impact the signal. Next, students tour an equipment dealership to learn how technicians read CAN bus fault codes using a scan tool. Finally, students create a flowchart detailing the relationship between transducers, ECUs, and a scan tool to complete the lesson.

Concepts	Performance Objectives
Students will know and understand	*Students will learn concepts by doing*
1. Diesel engines control connected systems using Controller Area Network (CAN) bus systems with Electronic Control Units (ECU) to monitor and control the engine.	• Diagnose faults in a CAN bus model using a DMM. (Activity 5.2.1) • Identify how a circuit fault in CAN bus impacts an 8-bit signal. (Activity 5.2.1)
2. A CAN bus allows a system of microcontrollers to control agricultural equipment.	• Simulate CAN bus data in response to sensor data. (Activity 5.2.2) • Inspect an oil pressure transducer for faults. (Activity 5.2.2)
3. High-pressure common rail diesel fuel systems have essential components with specific functions.	• Develop a flowchart of CAN bus operations within fuel and intake systems. (Project 5.2.3)

National AFNR Common Career Technical Core Standards Alignment

Power, Structural and Technical (AG-PST)
1. Apply physical science principles and engineering applications related to mechanical equipment, structures, and biological systems to solve problems and improve performance in AFNR power, structural, and technical systems.
• AG-PST 1.2: Use hand and power tools commonly required in power, structural, and technical systems
3. Service and repair mechanical equipment and power systems used in AFNR power, structural and technical systems.
• AG-PST 3.6: Service electrical systems by troubleshooting from schematics.
5. Use control, monitoring, geospatial and other technologies in AFNR power, structural and technical systems.
• AG-PST 5.1: Execute procedures and techniques for monitoring and controlling electrical systems using basic principles of electricity.
• AG-PST 5.2 Design control systems by referencing electrical drawings.

Next Generation Science Standards Alignment

Science and Engineering Practices	
Developing and Using Models	Modeling in 9–12 builds on K–8 experiences and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed world(s). • Evaluate merits and limitations of two different models of the same proposed tool, process, mechanism, or system in order to select or revise a model that best fits the evidence or design criteria. • Design a test of a model to ascertain its reliability. • Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system.
Analyzing and Interpreting Data	Analyzing data in 9–12 builds on K–8 experiences and progresses to introducing more detailed statistical analysis, the comparison of data sets for consistency, and the use of models to generate and analyze data. • Consider limitations of data analysis (e.g., measurement error, sample selection) when analyzing and interpreting data.

Common Core State Standards for English Language Arts

CCSS: English Language Arts Standards » Writing » Grade 11-12	
Research to Build and Present Knowledge	• **WHST.11-12.9 –** Draw evidence from informational texts to support analysis, reflection, and research.

Essential Questions

1. How does a technician check a CAN bus system using a digital multimeter?
2. How does a CAN bus system translate sensor data?
3. How do ECUs respond to 8-bit signals?
4. How does a CAN bus system communicate faults?
5. How do technicians use codes to isolate root causes?

Key Terms

8-bit	**Body control module (BCM)**	**CAN bus**
CAN_H	**CAN_L**	**Crankshaft position transducer**
Data link connector (DLC)	**Electronic control unit (ECU)**	**Fuel temperature transducer**
Manifold absolute pressure (MAP)	**Mass airflow (MAF)**	**Powertrain control module (PCM)**
Scan tool	**Terminating resistor**	

Day-to-Day Plans
Time: 6 days

Refer to the Teacher Resources section for specific information on teaching this lesson, in particular ***Lesson 5.2 Teacher Notes****,* ***Lesson 5.2 Glossary****,* ***Lesson 5.2 Materials****, and other support documents.*

Days 1 – 2:

- Present **Concepts**, **Performance Objectives**, **Essential Questions**, and **Key Terms** to provide a lesson overview.
- Provide students **Presentation Notes** pages to be used throughout the presentation to record notes and reflections. Students add these pages to their *Agriscience Notebook*.
- Present LunchBox Session© **Intro to CAN Bus.**
- Students take notes using the *Presentation Notes* pages provided by the teacher.

- Provide students with a copy of **Activity 5.2.1 CAN Bus Basics** and **CAN Bus Template**.
- Students work in groups to complete *Activity 5.2.1 CAN Bus Basics*.

Day 3:

- Provide students with a copy of **Activity 5.2.2 Monitor and Control**.
- Students work in groups to complete *Activity 5.2.2 Monitor and Control*.

Day 4:

- Provide students with a copy of **Project 5.2.3 Essential Components**.
- Provide the equipment dealership with a copy of **Project 5.2.3 Presenter Checklist**.
- Students complete Part One of *Project 5.2.3 Essential Components* during a tour of an equipment dealership.

Day 5:

- Students work in pairs to complete Part Two of *Project 5.2.3 Essential Components*.
- Access student work using the **Project 5.2.3 Evaluation Rubric**.

Day 6:

- Distribute **Lesson 5.2 Check for Understanding**.
- Students will complete *Lesson 5.2 Check for Understanding* and submit it for evaluation.
- Use **Lesson 5.2 Check for Understanding Key** to evaluate student assessments.

Instructional Resources

Lunchbox Session©

Intro to CAN Bus

Student Support Documents

Lesson 5.2 Glossary

Presentation Notes

CAN Bus Template

Activity 5.2.1 CAN Bus Basics

Activity 5.2.2 Monitor and Control

Project 5.2.3 Essential Components

Teacher Resources

Lesson 5.2 Diesel and Electrical PDF

Lesson 5.2 Teacher Notes

Lesson 5.2 Materials

Lesson 5.2 Check for Understanding

CAN Bus Basics Code

Monitor and Control Code

Project 5.2.3 Presenter Checklist

Answer Keys and Assessment Rubrics

Lesson 5.2 Check for Understanding Answer Key

Project 5.2.3 Evaluation Rubric

Reference Sources

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My Turbo Diesel. (n.d.). *How to replace the fuel temperature sensor and injection pump cover seal replacement on VW Audi TDI*. Retrieved July 12, 2021, from **https://www.myturbodiesel.com/d2/1000q/multi/fuel-temperature-sensor-TDI.htm**

FFA Connections

This lesson provides conceptual and procedural knowledge related to the following FFA awards, activities and educational resources.

- Agricultural Proficiency
  - **Agricultural Mechanics Repair and Maintenance –Placement**
  - **Agricultural Mechanics Repair and Maintenance –Entrepreneurship**
  - **Agriscience Research – Integrated Systems**
- Agriscience Fair
  - **Power, Structural and Technical Systems**
- Career Development Events
  - **Agricultural Technology & Mechanical Systems**
- Educational Resources
  - **All About Engines**
  - **SAE Idea Cards-Power, Structural and Technical Systems**
  - **Power, Structural and Technical System Careers**
  - **Power, Structural and Technical Systems Career Focus Area Resources**
  - Power, Structural and Technical Careers **(Word)**

For more information, visit the **National FFA Organization** website.

SAE for All

Immersion SAE

Students interested in this lesson's topics should explore the following related Immersion SAEs. An immersion SAE is optional and replaces the agricultural literacy component of the Foundational SAE.

- **Immersion SAE Learning Guides**

For more information on the guiding principles for implementing SAE programs, visit the **SAE for All: Evolving Essentials** site.

Critical Thinking and Application Extensions

Interpretation

1. Students will record CAN bus codes from a technician manual, and then they will identify system failures that can cause those codes.

Application

2. Students will use a multimeter to measure terminating resistance in equipment with a CAN bus.

Lesson 5.2 Teacher Notes

Lesson 5.2 Diesel and Electrical

In preparation for teaching this lesson, review Concepts, Performance Objectives, Essential Questions, and Key Terms, along with the LunchBox sessions. Also, review all activity directions, expectations, and work students will complete.

Students construct a model CAN bus system during this lesson and identify how changes in terminating resistance impact the signal. The model simulates an 8-bit electrical signal using LEDs. Next, students tour an equipment dealership to learn how technicians read CAN Bus fault codes using a scan tool. Then students create a flowchart detailing the relationship between transducers, ECUs, and a scan tool.

LunchBox Sessions©

Register for one **LunchBox Session©** account with the rights to present to your class. LunchBox Sessions© are short information sessions technicians can use to refresh themselves on fundamental mechanics.

Intro to CAN Bus

This session explains how diesel equipment uses a CAN bus network to communicate with a series of microprocessors.

Activities, Projects, and Problems

Activity 5.2.1 CAN Bus Basics

Students build a model CAN bus system on a piece of plywood and use a digital multimeter to measure network resistance during simulated faults.

Teacher Preparation

1. Cut an 8.5″ x 11″ piece of plywood for each group of four students. The plywood should be ½″ thick at a minimum.
2. Program the SparkFun RedBoard.
   - Download **Arduino IDE** onto your computer.
   - Open the **CAN Bus Basics Code** on your computer.
   - Connect the **SparkFun RedBoard** to your computer using the USB A/B cord.
   - Under **Tools**, select *Board* and *Arduino Uno*.
   - Select **Verify** and then **Upload**.
   - Continue the process for each RedBoard.
3. Before Day 2, create faults in the CAN Bus boards. Label the boards A-E. Complete the faults as labeled below.
   - Board A: Disconnect a terminating resistor
   - Board B: Short a CAN_H wire with a CAN_L wire at a terminal block connection
   - Board C: No-fault
   - Board D: Short a CAN_H wire with a CAN_L wire by stripping insulation and connecting the wires.
   - Board E: Open the circuit by disconnecting a cable at an ECU

Student Performance

Part One

Students construct a model CAN bus network, as shown in Figure 1. Stapling the **CAN Bus Template** over the 8.5″ x 11″ piece of plywood helps keep it in position. Next, groups attach terminal blocks to represent the nodes of the CAN bus network. Students construct the circuit using ring terminals and 22 gauge wire. The wires are different colors to signify the CAN_H and CAN_L wires. Terminating resistors, 120Ω, are added to both ends of the circuit. The circuit is attached to a RedBoard, as shown in Figure 2. Breadboards represent ECUs receiving signals and are connected to the circuit, as shown in Figure 3. The yellow cable is CAN_H in these diagrams, and the green cable is CAN_L.

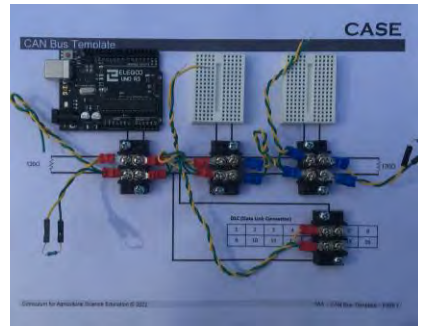


Figure 1. ECU Model

Part Two

The RedBoard connects to a USB power source. USB computer ports or charging blocks will. Students observe the signal simulated by the LEDs. The RedBoard sends the signal to the breadboard "ECUs." A CAN_H signal of 1 is indicated by the LED turning on. The CAN_L signals 0 when the LED turns off.

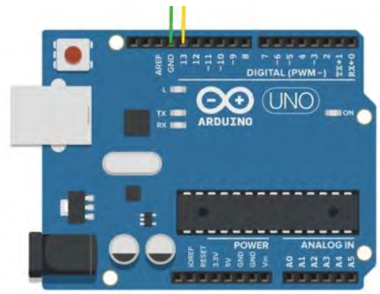


Figure 2. Connection to RedBoard

Part Three

Students connect 120Ω resistors in a series, parallel and open circuit to a DMM. The CAN Bus system uses two 120Ω terminating resistors aligned in parallel, with a total resistance of 60Ω. Technicians check for faults in a CAN Bus network to check the circuit with a DMM. A resistance of 120Ω indicates an open resistor. A resistance of 240Ω indicates a short circuit that placed the resistors in series. Students test each circuit and record data on the student data page.

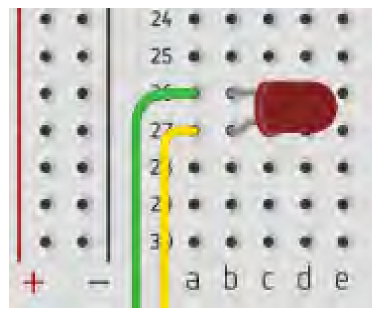


Figure 3. Connection to ECU

Part Four

Student groups troubleshoot the board faults created by the teacher, as outlined in *Teacher Preparation*. Students rotate across each board and observe the signal. Next, students isolate the cause and list suggested repairs on the student data page.

Results and Evaluation

Table 1 lists answers to Parts Two–Four on the student data page. Potential responses to analysis questions are listed in Table 2.

Table 1. Student Data Page Key

1st Bit	2nd Bit	3rd Bit	4th Bit	5th Bit	6th Bit	7th Bit	8th Bit
1	**0**	**0**	**1**	**1**	**0**	**0**	**1**
Circuit				**Resistance Reading (Ω)**			
Parallel				**60Ω**			
Open Resistor				**120Ω**			
Series				**240Ω**			
Board		**Signal Observations**		**Fault**		**Repairs**	
A		**Open signal or faults at one ECU**		**Open resistor**		**Repair terminating resistor**	

B	Open signal or signal at one ECU	Shorted CAN_H and CAN_L	Repair node connections at terminals
C	No faults	N/A	N/A
D	Weak or open signal	Shorted CAN_H and CAN_L	Repair the short
E	Only received at one ECU	Open CAN_H or CAN_L wire at ECU	Close circuit, repair connection

Table 2. ***Analysis Questions and Potential Responses***

Q1	Which ECU was sending the signal?	*The ECM, represented by the microprocessor, sent the signal.*
Q2	Which ECU was receiving the signal?	*The BCM and PCM received the signal.*
Q3	A technician measures the CAN Bus circuit at Pins 6 and 14. The DMM measures 120.5Ω. What is the fault?	*There is an open resistor or cable.*
Q4	A technician measures the CAN Bus circuit at Pins 6 and 14. The DMM measures 238.5Ω. What is the fault?	*The CAN_H and CAN_L wires have shorted, placing the resistors in series.*
Q5	How would faults in a circuit impact a CAN Bus digital signal?	*Signals may not be received or only received by some ECUs. As a result, the network would be compromised.*

Activity 5.2.2 Monitor and Control

Students monitor how ECU's send signals based on transducer data and inspect an oil pressure transducer with a DMM.

Teacher Preparation

1. Program the SparkFun RedBoard.
   - Download **Arduino IDE** onto your computer.
   - Open the **Monitor and Control Code** on your computer.
   - Connect the SparkFun RedBoard to your computer using the USB A/B cord.
   - Under **Tools**, select *Board* and *Arduino Uno*.
   - Under **Sketch**, choose *Include Library*, then *Manage Libraries*.
   - In the **Library Manager**, type *Vernier* in the search bar.
   - Select **VernierLib** and click **Install**.
   - Select **Verify** and then **Upload**.
   - Continue uploading to each RedBoard.
2. Cut a $^1/_8$″ inside diameter plastic tubing into 4″ pieces. Each group will need one section.

Student Performance

Part One

Students set up the CAN bus board to include the **Vernier Arduino® Interface Shield** on top of the microprocessor. The pins insert into the black strips on the SparkFun RedBoard. The interface shield includes sections for students to attach Vernier sensors. Students connect the **Pressure 400 sensor** to Analog 1.

Part Two

Students simulate the role of an oil pressure transducer with a Pressure 400 sensor and a 60cc syringe. Figure 4 shows how to attach the Pressure 400 sensor to the syringe using a 4″ section of $^1/_8$″ ID plastic tubing. Students bleed the tubing before attaching it to the sensor. Next, students pressure the line to simulate oil pressure. A signal is sent by the ECU when the oil pressure is low but will stop when the pressure meets OEM specifications. The *Purpose* includes information about the powertrain control module

(PCM) and body control module (BCM). Students track which ECU ignores or acts upon the signal received through the CAN Bus network.

Figure 4. Syringe and Pressure 400

Part Three
Students inspect a worn oil pressure transducer using a DMM, water, and an air compressor blow gun. The transducer will be normally closed or open, depending on the OEM design. Next, students use a DMM to determine its state at rest. The transducer should switch states when air is blown into the transducer using an air compressor. Finally, students test the transducer to see if the housing leaks when pressurized. Students add water to the electrical end of the transducer. If the water bubbles when students blow pressurized air on the oil side of the transducer, it is faulty.

Results and Evaluation
Table 3 includes potential responses to analysis questions.

Table 3. *Analysis Questions and Potential Responses*

Q1	How does the signal change as pressure changes?	*The signal stops when the system is pressurized.*
Q2	Which ECU is sending the signal?	*The ECM is sending the signal.*
Q3	Which ECU addresses the signal? How?	*The BCM addresses the signal by alerting the operator of low pressure.*
Q4	Which ECU ignores the signal? Why?	*The PCM ignores the signal. As a result, the powertrain control module would act upon lower transmission oil but not engine oil.*
Q5	Was your transducer faulty? Cite your data to support your answer.	*Answers will vary depending on the transducer used. For example, a faulty transducer will not change its switch state when under pressure.*
Q6	Why would a leaky transducer have inaccurate data?	*A leaky transducer will be exposed to elements, adding corrosion and increasing resistance.*

Project 5.2.3 Essential Components

Students tour an equipment dealership to learn how CAN bus systems interact within a fuel and intake system. A technician demonstrates how to connect and use a scan tool. Students utilize this information to construct a flowchart showing the relationship between CAN bus components and transducers in the fuel and intake systems.

Teacher Preparation

1. Schedule a technician to review a CAN bus system during a tour at a local equipment dealership. The tour should detail how transducers and ECUs interact. The technician should also demonstrate how to use a scan tool. Provide a copy of the **Project 5.2.3 Presenter Checklist** to the dealership as a guideline for presentation talking points.
2. Provide supplies for students to create flowcharts. Potential materials include poster boards, scissors, markers, and glue sticks.

Student Performance
During the demonstration, students will record notes and answer analysis questions. Then students work in pairs to create flowcharts during Part Two, demonstrating the relationship between transducers and ECUs in the fuel and intake system.

Results and Evaluation

Evaluate flowcharts using the **Project 5.2.3 Evaluation Rubric**.

Table 4. ***Analysis Questions and Potential Responses***

Q1	What transducers does a diesel fuel system have?	*Fuel temperature sensor, crankshaft position, MAP (manifold absolute pressure)* *Other sensors may be presented by the technician as well.*
Q2	What transducers does a diesel intake system have?	*MAP (manifold absolute pressure), MAF (mass airflow* *Other sensors may be presented by the technician as well.*
Q3	What ECUs are components of diesel fuel and intake systems?	*Answers will vary depending on the model presented. ECM (engine control module) is standard across models.*
Q4	How do ECUs in diesel fuel and intake systems respond to sensor data?	*Answers depend upon technician demonstration. The MAP transducer signals pressure in the manifold to an ECU. The ECU controls fuel injection volume and timing.*
Q5	How does a technician check a fault code? List the procedure.	*Processes vary depending on the model and scan tool.*
Q6	How does a technician use a fault code as part of the diagnostic process?	*Technicians cross-reference fault codes to service bulletins and manuals. The code provides the error. The technician should repair the fault and isolate and repair the cause of the fault.*

Assessment

Lesson 5.2 Check for Understanding

Lesson 5.2 Check for Understanding is included for you to use as an assessment tool for this lesson. Use **Lesson 5.2 Check for Understanding Answer Key** for evaluation purposes.

Name____

CASE

Activity 5.2.1 CAN Bus Basics

Purpose

As new models are released, vehicles use more electrical circuits and controls. Agricultural and construction equipment are on the same path. Incorporating computers allows diesel equipment to monitor the engine and equipment components, with transducers collecting system data. Computers use the data from transducers to modify operation or signal maintenance codes to the operator. At first glance, this seems to operate similarly to a programmable logic controller (PLC); however, the sheer number of computers and transducers in equipment complicates the system past a simple PLC. Instead, diesel equipment has a CAN (controller area network) bus system comprised of several small microprocessors called electronic control units (ECU) that communicate with each other to optimize engine performance.

Imagine a truck involved in an accident. The airbags are deployed, reducing bodily harm to the operator. A series of ECUs equipped with pressure transducers send a signal to a unit activating the airbag, while a second ECU shuts off the engine, and another contacts emergency services. The ECUs communicate with each other through the CAN bus network with a binary, digital signal. The digital signal is 8-bit or a series of eight “1’s” and “0’s”. When an ECU sends a signal, such as “*10011001*” each ECU in the network receives the signal. Each ECU responds to or dismisses the 8-bit signal during the example accident.

How does an ECU send a binary signal of “0” or “1”? ECUs are connected with a chain of two wires known as CAN_H (high) and CAN_L (low). Each wire sends a voltage signal. The signals are balanced, creating a range that each ECU reads as a CAN_H or CAN_L Signal. Figure 1 shows an example voltage signal. The CAN_H signal is between 2.5-3.5V. A CAN_L signal is between 1.5-2.5V. The CAN_L signal is dominant to CAN_H. Technicians use a 16-pin code reader attached to the data link connector (DLC) to interpret CAN bus signals.

A CAN bus system can fail, causing incorrect readings and making troubleshooting very difficult. CAN bus voltage and resistance readings indicate if the CAN bus is functional. How would a short in the CAN bus connections impact the voltage signal? Circuit interference impacts the voltage readings, thus impacting the digital 8-bit sequence sent and received by ECUs. Technicians can check the CAN bus network for faults using a DMM while the battery voltage is disconnected. A CAN Bus network contains two 120Ω resistors connected in parallel via the CAN_H and CAN_L wires. The resistors are known as terminating resistors. Figure 2 shows a simple schematic of a CAN bus network with three ECUs. Technicians check for CAN bus resistance at Pin 6 and 14 of the DLC. Since the terminating resistors are in parallel, the circuit should read 60Ω. When the CAN bus network is not working correctly, technicians use their base knowledge of electrical circuits to troubleshoot electrical faults. OEMs twist CAN_H and CAN_L wires together to reduce electrical interference, as shown in Figure 3. A foil shield covers the chain to protect it from environmental conditions.

How does a technician use a DMM to diagnose a CAN bus failure?

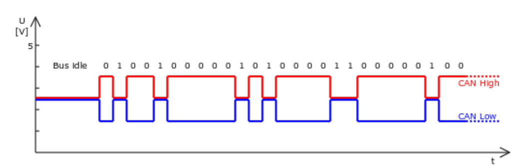


Figure 1. CAN_H and CAN_L Digital Signal

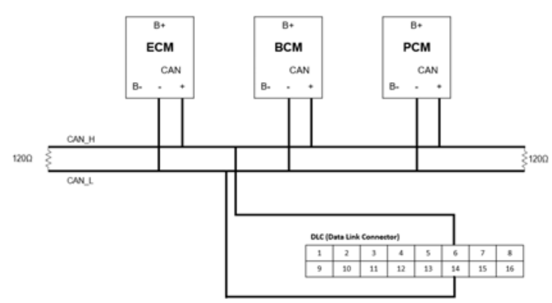


Figure 2. Simplified CAN Bus Schematic

Figure 3. Twisted Cables

Materials

Per group of four students:

- (2) Breadboard pin wires, female to female
- (2) Breadboards, small
- *CAN Bus Template*
- Digital multimeter (DMM)
- Phillips screwdriver
- Plywood, 8.5″ x 11″, minimum ½″ thick
- (4) Resistors, 120Ω
- (14) Ring terminals, red
- SparkFun® RedBoard with wire
- (4) Terminal block, 2-pole
- USB power source
- Wire crimper, 12–16 ga
- Wire stripper
- (4) Wire with alligator clips
- (8) Wood screw, #6 x ¾”

Per student:

- *Agriscience Notebook*
- Safety glasses

Per class:

- Electrical wire, solid strand, various colors, 22 ga
- Manual staple gun with staples

Procedure

Construct a model CAN bus board and read the simulated signal sent across the ECUs. Next, use a DMM to read resistance in circuits with two 120Ω resistors. Then identify circuit faults.

Part One – CAN Bus Model

1. Put on safety glasses and tie back long hair.
2. Obtain a *CAN Bus Template* from your instructor.
    - The template has three ECUs.
3. Staple the template to an 8.5″ x 11″ section of plywood.
4. Fasten the terminal blocks at CAN_H, CAN_L, and the DLC connections with ¾” wood screws, as shown in Figure 4.
5. Assemble the CAN_H and CAN_L circuits shown in Figure 5.
    - Designate a color for CAN_H and another for CAN_L.
    - Splice multiple connections together using ring terminals and a crimping tool.
    - Leave 4″ of twisted cables leading up to each ECU.
    - Connect a 120Ω resistor at each terminating point using female-to-female breadboard wires.
    - Connect CAN_H to the terminal screw representing Pin 6 at the DLC. CAN_L connects to Pin 14.

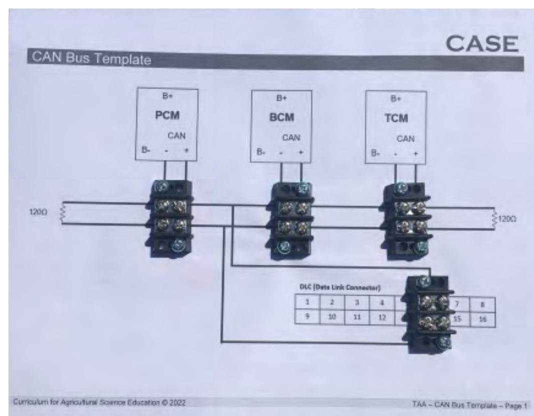


Figure 4. Terminal Block Placement

6. Place the microprocessor and breadboards on the CAN bus board, as shown in Figure 6. These will simulate the following ECUs.
    - PCM
    - BCM
    - TCM

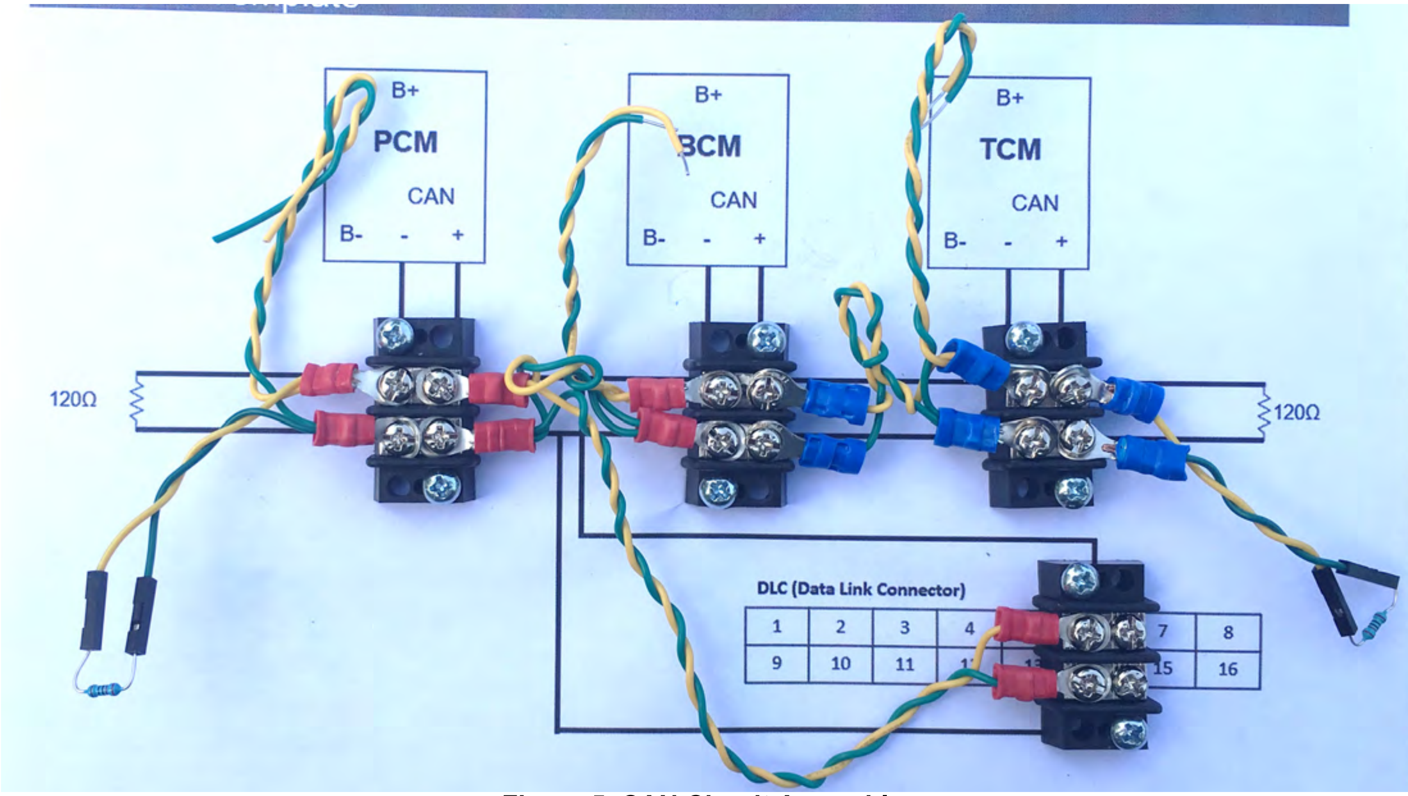


Figure 5. CAN Circuit Assembly

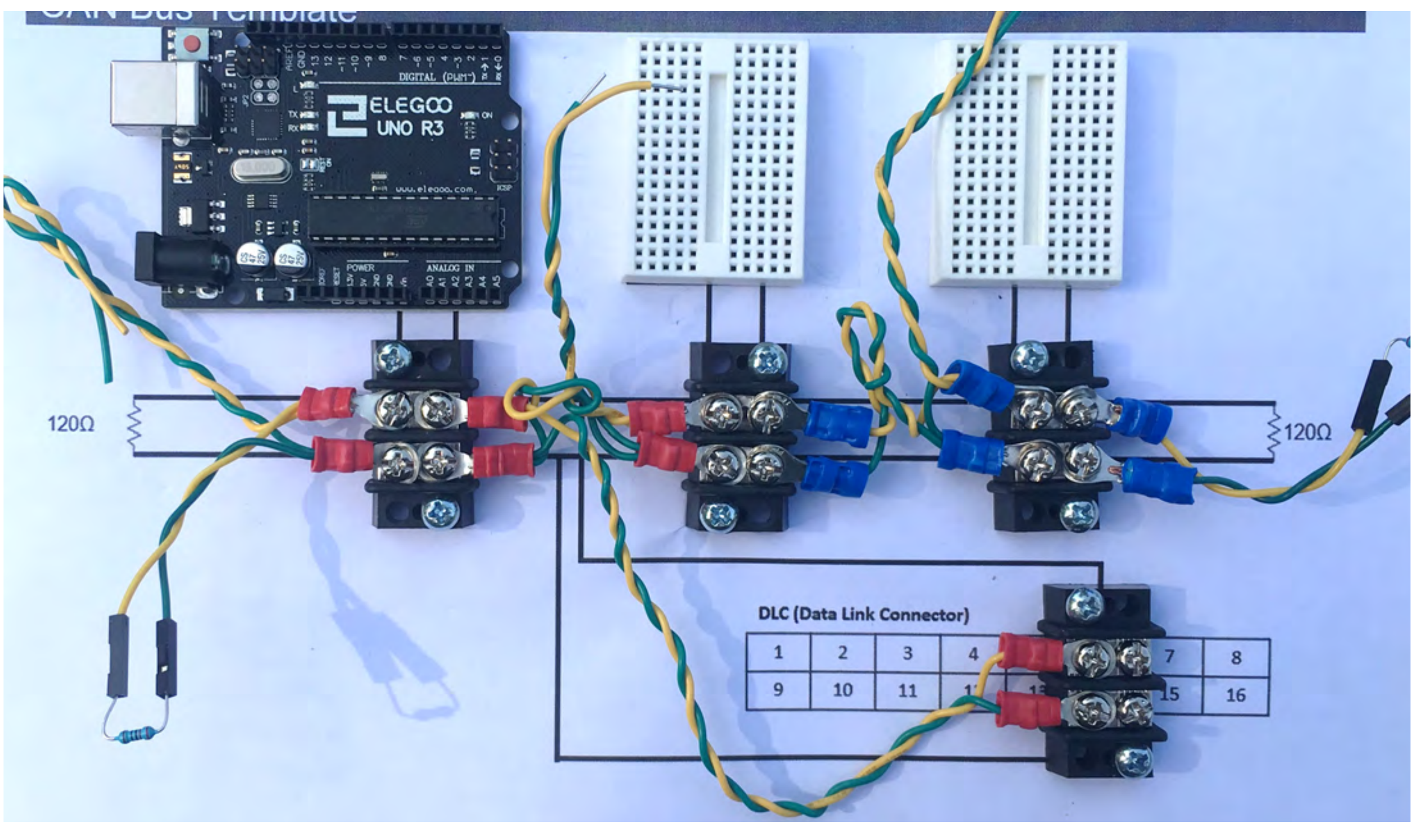


Figure 6. ECU Placement

7. Connect the microprocessor to the circuit, as shown in Figure 7. Connect CAN_H to pin13 and CAN_L to the ground.
8. Assemble the breadboards shown in Figure 8.
    - The LED should be placed on separate horizontal lines as shown. Placing the LED on the same line with short the signal.
    - The CAN_H wire connects to the longer leg of the LED (anode) on the breadboard.

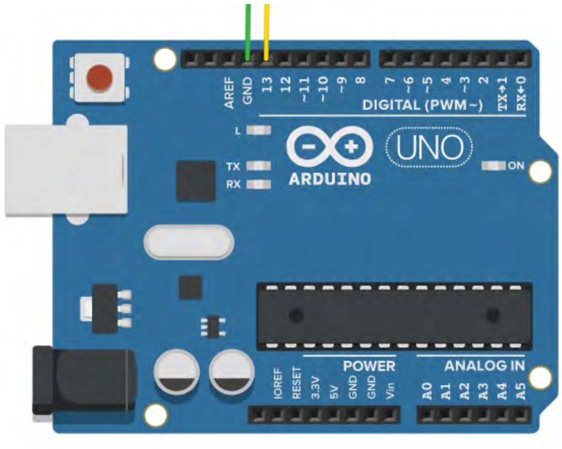


Figure 7. Connect to ECU

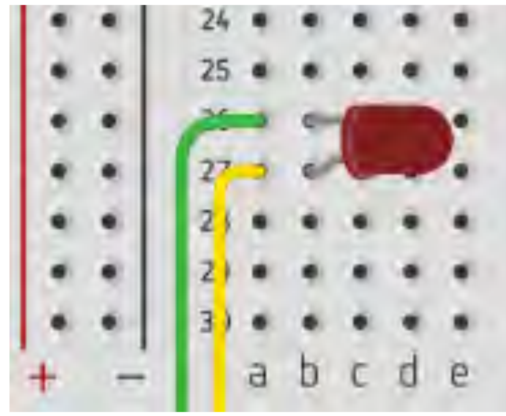


Figure 8. Connect to ECU

Part Two – CAN Bus Signal

1. Connect the microprocessor to a USB power source.
2. Observe the simulated signal.
    - The blinking LEDs on the microprocessor and the breadboards simulate a signal sent by the microprocessor. Each bit of the 8-bit signal is one second long and repeats after a five-second pause. The LED turns on during a “1” and off during a “0”.
3. Record the signal in Table 1 of *Activity 5.2.1 Student Data*.
4. Disconnect the microprocessor from the power source.
5. Answer *Part Two Analysis Questions*.

Part Three – Resistance Review

1. Connect two 120Ω in parallel to your DMM using four wires with alligator clips, as shown in Figure 9.
2. Measure the resistance with a DMM and record it in Table 2.
3. Repeat Steps 1–2 with the schematic in Figure 10.
4. Repeat Steps 1–2 with the schematic in Figure 11.
5. Answer *the Part Three Analysis Questions*.

Figure 9. CAN Bus Parallel Circuit

Figure 10. CAN Bus Open Resistor

Figure 11. CAN Bus Series Circuit

Part Four – CAN Bus Circuit Faults

Your teacher has created a fault in each CAN Bus board. Rotate to each board and observe the signal by connecting the microprocessor to a power source. Record your observations in Table 3, disconnect the power source, and isolate the cause using a DMM. Then record the fault and suggested repairs in Table 3.

Conclusion

1. What are the components of an 8-bit signal?
2. What ECUs receive a signal sent by an ECU?
3. What changes would you make to the model to represent a more complex CAN Bus system?

Name____

Activity 5.2.1 Student Data

Table 1. ***CAN Bus Signal***

1^{st} Bit	2^{nd} Bit	3^{rd} Bit	4^{th} Bit	5^{th} Bit	6^{th} Bit	7^{th} Bit	8^{th} Bit

Part Two Analysis Questions

Q1 Which ECU was sending the signal?

Q2 Which ECU was receiving the signal?

Table 2. ***CAN Bus Signal***

Circuit	Resistance Reading (Ω)

Part Three Analysis Questions

Q3 A technician measures the CAN bus circuit at Pins 6 and 14. The DMM measures 120.5Ω. What is the fault?

Q4 A technician measures the CAN bus circuit at Pins 6 and 14. The DMM measures 238.5Ω. What is the fault?

Q5 How would faults in a circuit impact a CAN bus digital signal?

Table 3. ***CAN Bus Signal***

Board	Signal Observations	Fault	Repairs
A			
B			
C			
D			
E			

Name____ CASE

Activity 5.2.2 Monitor and Control

Purpose

CAN bus systems relay signals between ECUs. Each ECU has a specific role within the network. The powertrain control module (PCM) collects data and processes signals to regulate the transmission, differentials, and the final drive. When the PCM sends a signal indicating low pressure on the transmission oil, each ECU receives the 8-bit signal. Corresponding ECUs act upon a signal. ECUs ignore a signal if irrelevant to its role. In this example, the signal sent by the PCM would be acted upon by the body control module (BCM), sending an error code to the dash and activating a warning light. The engine control module (ECM) would ignore the signal.

CAN bus systems collect data from the transducers. An oil pressure sensor is an example of a transducer connected to the ECM in a CAN bus system. The optimum oil pressure ranges between models, from 0.25-0.75 bar (3.5-11 psi). If oil falls below the pressure threshold, the ECM sends a signal to the BCM. The BCM then turns on the oil warning light on the driver dashboard to tell a technician to check the oil. If nothing is wrong with the oil level and pressure, the technician will check for a faulty transducer on the cylinder block, engine head, or oil filter housing.

How does a CAN Bus system signal transducer data? How do ECUs respond to 8-bit signals?

Materials

Per group of four students:

- Beaker, 100ml
- CAN bus board from *Activity 5.2.1*
- Computer with internet access
- Digital multimeter (DMM)
- Oil pressure transducer, used
- Plastic tubing, ⅛″ ID x 4″
- Pressure 400 sensor
- Syringe, 60cc
- Vernier Arduino® Interface Shield

Per student:

- *Agriscience Notebook*
- Safety glasses

Per class:

- Air compressor with blowguns
- Hot glue guns with glue sticks
- Water

Procedure

Attach a transducer to a CAN bus system to simulate oil pressure. Next, determine which ECUs address a signal. Then test an oil pressure sensor with a DMM.

Part One – CAN Bus Setup

1. Put on safety glasses and tie back long hair.
2. Repair any faults present from *Activity 5.3.1 CAN Bus Basics*.
3. Disconnect the CAN_L and CAN_H from the Arduino®.
4. Place the Vernier Arduino® Interface Shield on top of the microprocessor, as shown in Figure 1. Carefully line up the pins before pressing them down.
5. Connect the interface shield to the circuit.
   - Connect CAN_L to ground.
   - Connect CAN_H to D13.

Figure 1. Interface Shield

6. Connect the microprocessor to a USB power source.
7. Check each ECU to ensure that the LED blinks in sequence with the D13 LED on the interface shield. If the lights are not in sequence, revisit Step 1.
8. Attach the Pressure 400 sensor to the port labeled *Analog 1*.
9. Look under each ECU to determine their assigned role.
10. Use a computer with internet access to research the roles of each ECU. Record the roles in Table 1 of *Activity 5.2.2 Student Observations*.

Part Two – Transducer Simulation

1. Obtain a 4″ piece of 1/8″ inside diameter plastic tubing, 60cc syringe, pressure sensor, and 100ml beaker.
2. Attach the tubing to the 60cc syringe and add hot glue to the connection.
3. Fill the 100ml beaker with water.
4. Insert the tubing into the water and pull back on the plunger until the piston is at 50cc.
5. Bleed the line by pressing the plunger until all air has escaped the line.
6. Figure 2 shows how to attach the 60cc syringe, tubing, and pressure sensor.

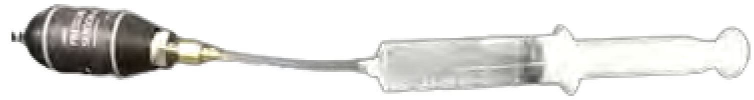


Figure 2. Syringe and Pressure 400

7. Press on the plunger of the syringe.
8. Answer *Part Two Analysis Questions*.
9. Create a fault on the board preventing an ECU from receiving the signal. The fault should not impact the ECU sending the signal.
10. Record the fault and how it affected the ECU on Table 2.
11. Clean up your station as instructed by your teacher.

Part Three – Test Oil Pressure Transducer

1. Obtain a worn oil pressure transducer from your teacher.
2. Inspect the body of the transducer. Record the pressure range, if listed, in Table 2.
3. Use a DMM to determine if the transducer is normally open or normally closed. Record in Table 2.
    - If there is only one terminal, place the black lead on the metal side of the transducer, as shown in Figure 3.
4. Measure the resistance of the transducer when the sensor is not pressurized.
5. Record the resistance in Table 3.
6. Pressurize the transducer by blowing compressed air into the sensor.
7. Record the resistance while pressurized in Table 3.

Figure 3. Testing Oil Transducer

8. Determine if your transducer switches as designed. Record any faults in Table 3.
    - A normally closed transducer will have continuity when the sensor is not pressurized and be open when under pressure.
    - A normally open transducer will have continuity when the sensor is pressurized and be open when not under pressure.
    - A transducer that remains open or closed is faulty.
9. Disconnect the DMM from the transducer.
10. Fill the electrical end with a small amount of water, as shown in Figure 4.
11. Holding the transducer vertically, pressurize the sensor by blowing compressed air into the sensor.
    - If bubbles were present, the sensor is leaking and not insulating itself.
12. Record any faults in Table 2.
13. Answer *Part Three Analysis Questions*.

Figure 4. Leak Test

Conclusion

1. How does a CAN bus system control agricultural equipment?

2. How does a CAN bus system alert operators?

3. How are transducers an extension of a CAN bus system?

Name____

Activity 5.2.2 Student Observations

Table 1. ECU Roles

ECU	Role
ECM	
BCM	
PCM	

Part Two Analysis Questions.

Q1 How does the signal change as pressure changes?

Q2 Which ECU is sending the signal?

Q3 Which ECU addresses the signal? How?

Q4 Which ECU ignores the signal? Why?

Table 2. ECU Observations

Fault	Effect

Table 3. CAN Bus Signal

Transducer Information	Data
Pressure Range	
Normally Open or Normally Closed	
Resistance (Ω), Not pressurized	
Resistance (Ω), Pressurized	
Transducer Faults	

Part Three Analysis Questions

Q5 Was your transducer faulty? Cite your data to support your answer.

Q6 Why would a leaky transducer have inaccurate data?

Name____

Project 5.2.3 Essential Components

Purpose

Diesel systems utilize several transducers and ECUs to optimize engine performance. The codes sent by ECUs control engine components and send fault codes to the operator. Some fault codes activate specific indicators, such as a low oil pressure signal. Other signals direct the operator to check the engine with a generic symbol, as shown in Figure 1. So how does a technician check the engine code?

Figure 1. Check Engine

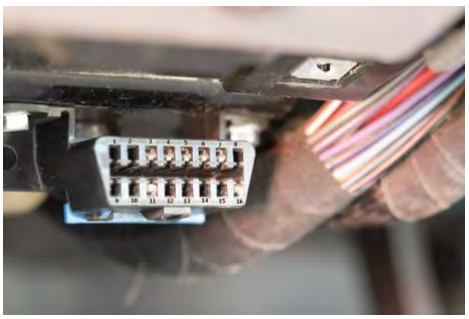


Figure 2. DLC

Figure 3. Diagnostic Port

Technicians use a scan tool connected to the 16-pin data link connector (DLC), as shown in Figure 2, to read scan codes. Tractors are often equipped with a simpler connection, as shown in Figure 3. The technician plugs a scan tool into the diagnostic port to read codes. The scan tool communicates active codes and the frequency of the fault. OEMs provide service guidelines to technicians that include conditions that cause the faults. Often, faults in diesel systems are related to faulty transducers. Table 1 summarizes common transducers found in diesel fuel and intake systems.

Table 1. ***Fuel and Intake System Transducers***

Transducer	Purpose
Fuel temperature	Signals fuel temperature to the ECU. When fuel is warm, it is less dense and more volatile. The ECU controls the electronic injectors to inject more fuel and slows down the timing between injections. Fuel injection decreases, and timing is advanced when fuel is cool.
MAF	The mass airflow (MAF) transducer measures the air flowing through the intake system. The MAF includes a heated wire sensing the air temperature. As airflow increases, the wire cools. The ECU opens and closes the wastegate on the turbocharger to regulate airflow.
MAP	The manifold absolute pressure (MAP) transducer inside the intake manifold sends the ECU vacuum and positive air pressure readings to control fuel injection for optimum combustion.
Crankshaft position	The crankshaft position transducer determines the position and rotational speed of the crankshaft. The ECU uses CAN Crank data to control fuel injection timing.

How does a CAN bus system communicate faults? How do technicians use codes to isolate root causes?

Materials

Per pair of students:

- Posterboard
- Supplies to make flowcharts
- *Project 5.2.3 Evaluation Rubric*

Per student:

- *Agriscience Notebook*
- *Logbook*
- Clipboard
- Ear plugs
- Safety glasses

Procedure

Tour an equipment dealership to learn more about CAN bus systems. Record notes and answers to analysis questions during a technician demonstration of a CAN bus. Develop a flowchart detailing connections between ECUs and transducers in diesel fuel and intake systems.

Part One – CAN Bus Field Trip

A technician will explain how transducers in diesel fuel and intake systems work and use a code breaker to read faults in a CAN bus system. Answer the following analysis questions during the demonstration.

Q1 What transducers does a diesel fuel system have?

Q2 What transducers does a diesel intake system have?

Q3 What ECUs are part of diesel fuel and intake systems?

Q4 How do ECUs in the diesel fuel and intake systems respond to sensor data?

Q5 How does a technician check a fault code? List the procedure.

Q6 How does a technician use a fault code as part of the diagnostic process?

Part Two – CAN Bus Flowchart

Use the information from the demonstration to construct a flowchart on a posterboard. It must show the relationship between diesel fuel system components, intake system components, transducers, CAN bus ECUs, the DLC, and the code reader. The flowchart should include the names of components, their roles, and relationships. Include at least three transducers in the flow chart and explain how ECUs respond to their data to manage diesel equipment.

Your teacher will evaluate the flowchart using the *Project 5.2.3 Evaluation Rubric*.

Conclusion

1. How can transducers in the intake system impact the operations of fuel systems?

2. How does a technician read codes to isolate causes?

Name____

CASE

Project 5.2.3 Evaluation Rubric

Areas with Room for Improvement	Criteria	Areas that Meet or Exceed Expectations
	Fuel System Diesel and electrical components, including the fuel system’s transducers and ECUs, are detailed and labeled in the flowchart.	
	Intake System Diesel and electrical components, including the intake system’s transducers and ECUs, are detailed and labeled in the flowchart.	
	Transducer Data The flowchart includes a minimum of three transducers found in the fuel and intake systems. The chart demonstrates the role of transducers, where to locate them, and describes the data they collect.	
	ECU Controls The flowchart illustrates how ECUs use transducer data to control engine systems. In addition, the flowchart includes an explanation of the ECU’s output controls.	

Project 5.2.3 Presenter Checklist

Thank you!

Thank you for providing this experience for our students! Students will learn from a technician during today's field experience. The objective of the presentation is for students to learn how transducers (sensors) are used in intake and diesel fuel systems and how transducers communicate to ECUs. Additionally, students will observe how to read ECU fault codes with a scan tool and use the codes in the diagnostic process.

Please feel free to add any pointers or extra material pertinent to your business.

Technician Checklist

Concept: High-pressure common rail diesel fuel systems have essential components with specific functions.

Parts Identification and Function: Detail the location and function of the following components.

- Fuel system transducers, including but not limited to fuel temperature, MAP, and crankshaft position.
- Intake system transducers, including but not limited to MAP and MAF.
- ECUs within the fuel and intake system

Network: Detail the relationship of transducers and how ECUs respond to transducer data.

- Simulate a fault in a fuel or intake system transducer.
- Demonstrate how the equipment responds to the change in or lack of data.

Scan Tool: Detail how CAN bus systems send fault codes.

- Detail the process of how to connect and read fault codes.
- Show a fault code to students on the scan tool.
- Explain how you use the fault codes to diagnose and isolate causes.

Name____ CASE

Lesson 5.2 Check for Understanding

1. A technician measures the resistance of a CAN Bus network at Pin 6 and Pin 14. Match the resistance reading with the CAN Bus fault.

______60Ω	A. A terminating resistor is open
______120Ω	B. CAN_H and CAN_L are shorted
______240Ω	C. No fault

2. Explain how a CAN Bus tells an engine how to function. Use the following terms in your explanation – 8-bit, CAN_H, CAN_L, ECU, transducer.

3. Which transducer sends the ECU vacuum and positive air pressure readings from inside the intake manifold to control fuel injection for optimum combustion.
   a) Crankshaft position
   b) Fuel temperature
   c) MAF
   d) MAP

Name____ **CASE**

Lesson 5.2 Check for Understanding Answer Key

1. A technician measures the resistance of a CAN Bus network at Pin 6 and Pin 14. Match the resistance reading with the CAN Bus fault.

__**C**__ 60Ω

__**A**__ 120Ω

__**B**__ 240Ω

a. A terminating resistor is open

b. CAN_H and CAN_L are shorted

c. No fault

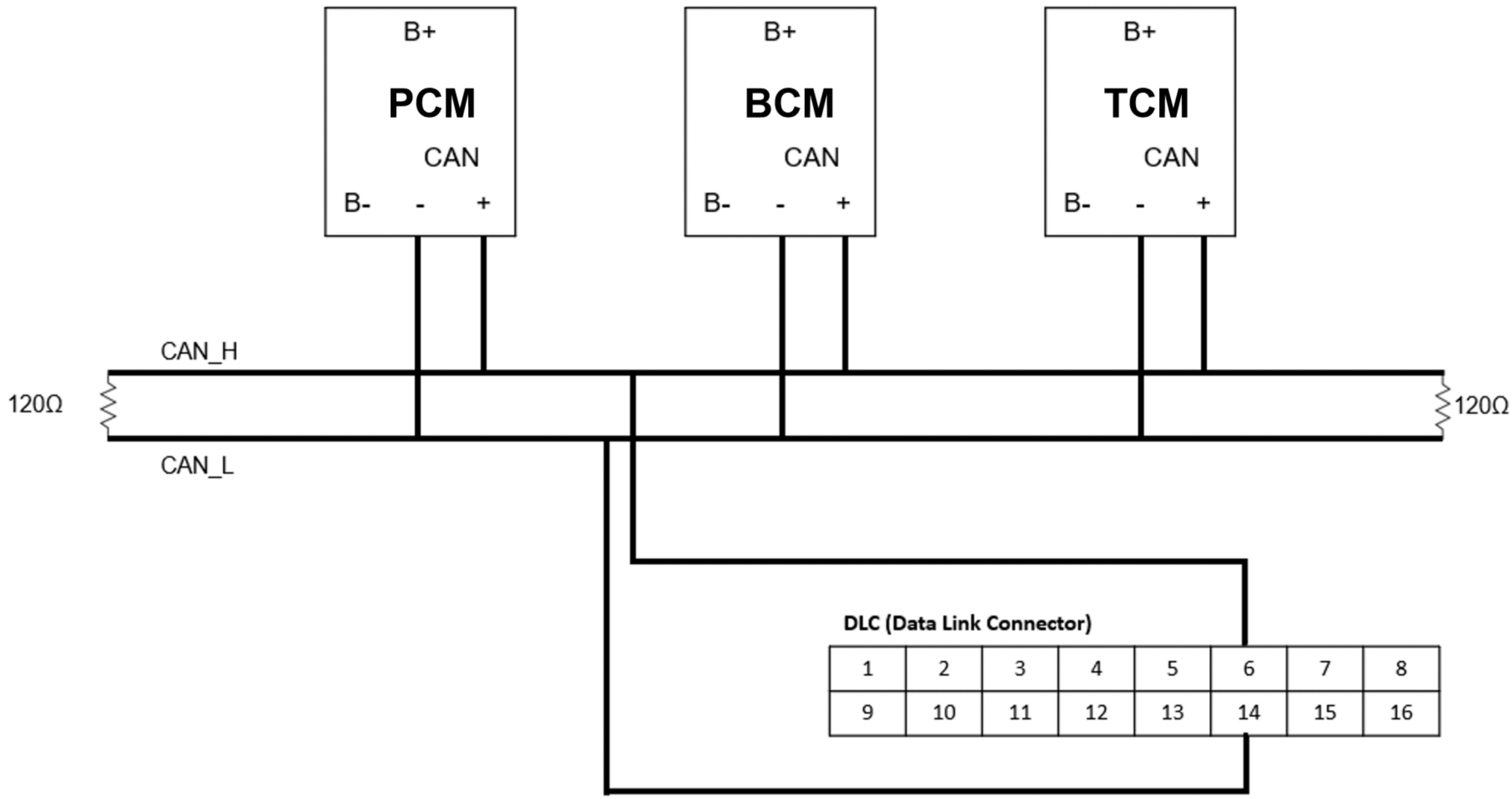
2. Explain how a CAN Bus tells an engine how to function. Use the following terms in your explanation – 8-bit, CAN_H, CAN_L, ECU, transducer.

A transducer collects engine data and sends it to an ECU. The ECU then sends an 8-bit signal to all ECUs as a CAN_H or CAN_L Signal. Specific ECUs then respond to signals to adjust how the engine is operating. Examples include opening and closing the wastegate, controlling fuel injection timing and volume, or activating an indicator light.

3. Which transducer sends the ECU vacuum and positive air pressure readings from inside the intake manifold to control fuel injection for optimum combustion.

a) Crankshaft position
b) Fuel temperature
c) MAF
d) MAP

CAN Bus Template



CASE

Lesson 6.1 Hydraulic Principles

Preface

Agricultural equipment, large to small, utilizes hydraulics as a means of mobility or equipment operation. Technicians need to understand fluid power fundamentals to troubleshoot and maintain equipment with hydraulic systems. Fundamentals include components, schematics, and system designs. Hydraulic systems use different pumps and valves to control fluid direction, pressure, and flow.

Hydraulic systems depend upon a pump pushing and pulling fluid through a network of hoses, valves, and actuators. Valves direct fluid through hoses to actuators, which are the power outputs. Actuators convert fluid energy into linear or rotary movement. Hydraulic cylinders move in a straight line while motors rotate.

Technicians view an entire hydraulic system on paper as a schematic consisting of symbols representing each component. Reviewing a schematic, a technician can locate and identify pumps, valves, hoses, and actuators. In addition to a schematic, a technician will use fundamental physics, such as Pascal's Law, to troubleshoot a system. Pascal's Law states that when pressure is applied to a fluid in a contained system, the fluid applies pressure everywhere in the system. A technician uses fluid pressure and flow information to diagnose machine malfunctions.

During this lesson, students practice assembling virtual hydraulics systems, reading schematics, and constructing model systems. They complete the lesson using Pascal's Law to find the cause and correction for customer complaints.

Concepts	Performance Objectives
Students will know and understand	*Students will learn concepts by doing*
1. A hydraulic system has a pump, control valves, actuators, fluid, and hoses.	• Virtually assemble a fluid power system. (Activity 6.1.1)
2. Technicians use schematics to identify fluid power components and systems.	• Draw and identify the components found in a hydraulic system schematic. (Activity 6.1.2)
3. The hydraulic systems can be closed or open-loop systems using positive or non-positive pumps.	• Construct example models of hydraulic systems (Activity 6.1.3)
4. A technician can control the fluid flow and pressure in a hydraulic system.	• Add flow and pressure gauges and adjust the fluid pressure and flow in a hydraulic system. (Activity 6.1.4) • Calculate pressure drop in a hydraulic system. (Activity 6.1.4)
5. Pascal's Law determines the system pressure and components a machine needs to operate.	• Find the force exerted by hydraulic cylinders. (Activity 6.1.5) • Use Pascal's Law to find equipment's needed pressure and cylinder size. (Activity 6.1.5)

National AFNR Common Career Technical Core Standards Alignment

Career Ready Practices
2. Apply appropriate academic and technical skills.

• CRP.02.01: Use strategic thinking to connect and apply academic learning, knowledge, and skills to solve problems in the workplace and community.
• CRP.02.02: Use strategic thinking to connect and apply technical concepts to solve problems in the workplace and community.
Agriculture, Food, and Natural Resources Career Cluster
Power, Structural and Technical (AG-PST)
1. Apply physical science principles and engineering applications related to mechanical equipment, structures, and biological systems to solve problems and improve performance in AFNR power, structural, and technical systems.
• AG-PST 1.1: Select energy sources for power generation.
3. Service and repair mechanical equipment and power systems used in AFNR power, structural and technical systems.
• AG-PST 3.3: Service and repair hydraulic systems by evaluating performance using maintenance manuals.

Next Generation Science Standards Alignment

Disciplinary Core Ideas	
Science and Engineering Practices	
Asking Questions and Defining Problems	Asking questions and defining problems in 9–12 builds on K–8 experiences and progresses to formulating, refining, and evaluating empirically testable questions and design problems using models and simulations. • Define a design problem that involves the development of a process or system with interacting components and criteria and constraints that may include social, technical and/or environmental considerations.
Developing and Using Models	Modeling in 9–12 builds on K–8 experiences and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed world(s). • Develop and/or use a model (including mathematical and computational) to generate data to support explanations, predict phenomena, analyze systems, and/or solve problems.
Analyzing and Interpreting Data	Analyzing data in 9–12 builds on K–8 experiences and progresses to introducing more detailed statistical analysis, the comparison of data sets for consistency, and the use of models to generate and analyze data. • Compare and contrast various types of data sets (e.g., self-generated, archival) to examine consistency of measurements and observations. • Evaluate the impact of new data on a working explanation and/or model of a proposed process or system. • Analyze data to identify design features or characteristics of the components of a proposed process or system to optimize it relative to criteria for success.
Using Mathematics and Computational Thinking	Mathematical and computational thinking in 9-12 builds on K-8 and experiences and progresses to using algebraic thinking and analysis, a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms, and computational tools for statistical analysis to analyze, represent, and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions. • Apply techniques of algebra and functions to represent and solve scientific and engineering problems.
Constructing Explanations and Designing Solutions	Constructing explanations and designing solutions in 9–12 builds on K– 8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories. • Apply scientific ideas, principles, and/or evidence to provide an explanation of phenomena and solve design problems, taking into account possible unanticipated effects.
Obtaining, Evaluating, and Communicating Information	Obtaining, evaluating, and communicating information in 9–12 builds on K–8 experiences and progresses to evaluating the validity and reliability of the claims, methods, and designs. • Communicate scientific and/or technical information or ideas (e.g. about phenomena and/or the process of development and the design and performance of a proposed process or system) in multiple formats (including orally, graphically, textually, and mathematically).

Crosscutting Concepts	
Patterns	Observed patterns in nature guide organization and classification and prompt questions about relationships and causes underlying them.
	• Patterns of performance of designed systems can be analyzed and interpreted to reengineer and improve the system. • Mathematical representations are needed to identify some patterns. • Empirical evidence is needed to identify patterns.

Cause and Effect: Mechanism and Prediction	Events have causes, sometimes simple, sometimes multifaceted. Deciphering causal relationships, and the mechanisms by which they are mediated, is a major activity of science and engineering.
	• Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. • Cause and effect relationships can be suggested and predicted for complex natural and human designed systems by examining what is known about smaller scale mechanisms within the system. • Systems can be designed to cause a desired effect. • Changes in systems may have various causes that may not have equal effects.
Systems and System Models	A system is an organized group of related objects or components; models can be used for understanding and predicting the behavior of systems.
	• Systems can be designed to do specific tasks. • When investigating or describing a system, the boundaries and initial conditions of the system need to be defined and their inputs and outputs analyzed and described using models. • Models (e.g., physical, mathematical, computer models) can be used to simulate systems and interactions—including energy, matter, and information flows—within and between systems at different scales. • Models can be used to predict the behavior of a system, but these predictions have limited precision and reliability due to the assumptions and approximations inherent in models.
Energy and Matter: Flows, Cycles, and Conservation	Tracking energy and matter flows, into, out of, and within systems helps one understand their system's behavior.
	• The total amount of energy and matter in closed systems is conserved. • Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system. • Energy cannot be created or destroyed—only moves between one place and another place, between objects and/or fields, or between systems.

Understandings about the Nature of Science	
Science Addresses Questions About the Natural and Material World.	• Not all questions can be answered by science.

Common Core State Standards for High School Mathematics

Modeling standards are indicated by the star symbol (*) throughout other conceptual categories.

CCSS: Conceptual Category – Number and Quantity	
Quantities	*Reason quantitatively and use units to solve problems.

CCSS: Conceptual Category – Algebra	
Seeing Structure in Expressions	*Interpret the structure of expressions. *Write expressions in equivalent forms to solve problems.
Creating Equations	*Create equations that describe numbers or relationships.
Reasoning with Equations and Inequalities	Understand solving equations as a process of reasoning and explain the reasoning. Solve equations and inequalities in one variable. Solve systems of equations. *Represent and solve equations and inequalities graphically.

CCSS: Conceptual Category – Geometry	
Circles	Understand and apply theorems about circles.
Modeling with Geometry	*Apply geometric concepts in modeling situations.

Common Core State Standards for English Language Arts

CCSS: English Language Arts Standards » Science & Technical Subjects » Grade 11-12

Key Ideas and Details	• **RST.11-12.3 –** Follow precisely a complex multistep procedure when carrying out experiments, taking measurements, or performing technical tasks; analyze the specific results based on explanations in the text.
Craft and Structure	• **RST.11-12.4 –** Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to grades 11-12 texts and topics.
Integration of Knowledge and Ideas	• **RST.11-12.7 –** Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem.

CCSS: English Language Arts Standards » Writing » Grade 11-12	
Production and Distribution of Writing	• **WHST.11-12.4 –** Produce clear and coherent writing in which the development, organization, and style are appropriate to task, purpose, and audience.
Range of Writing	• **WHST.11-12.10 –** Write routinely over extended time frames (time for reflection and revision) and shorter time frames (a single sitting or a day or two) for a range of discipline-specific tasks, purposes, and audiences.

Essential Questions

1. How do hydraulic systems work?
2. How do technicians diagnose problems within a hydraulic system?
3. How are hydraulic theory and mathematics related?
4. What are the major components of a fluid power system?
5. What is an actuator?
6. What are the energy input and outputs of a hydraulic system?
7. How do technicians use schematics to assemble and maintain hydraulic systems?
8. Which rules do all schematic drawings follow?
9. How does pump selection impact hydraulic system operations?
10. How is fluid pressure different from fluid flow?
11. How can math be used to solve customer complaints?
12. What causes pressure to occur in a fluid system?

Key Terms

Actuator	**Check valve**	**Closed-loop**
Conductor	**Cylinder**	**Directional control valve**
Double-acting cylinder	**Flow control valve**	**Flowmeter**
Flow-rate	**Fluid**	**Fluid power**
Fluid power system	**Force**	**Hydraulic cylinder**
Hydraulic motor	**Hydraulics**	**Input**
Needle valve	**Non-positive displacement pump**	**Open-loop**
Output	**Pascal's Law**	**Piston**
Piston rod	**Positive displacement pump**	**Port**
Pounds per square inch (psi)	**Pressure**	**Pressure gauge**

Pressure relief valve	**Reservoir**	**Schematic**
Valve	**Variable displacement pump**	

Time: 12 days

Refer to the Teacher Resources section for specific information on teaching this lesson, in particular ***Lesson 6.1 Teacher Notes****,* ***Lesson 6.1 Glossary****,* ***Lesson 6.1 Materials****, and other support documents.*

Day 1:

- Present **Concepts**, **Performance Objectives**, **Essential Questions**, and **Key Terms** to provide a lesson overview.
- Provide students with **Presentation Notes**.
- Present LunchBox Session© **Fluid Power Basics**.
- Students will take notes using the *Presentation Notes* pages.
- Students work individually to complete Amatrol® *Hydraulic Power Systems Segments 1 and 2*.

Day 2:

- Provide students with a copy of **Activity 6.1.1 Fluid Components**.
- Students work with a hydraulic simulator individually to complete *Activity 6.1.1 Fluid Components*.

Day 3:

- Present LunchBox Session© **Hydraulic Schematic Symbols**.
- Students will take notes using the *Presentation Notes* pages.
- Provide students with a copy of **Activity 6.1.2 Fluid Drawings**.
- Students begin Amatrol® *Hydraulic Power Systems Segments 3 and 4*.

Day 4 – 5:

- Students complete Amatrol® *Hydraulic Power Systems Segments 3 and 4*.
- Students complete *Activity 6.1.2 Fluid Drawings*.

Day 6:

- Present LunchBox Session© **Positive and Non-positive Pumping**.
- Students will take notes using the *Presentation Notes* pages.
- Provide students with **Activity 6.1.3 Positively Pumping**.
- Students work in pairs to complete Part One of *Activity 6.1.3 Positively Pumping*.

Day 7:

- Students work in pairs to complete *Activity 6.1.3 Positively Pumping*.

Day 8 – 9:

- Present LunchBox Session© **Pressure and Flow**.
- Students will take notes using the *Presentation Notes* pages.
- Provide students with **Activity 6.1.4 Pressure and Flow Control**.
- Students will work individually on *Activity 6.1.4 Pressure and Flow Control*.

Day 10:

- Present LunchBox Session© **Pressure Parts 1–3**.
- Students will take notes using the *Presentation Notes* pages.
- Provide students with **Activity 6.1.5 System Settings**.
- Students will work in pairs on Part 1 of *Activity 6.1.5 System Settings*.

Day 11:

- Present LunchBox Session© **Pressure Parts 4–5**.
- Students will take notes using the *Presentation Notes* pages.
- Students will complete *Activity 6.1.5 System Settings*.

Day 12:

- Distribute **Lesson 6.1 Check for Understanding**.
- Students will complete *Lesson 6.1 Check for Understanding* and submit for evaluation.
- Use **Lesson 6.1 Check for Understanding Key** to evaluate student assessments.

Instructional Resources

LunchBox Sessions©

Fluid Power Basics – Hydraulic Basics

Hydraulic Schematic Symbols

Positive and Non-positive Pumping

Pressure and Flow

Pressure (Part 1 – Part 5)

Student Support Documents

Lesson 6.1 Glossary

Presentation Notes

Activity 6.1.1 Fluid Components

Activity 6.1.2 Fluid Drawings

Activity 6.1.3 Positively Pumping

Activity 6.1.4 Pressure and Flow Control

Activity 6.1.5 System Settings

Teacher Resources

Lesson 6.1 Hydraulic Principles PDF

Lesson 6.1 Teacher Notes

Lesson 6.1 Materials

Lesson 6.1 Check for Understanding

Answer Keys and Assessment Rubrics

Lesson 6.1 Check for Understanding Answer Key

Reference Sources

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National Fluid Power Association. (2017). *Fluid power advantages*. **http://www.nfpa.com/fluidpower/fluidpoweradvantages.aspx**

FFA Connections

This lesson provides conceptual and procedural knowledge related to the following FFA awards, activities and educational resources.

- Agricultural Proficiency
  - **Agricultural Mechanics Repair and Maintenance –Placement**
  - **Agricultural Mechanics Repair and Maintenance –Entrepreneurship**
  - **Agriscience Research – Integrated Systems**
- Agriscience Fair
  - **Power, Structural and Technical Systems**
- Career Development Events
  - **Agricultural Technology & Mechanical Systems**
- Educational Resources
  - **SAE Idea Cards-Power, Structural and Technical Systems**
  - **Power, Structural and Technical System Careers**
  - **Power, Structural and Technical Systems Career Focus Area Resources**
  - Power, Structural and Technical Careers **(Word)**

Skills and knowledge from this lesson support the development and implementation of service-learning projects that address hydraulic principles.

- **Service-Learning and Living to Serve Grants**
  - Service-learning projects focused on diagnosing hydraulic system issues in agricultural and other outdoor equipment.
  - Project ideas include hosting a spring tune-up or winterization event for local community members for lawnmowers and other equipment with hydraulic systems.
  - Living to Serve Grants provide funding to FFA chapters to support service-learning and community service projects.

For more information, visit the **National FFA Organization** website.

SAE for All

Immersion SAE

Students interested in this lesson’s topics should explore the following related Immersion SAEs. An immersion SAE is optional and replaces the agricultural literacy component of the Foundational SAE.

- **Immersion SAE Learning Guides**

For more information on the guiding principles for implementing SAE programs, visit the **SAE for All: Evolving Essentials** site.

Critical Thinking and Application Extensions

Explanation

1. Students will make a chart explaining the differences between positive and non-positive pumps in open and closed-loop systems
2. Students will identify the hydraulic components found on a selected piece of agricultural equipment at a dealership.

Lesson 6.1 Teacher Notes

Lesson 6.1 Hydraulic Principles

In preparation for teaching this lesson, review Concepts, Performance Objectives, Essential Questions, and Key Terms, along with presentations. Also, review all activity directions, expectations, and work students will complete.

Students begin the lesson by identifying the major components of a fluid power system and assembling a virtual system. Next, they practice reading and drawing hydraulic schematics. Then students assemble model hydraulic systems to demonstrate what they have viewed virtually. They complete the lesson using Pascal's law to solve customer complaints.

Amatrol® Hydraulic Simulator

Register each student for an Amatrol® account with access to a hydraulic simulator. Students will use the hydraulic simulator to complete three activities during this lesson.

Hydraulic Power Systems

Students view portions of this virtual session independently before *Activity 6.1.1 Fluid Components* and *Activity 6.1.2 Fluid Drawings*.

LunchBox Sessions©

Register for one **LunchBox Session©** account with the rights for presenting to your class. LunchBox Sessions© are short information sessions technicians can use to refresh themselves on fundamental mechanics.

Fluid Power Basics – Hydraulic Basics

Use the presentation at the beginning of the lesson to provide background knowledge on basic fluid principles of flow, pressure, and velocity.

Hydraulic Schematic Symbols

This presentation provides students with the basic concepts of drawing and reading a hydraulic schematic.

Positive and Non-positive Pumping

Use this presentation to explain the difference between positive and non-positive pumps visually.

Pressure and Flow

The presentation explains pressure and flow control in an open-loop system with a positive displacement pump.

Pressure (Part 1 – Part 5)

Use these presentations to demonstrate how to diagnose a complaint about a system lacking pressure.

Activities, Projects, and Problems

Activity 6.1.1 Fluid Components

Students work individually using a hydraulic simulator to assemble a system with a double-acting cylinder and hydraulic motor.

Teacher Preparation
Before starting the activity, present *Hydraulic Basics* from the *LunchBox Sessions*©, have students work independently to complete *Amatrol® Hydraulic Power Systems Segments 1 and 2*.

Student Performance
Students connect a hydraulic pump to a 4-way, 3-position directional control valve (4/3 DCV) and double-acting cylinder. They observe how the system functions and record their observations, including the locations of the power input, output, conductors, and control devices. Next, students repeat the assembly process for a hydraulic motor and continue to record observations.

Results and Evaluation
Review student sketches on the student observation sheets for correct labeling of each component. Students label components as follows. Example answers to analysis questions are in Table 1.

- Power input – pump
- Power output – hydraulic cylinder and motor
- Conductor – hoses
- Control device – 4/3 DCV

Table 1. *Analysis Questions and Potential Responses*

Q1	Why is it important to connect the hose to the correct port on a cylinder?	*Hose connections directly impact the relationship between DCV position and cylinder rod movement.*
Q2	Why is it important to connect the hose to the correct port on a motor?	*Hose connections directly impact the relationship between DCV position and motor rotation.*

Activity 6.1.2 Fluid Drawings

Students review the standard symbols used when drawing hydraulic schematics. Then they practice reading and drawing schematics.

Teacher Preparation
Before starting the activity, present *Hydraulic Schematic Symbols* from the *LunchBox Sessions*©.

Student Performance
Students start by reviewing schematic drawings from the *Amatrol® Hydraulic Power Systems Segments 3 and 4*. Next, they sketch example symbols and components while answering analysis questions. Then they read a schematic and complete a virtual assembly of a system. Students complete the activity by drawing schematics for the designs they completed during *Activity 6.1.1 Fluid Components*.

Results and Evaluation
Review student drawings to ensure they follow the rules outlined in the activity's *Purpose*. Example answers to the analysis questions are in Table 2.

Table 2. *Analysis Questions and Potential Responses*

Q1	Which symbols are combined to draw the schematic of a pump?	*Circle, triangle, square, dotted lines, and solid lines*
Q2	Which symbols are combined to draw a control valve?	*Square, triangle, and solid lines*
Q3	How many positions and ports are on a 3/2 valve?	*Two positions and three ports*

Activity 6.1.3 Positively Pumping

Students work in pairs to assemble model open-loop and closed-loop hydraulic systems while comparing how each operates and how to identify the type of pump in a system.

Teacher Preparation

Each student pair will need a hydraulic pump. You can purchase the INTLLAB™ Model DP-DIY pump used in this activity from **Amazon**. This is a positive displacement pump, similar to those in industrial hydraulic systems.

Material

- Use scissors to cut four 1′ sections of $^{1}/_{8}$″ inside diameter tubing for each student pair.
- Check the fit between the plastic tubing fittings (tee and coupler) to ensure they are snug.

System Operation

Power each pump with a 9-volt battery identifying the input and output. Note that the lead on the pump marked with a plus is the positive lead connection. To reduce friction and pressure build-up, students must lubricate the rubber pistons with cooking oil before assembling the system.

Student Performance

Students assemble a model of an open-loop system with a positive displacement pump. They use their prior knowledge of pumps from the *LunchBox*© presentation and activity's *Purpose* to identify the pump type and what each system component represents.

Results and Evaluation

Table 3 has example answers to analysis questions. Use Figure 1 to guide students when identifying system components.

Table 3. *Analysis Questions and Potential Responses*

Q1	What type of pump are you using? Explain	*Positive displacement. The flow does not change when pressure is added to the system.*
Q2	Where does the fluid flow? Why?	*The fluid flows back to the tank because it follows the path of least resistance.*
Q3	What type of pump system have you assembled?	*Open-loop system*

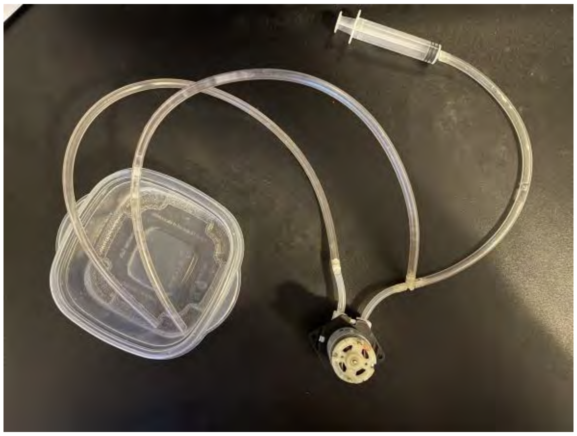


Figure 1. Open-Loop System

Activity 6.1.4 Pressure and Flow Control

Students work in pairs to assemble hydraulic systems controlling fluid pressure and flow.

Teacher Preparation

Present the *LunchBox Session*© *Pressure and Flow* before starting this activity. Students need access to the Amatrol® hydraulic simulator to complete the activity.

Student Performance

Part One
Students use a schematic to assemble a flow meter and needle valve. Then, they adjust the needle valve to see its effect on fluid flow.

Part Two
Students add pressure gauges upstream (before the needle valve) and downstream (after the needle valve). Students adjust each needle valve to observe the effect on pressure. They find the difference between the pressure at each point and learn that the sum of pressure differences equals the system's total pressure.

Part Three
Students use a schematic to assemble a needle valve and 4/3 DCV to control a hydraulic cylinder. They record the cylinder speed at various needle valve settings.

Part Four
Students use a schematic containing a flow meter, 4/3 DCV, flow control valve, and hydraulic motor. They observe how the motor's speed is controlled when fluid flows in one direction but not controlled when flowing in the other.

Results and Evaluation
Table 4 has example answers to analysis questions. Use Tables 5–9 as example data sets to compare student results.

Table 4. ***Analysis Questions and Potential Responses***

Part One		
Q1	What happens to the flow as you adjust the needle valve? Why?	*The flow remains constant until the needle valve is about to shut off the flow.*
Q2	Why does the flow rate drop when you reduce the needle valve setting to zero?	*No fluid can flow through the system when the needle valve is shut.*
Part Two		
Q3	What is the relationship between pressure upstream and downstream of the needle valve?	*The pressure is higher upstream and lower downstream.*
Q4	What is the relationship between total pressure drop in Table 4 and the pressure reading at the relief valve?	*The total pressure drop is equal to the pressure at the relief valve.*
Q5	What is the maximum pressure at any location in the system? Why?	*500 psi, the relief valve pressure setting is the maximum pressure allowed in the system.*
Part Three		
Q6	How does the flow rate affect the speed of the actuator?	*As the flow decreases, the speed of the actuator decreases.*
Q7	What would happen to the cylinder's speed if the cylinder had a larger volume? Why?	*The speed would be slower because of the time it would take to fill the cylinder with fluid.*
Part Four		
Q8	How does a flow control valve differ from a needle valve?	*Flow control valves control fluid flow in one direction.*
Q9	What are the advantages of a flow control valve in this situation?	*The flow in one direction can be controlled without affecting the flow in the other direction.*
Q10	What other fluid power designs would require a flow control valve?	*A cylinder that needs to extend slowly but retract quickly would require a flow control valve.*

Table 5. ***Flow Rate Observations***

Needle Valve Setting	Relief Valve Pressure Reading (psi)	Flow Meter Reading (gpm)
7 turns	**30 psi**	**2.5 gpm**
3 turns	**120 psi**	**2.5 gpm**
2 turns	**255 psi**	**2.5 gpm**

1 turn	**495 psi**	**2 gpm**
0.8 turn	**495 psi**	**1.5 gpm**
0.6 turn	**495 psi**	**1.0 gpm**
0.5 turn	**495 psi**	**1.0 gpm**
0 turns	**500 psi**	**0 gpm**

Table 6. ***Needle Valve Observations***

Needle Valve Setting	Relief Valve Pressure	Upstream Pressure Gauge Reading	Downstream Pressure Gauge Reading	Tank Pressure
7 turns (open)	**80 psi**	**80 psi**	**30 psi**	0 psi
3 turns	**170 psi**	**170 psi**	**30 psi**	0 psi
2 turns	**305 psi**	**305 psi**	**30 psi**	0 psi
1 turn	**490 psi**	**490 psi**	**10 psi**	0 psi
0 turns	**500 psi**	**500 psi**	**0 psi**	0 psi

Table 7.

Needle Valve Setting	US Pressure – DS Pressure	DS Pressure – Tank Pressure	Total Pressure Drop
7 turns (open)	**50 psi**	**30 psi**	**80 psi**
5 turns	**120 psi**	**30 psi**	**170 psi**
3 turns	**275 psi**	**30 psi**	**305 psi**
1 turn	**480 psi**	**10 psi**	**490 psi**
0 turns	**500 psi**	**0 psi**	**500 psi**

Table 8.

Needle Valve Setting	Actuator Speed	
	Lever Toward	Lever Away
1.0	**Fast**	**Fast**
0.8	**Fast**	**Fast**
0.5	**Fast**	**Fast**
0.3	**Slower**	**Slower**
0.2	**Slower**	**Slower**
0.1	**Slowest**	**Slowest**

Table 9. ***Motor Observations***

Flow Control Setting	Lever Toward			Lever Away		
	Pressure Gauge Reading	Flow Rate	Actuator Speed	Pressure Gauge Reading	Flow Rate	Actuator Speed
2.0	**270 psi**	**2.5 gpm**	**288 rpm**	**60 psi**	**2.5 gpm**	**288 rpm**
1.0	**500 psi**	**2.0 gpm**	**203 rpm**	**60 psi**	**2.5 gpm**	**288 rpm**
0.5	**490 psi**	**1.0 gpm**	**100 rpm**	**60 psi**	**2.5 gpm**	**288 rpm**
0	**500 psi**	**0 gpm**	**0 rpm**	**60 psi**	**2.5 gpm**	**288 rpm**

Activity 6.1.5 System Settings

Students work in pairs to calculate the force produced by different-sized cylinders in a hydraulic system. Then they find the cause and correction for mechanical complaints.

Teacher Preparation

Present *LunchBox Sessions©* *Pressure Part 1 – 3* before starting the session. Present *Pressure Part 4 – 5* before students start Part Two of the Activity.

Students use the **Vernier Pressure Sensor 400** and **LabQuest** to measure fluid pressure. Review the user manuals if needed.

Student Performance

Part One

Students reassemble the model open-loop hydraulic system they completed during A*ctivity 6.1.3 Positively Pumping*. Students measure piston surface area for 10ml, 20ml, and 60ml syringes. Next, they attach each syringe to the system and measure the pressure and rod extension when the cylinder contains 10ml of water.

Part Two

Students view the *LunchBox Session© Pressure Parts 4–5*. Then they review the customer complaints and record their diagnosed cause and correction in their *Logbook*.

Results and Evaluation

Table 11 has example answers to analysis questions. Use Tables 10 and 12, including data results and analysis of customer complaints, to review student responses and provide feedback.

Table 10. ***System Measurements and Calculations***

Syringe	Piston Diameter	Surface Area	Pressure	Force	Extension
10 ml	**0.700 inches**	**0.385 in^2**	**10 psi**	**3.85 pounds**	**5.000 inches**
20 ml	**0.750 inches**	**0.442 in^2**	**10 psi**	**4.42 pounds**	**1.500 inches**
60 ml	**1.000 inches**	**0.785 in^2**	**10 psi**	**7.85 pounds**	**1.250 inches**

Table 11. ***Analysis Questions and Potential Responses***

Q1	How did the piston diameter affect the pressure in the system?	*The piston diameter did not affect the pressure in the system.*
Q2	What is the relationship between volume, piston diameter, and extension?	*The greater the piston diameter, the larger the volume of liquid needed for the rod to extend.*
Q3	How does the piston diameter affect the lifting force of a cylinder?	*The larger the piston diameter, the greater the force of the piston.*
Q4	Which cylinder has the largest potential force? Why?	*The 60 ml cylinder has the largest piston diameter and, therefore, the largest potential force.*

Table 12. ***Customer Complaints***

Complaint	Calculation and Cause	Correction
A customer's hydraulic cylinder with a 1-inch piston diameter cannot lift a 1000-lb implement. The system is an open-loop system with a maximum pressure of 500 psi.	*Piston surface area = 0.785 inches* *Force = 0.785 in x 500 psi* *Force = 392.5 lbs* *The cylinder can lift 392.5 lbs, which is not enough to raise the 1000 implement.*	*Swap the hydraulic cylinder with a wider diameter to increase the potential force and lift the implement.*
A customer has a loader tractor with a single 1.5-inch piston diameter cylinder. The loader is unable to lift a 1000-pound load. The relief valve pressure is 500 psi but can be increased to 600 psi.	*Piston surface area = 1.76 inches* *Force = 1.76 in x 500 psi* *Force = 880 lbs* *The cylinder can lift 880lbs, which is not enough to raise the 1000 implement.*	*Increase the relief valve setting to 600 psi.*
A customer has a loader tractor with two cylinders. Each cylinder has a 2-inch diameter piston but cannot lift a 500-pound load. The relief valve pressure setting is 100 psi.	*Piston surface area = 3.14 inches* *Force = 3.14 in x 100 psi* *Single piston force = 314 lbs* *2 piston force = 628 lbs*	*Check all lines and valves for debris and clean them. Replace the fluid in the system.*

	The force should be able to lift the 500 lb load. A valve or hose may have debris.	

Assessment

Lesson 6.1 Check for Understanding

Lesson 6.1 Check for Understanding is included for you to use as an assessment tool for this lesson. Use **Lesson 6.1 Check for Understanding Answer Key** for evaluation purposes.

Name____ CASE

Activity 6.1.1 Fluid Components

Purpose

Standard components in a hydraulic system include an input, control device, output devices, conductor, and fluid. The power input consists of a reservoir and pump, pressuring the system with fluid in the hoses and conductors. Hoses connect control devices to the output devices called actuators.

Control devices consist of valves controlling the flow, pressure, and direction the fluid flows through the system. Actuators consist of motors and cylinders that convert fluid energy into rotational or linear mechanical energy. Motors produce rotational movement, while cylinders produce linear motion. The type of actuator used will affect the valve chosen for the system.

How are the components of a hydraulic system connected in the proper order?

Materials

Per student:

- Amatrol® account with hydraulic simulator
- *Agriscience Notebook*
- Device with internet access
- Headphones
- Pen

Procedure

Assemble a hydraulic system for a double-acting cylinder and a hydraulic motor.

Part One – Double Acting Cylinder System

1. Log in to the Amatrol© LMS and select **eLearning courses**.
   - Mute your device or connect it to headphones.
2. Select **Amatrol-Main Library, Fluid Power,** and choose **Basic Hydraulics**.
3. **Launch** *Hydraulic Power Systems* and take the pre-quiz.
4. Select **Segment 2 Power Unit Operation** and choose **Skill 3** to open the hydraulic simulator on your computer.
5. Select **Add Component** at the top of the screen and add the following components.
   - 4-way, 3-position Directional Control Valve (DCV 4/3)
   - Cylinder, small bore
6. Connect a hose to the power source (blue-handled valve) and the P (pump) connection on the DCV 4/3.
7. Connect the T (tank) port on the DCV 4/3 to the power source's return with a hose.
8. Connect the DCV 4/3 A port to one cylinder port.
9. Connect the DCV 4/3 B port to the other cylinder port.
10. Click on the pressure gauge to enlarge it.

11. Select the green button on the pump to turn it on.
12. Click on the regulator and turn clockwise until the pressure reads 200 psi.
13. Open the blue-handled valve on the pump.
14. Click on the DCV lever and move it toward and away from you.
15. Switch the two hoses to connect to the cylinder.
16. Click on the DCV lever and move it toward and away from you.
17. Sketch the system in Figure 1 on *Activity 6.1.1 Student Observations* sheet and identify the following components using abbreviations.
    - P – power input
    - O – power output
    - C – conductors
    - D – control device
18. In Table 1, record the hydraulic fluid flow and the cylinder's position related to the following DCV lever positions.
    - Vertical position
    - Toward you
    - Away from you
19. Answer *Part One Analysis Question*.

Part Two – Hydraulic Motor System

1. Log in and open the hydraulic simulator on your computer.
2. Select **Add Component** at the top of the screen and add the following.
    - 4-way, 3-position Directional Control Valve (DCV 4/3)
    - Hydraulic motor
3. Connect a hose to the power source (blue-handled valve) and the P connection on the DCV 4/3.
4. Connect the T port on the DCV 4/3 to the return on the power source with a hose.
5. Connect the DCV 4/3 A port to one hydraulic motor port.
6. Connect the DCV 4/3 B port to the other hydraulic port.
7. Click on the pressure gauge to enlarge it.
8. Select the green button on the pump to turn it on.
9. Click on the regulator and turn clockwise until the pressure reads 200 psi.
10. Open the blue-handled valve on the pump.
11. Click on the DCV lever and move it towards and away from you.
12. Switch the two hoses connected to the motor.
13. Click on the DCV lever and move it toward and away from you.
14. Sketch the system in the observations sheet and identify the following components using abbreviations in Figure 2.
    - P – power input
    - O – power output
    - C – conductors
    - D – control device

15. In Table 2, Record the hydraulic fluid flow and the motors rotation related to the following DCV lever positions.
    - Vertical position
    - Toward you
    - Away from you
16. Answer *Part Two Analysis Question*.

Conclusion

1. What are the five standard components of a hydraulic system?

2. What will happen if a technician connects hoses to the incorrect port?

3. How is a hydraulic motor act like a pump?

4. What are two types of actuators, and how would each function on an agricultural implement?

5. What are the three functions of hydraulic controls?

Name____

Activity 6.1.1 Student Observation Sheet

Figure 1. Double Acting Cylinder Sketch

Table 1. ***Cylinder Observations***

Lever Position	Cylinder Position	Fluid Flow
Vertical position		
Toward you		
Away from you		

Part One Analysis Question

Q1 Why is it important to connect the hose to the correct port on a cylinder?

Figure 2. Hydraulic Motor Sketch

Table 2. ***Motor Observations***

Lever Position	Motor Rotation	Fluid Flow
Vertical position		
Toward you		
Away from you		

Part Two Analysis Question

Q2 Why is it important to connect the hose to the correct port on a motor?

Name____ CASE

Activity 6.1.2 Fluid Drawings

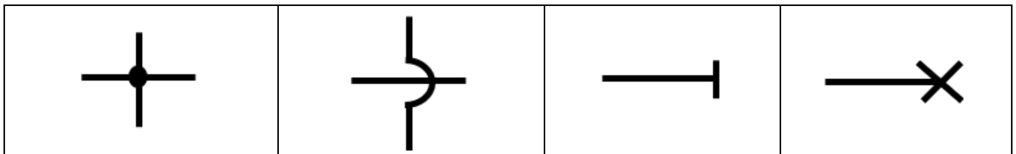
Purpose

When engineers plan a fluid power system, they draw the system in a schematic. Fluid power schematics are similar to the electrical schematics used in *Unit 4 Electrical Systems*. Technicians read schematics to assemble, maintain, and troubleshoot hydraulic systems.

Fluid power schematics have symbols representing the components found in the system. Solid lines represent hoses connecting each component. A technician reads a variety of symbols that represent how valves direct fluid through a system. There are a few *Schematics Basic Rules*.

Schematics Basic Rules

- Symbols may be rotated or reversed
- A single reservoir can be shown many times
- Symbols show connections, flow paths, and functions
- Draw symbols in the de-energized position, usually the center position of a 3-position valve
- Use a solid arrow on the line to show the flow direction
- Use standard methods to draw connecting and crossing lines, as seen in Figure 1



Connected Lines	Crossing Lines	Blocked Line	

Figure 1.

How are schematics used to identify valves and actuators in a hydraulic system?

Materials

Per student:

- Amatrol® hydraulic simulator
- *Agriscience Notebook*
- *Logbook*
- Pen

Procedure

Review schematic symbols and sketch them in your Logbook. Then use schematics to construct virtual hydraulic systems. Record answers to analysis questions in your *Logbook*.

Part One – Schematic Information

Complete Segments 3 and 4 of Amatrol's *Hydraulic Power Systems*. As you go through each segment, complete the following steps.

1. Log in to the Amatrol© LMS and select **eLearning courses**.
2. Select **Amatrol-Main Library, Fluid Power,** and choose **Basic Hydraulics**.
3. **Launch** *Hydraulic Power Systems.*

4. Select **Segment 3 Circuit Connections**
5. Complete *Segment 3 Circuit Connections* and *Segment 4 Basic Cylinder Circuits* while completing Part One.
6. In your *Logbook*, sketch the symbols for the following components found in a hydraulic system
    - Input Devices
        - Reservoir
        - Filter
        - Pump
        - Relief valve
        - Pressure gauge
    - Control Devices
        - Flow control valve
        - 4/3 directional control valve
    - Output Devices
        - Double-acting cylinder
    - Fluid
        - Flow direction
    - Conductor
        - Hose
        - Quick connect fitting
        - Tee
7. Sketch the basic symbols listed below that technicians combine to define each hydraulic component.
    - Accumulator
    - Rotating Device
    - Spring
    - Valve
    - Cylinder
    - Conductor
    - Conditioning Device
    - Restriction Line Connected
    - Variable
8. Answer the analysis questions in your *Logbook*.

    Q1 Which symbols are combined to draw the schematic of a pump?
    Q2 Which symbols are combined to draw a control valve?
    Q3 How many positions and ports are there on a 3/2 valve?

Part Two – Schematic Reading

1. Review the schematic in Figure 2 and label all the components.

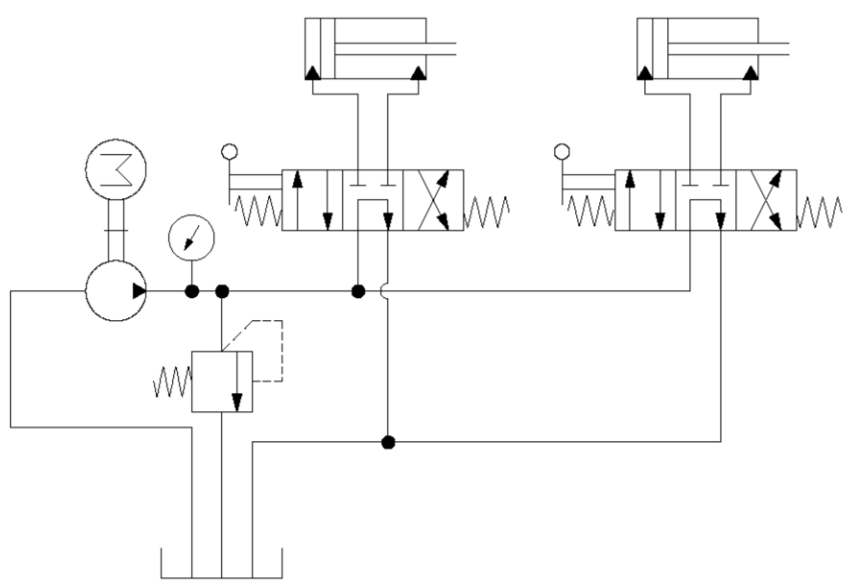


Figure 2. Hydraulic Schematic

2. Open the Amatrol hydraulic simulator.

3. **Launch** Hydraulic Power Systems.
4. Select **Skill 3** to open the hydraulic simulator on your computer.
5. Assemble all components as shown in Figure 2.
6. Start the pump and adjust the pressure to 200 psi.
7. Operate the DCV to ensure the valve controls both cylinders.
8. Sketch a picture of the system in your *Logbook*.

Part Three – Schematic Drawing

Review the sketch of your hydraulic system from Part Two of *Activity 6.1.1 Fluid Components*. Next, draw a schematic for that system in your *Logbook*. Use the basic rules from the purpose when completing your schematic.

Conclusion

1. Why does a hydraulic power source consist of multiple schematic symbols?

2. How could a technician use a schematic when troubleshooting a hydraulic system?

3. How is a schematic different from a sketch?

4. Why are schematics used instead of sketches when repairing hydraulic systems?

Name____

CASE

Activity 6.1.3 Positively Pumping

Purpose

A pump forces fluid throughout the hydraulic system, providing the energy input. Pumps vary in size and design depending on the system's output. Which types of hydraulic pumps will you maintain as a technician?

Pumps use rotating components to create a vacuum in a hydraulic system, causing the fluid to flow in a single direction. A technician needs to understand that pumps cause fluid flow but **DO NOT** cause fluid pressure. Pumps can be positive or non-positive. Positive displacement pumps move the same amount of fluid for each revolution of the pump. The pressure in the system will not affect the flow of the fluid. Non-positive pumps transfer fluid from one location to another with little pressure in the system. Non-positive pumps will slip when there is pressure in the system, and the flow rate will change.

Hydraulic systems use two types of positive displacement pumps, fixed displacement and variable displacement. The volume of liquid displaced by a fixed displacement pump can only be changed by an operator altering the pump's speed (rpm). An operator can adjust a variable displacement pump's volume while keeping the speed constant.

Hydraulic systems function as open- or closed-loop systems. An open-loop system has a fluid reservoir and a pressure relief valve to set maximum pressure. A closed-loop system returns the fluid to the pump and does not have to draw fluid from the reservoir.

As a technician, will you be able to identify and describe the hydraulic system found on a machine for a customer?

Materials

Per pair of students:

- Battery, 9V
- Cup, 30ml
- Plastic container, 10 oz
- (3) Plastic coupler, $^{1}/_{8}$″ O.D.
- Plastic tee, $^{1}/_{8}$″ O.D.
- (4) Plastic tubing,1′ x $^{1}/_{8}$″ I.D.
- Positive displacement pump, 12V
- (2) Syringes, 10ml
- Wire with alligator clips, black
- Wire with alligator clips, red

Per student:

- *Agriscience Notebook*
- *Logbook*
- Pen
- Safety glasses

Per class:

- Cooking spray
- Water source

Procedure

Work with a partner to construct a hydraulic pump system and use their characteristics to identify it. Record sketches, schematics, and answers to analysis questions in your *Logbook*.

1. Fill the plastic container with water.
2. Use two couplers to connect two hoses to the pump.
3. Place both pump hoses in the water.

4. Connect the wires to the pump as described below.
   - Black wire to the negative terminal
   - Red wire to the positive terminal
5. Connect the wires to the 9-volt battery.
   - Black wire to the negative terminal
   - Red wire to the positive terminal
6. Observe the direction of water flow through the pump.
7. Sketch the pump in your *Logbook*, including the input, output, electrical terminals, and water flow.
8. Stop the pump by disconnecting the positive wire from the battery's positive terminal.
9. Hold the output hose in a 30ml cup.
10. Start a time and turn on the pump by connecting the positive wire to the battery's positive terminal.
11. Shut off the pump once the cup is full and stop the timer.
12. Record the time in your *Logbook*.
13. Calculate the flow rate by dividing 30ml by the time it took to fill the cup.
14. Record the rate in your *Logbook*.
15. Discard the water from the cup and add a coupler on the end of the output hose.
16. Repeat Steps 9–15.
17. Answer the analysis question in your *Logbook*.

    Q1 What type of pump are you using? Explain.
18. Replace the coupler on the output hose with a tee connected to two additional hoses.
19. Lubricate the rubber piston of the syringe with cooking spray.
    - Insert the piston into the syringe and move it up and down to ensure it moves freely.
    - Push the piston down on the syringe, so no air is in the cylinder.
20. Attach the piston to one of the hoses connected to the tee.
21. Place the open hose in the water.
22. Sketch the assembled system in the *Logbook* and identify the following components.
    - Positive displacement pump
    - Relief valve
    - Reservoir
    - Piston
23. Draw a schematic of the system in your *Logbook*.
24. Turn on the system.
25. Answer the analysis question in your *Logbook*.

    Q2 Where does the fluid flow? Why?
26. Shut off the system.
27. Pinch the open hose to simulate an increase in the pressure setting on the relief valve.
28. Turn on the system and observe the piston.
29. Release the open hose once the piston is fully extended.
30. Answer the analysis question in your *Logbook*.

    Q3 What type of pump system have you assembled?

Conclusion

1. What are the characteristics of a positive displacement pump?

2. How would you convert your system to a closed-loop system?

3. What is the purpose of a relief valve in an open-loop system?

Name____

CASE

Activity 6.1.4 Pressure and Flow Control

Purpose

When watching agricultural equipment in action, you will see actuators doing tasks that require a large amount of force with slow, precise movements. How do technicians monitor and control pressure and flow in hydraulic systems?

A technician uses gauges to monitor a system's fluid flow and pressure. A flow meter measures the fluid flow in gallons per minute (gpm), while a pressure gauge measures pressure in pounds per square inch (psi).

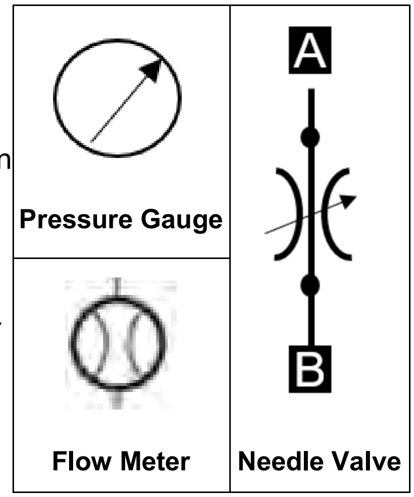


Figure 1. Schematics

A technician must understand the fundamental cause of pressure and flow in a system to control them. Pumps in a hydraulic system do not produce hydraulic pressure; they only produce hydraulic flow. Resistance to flow, such as gravity, a pinch in a hose, and cylinder diameter, cause pressure to occur in a hydraulic system. Resistance in a system can be intentional or unintentional. Unintentional resistance includes bends and kinks in hoses or debris in a hydraulic line. Valves cause intentional resistance where a machine needs additional pressure in a system.

Placing a needle valve in a system causes resistance to flow, increasing pressure upstream from the valve and decreasing pressure downstream. A needle valve restricts flow in both directions: A to B or B to A, as seen in Figure 1.

The pressure relief valve at the pump controls the maximum total pressure placed in the system, measured in pounds per square inch (psi). Technicians use pressure relief valves to set constant pressure throughout a system. The actual pressure in any location in the system may be lower than the relief valve's pressure. The difference between the pressure at two points in a system is called the pressure drop. The total pressure drop in an open-loop system will equal the relief valve pressure.

Flow control valves control the rate of fluid flow in a system in one direction while allowing free flow in the other. Flow control valves regulate the speed of actuators. Slowing down the speed of an actuator enables an operator to have precise control. Flow control valves restrict flow from A to B but allow free-flowing fluid from B to A, as shown in Figure 2.

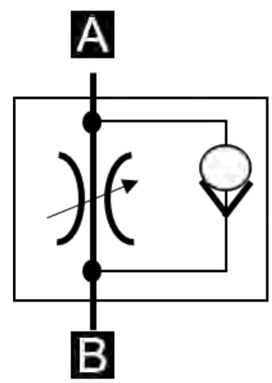


Figure 2. Flow Control Valve

Where should needle valves and flow control valves be placed in a hydraulic system? How do they affect the pressure in the system?

Materials

Per pair of students:

- Amatrol® account with hydraulic simulator
- Device with internet access

Per student:

- Calculator
- Pen
- *Agriscience Notebook*

Procedure

Simulate the assembly of hydraulic systems and measure the system's pressure and flow.

Part One –Flow Meter

1. Log in to the Amatrol© LMS and select **eLearning courses**.
    - Mute your device or connect it to headphones.
2. Select **Amatrol-Main Library, Fluid Power,** and choose **Basic Hydraulics**.
3. Select **Segment 2 Power Unit Operation** and choose **Skill 3** to open the hydraulic simulator on your computer.
4. Assemble the components as shown in Figure 3.
5. Turn on the hydraulic unit.
6. Adjust the relief valve pressure to 500 psi.
7. Close the shutoff valve.
8. Record the relief valve pressure, upstream pressure and downstream pressure in the first row of Table 1 on *Activity 6.1.4 Student Observations*.
    - The tank pressure will always be zero.
9. Open the shutoff valve.
10. Turn the knob on the needle valve counterclockwise, so it is fully open (seven turns).
11. Record the pressure and flow readings in Table 1.
12. Repeat Step 11 for each needle valve setting in Table 1.
13. Close the shutoff valve, shut off the pump, and adjust the needle valve to 7 turns so it is open.
14. Answer *Part One Analysis Questions*.

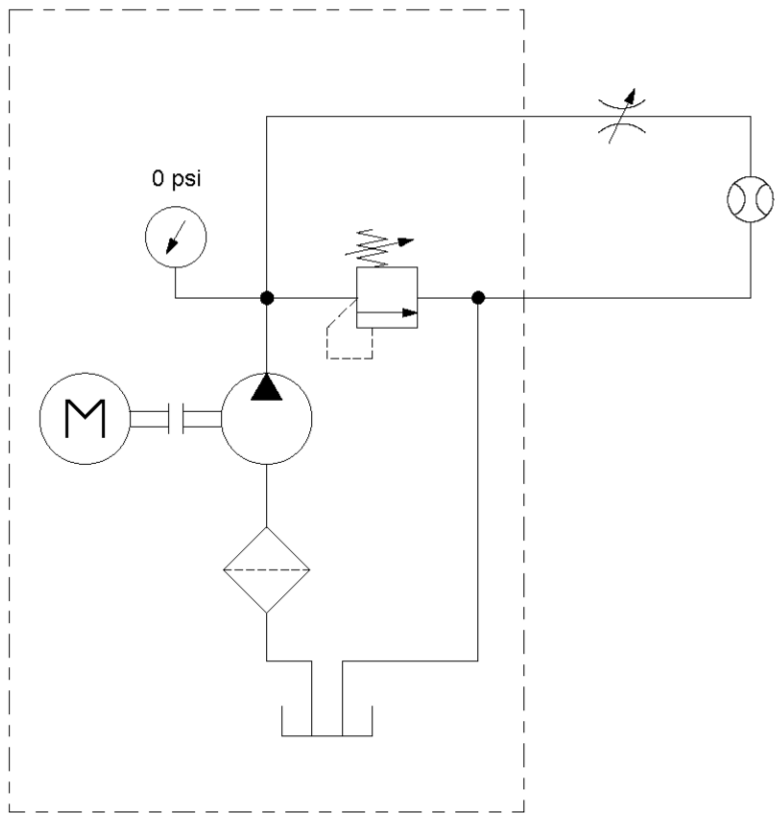


Figure 3. Flow Meter Schematic

Part Two – Pressure Drop

1. Remove the hoses from your virtual system.
2. Use two tees with hoses to place a pressure gauge upstream (US) and downstream (DS) from the needle valve.
3. Turn on the pump, adjust the relief valve pressure to 500 psi, and adjust the needle valve to 7 turns, so it is open.
4. Open the shutoff valve.
5. Record the pressure of the pump gauge, US gauge, and DS gauge in Table 2.
6. Repeat Step 5 for the remaining needle valve adjustments listed in Table 2.

7. Subtract the downstream pressure from the upstream pressure for the each needle valve setting and record in Table 4.
8. Subtract the downstream pressure from the tank pressure for each needle valve setting and record in Table 4.
9. Add the two pressure differences to find the pressure drop in the system for each needle valve setting.
10. Answer *Part Two Analysis Questions*.

Part Three – Flow Control

1. Use the hydraulic simulator on your computer to assemble the components, as seen in Figure 4.

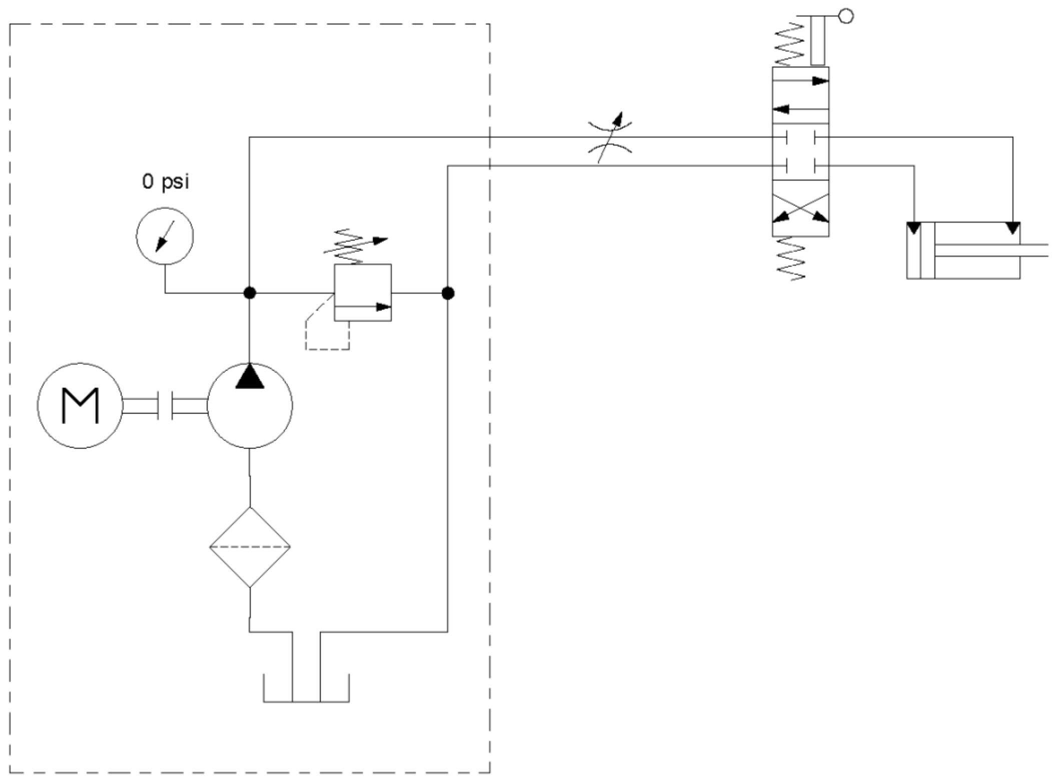


Figure 4. Needle Valve Schematic

2. Turn the knob on the needle valve counterclockwise so it is partially open at two turns.
3. Turn on the hydraulic unit.
4. Adjust the relief valve pressure to 500 psi.
5. Open the shutoff valve.
6. Move the lever on the DCV back and forth to activate the cylinder.
7. Record the speed of the cylinder in Table 4.
8. Turn the needle valve clockwise until it is 1.0 turn open.
9. Move the lever on the DCV to activate the cylinder.
10. Record the cylinder speed in Table 3.
11. Repeat Steps 7–10, adjusting the flow control to the settings shown in Table 3.

Part Four – One Direction

1. Use the hydraulic simulator on your computer to assemble the components, as seen in Figure 5.

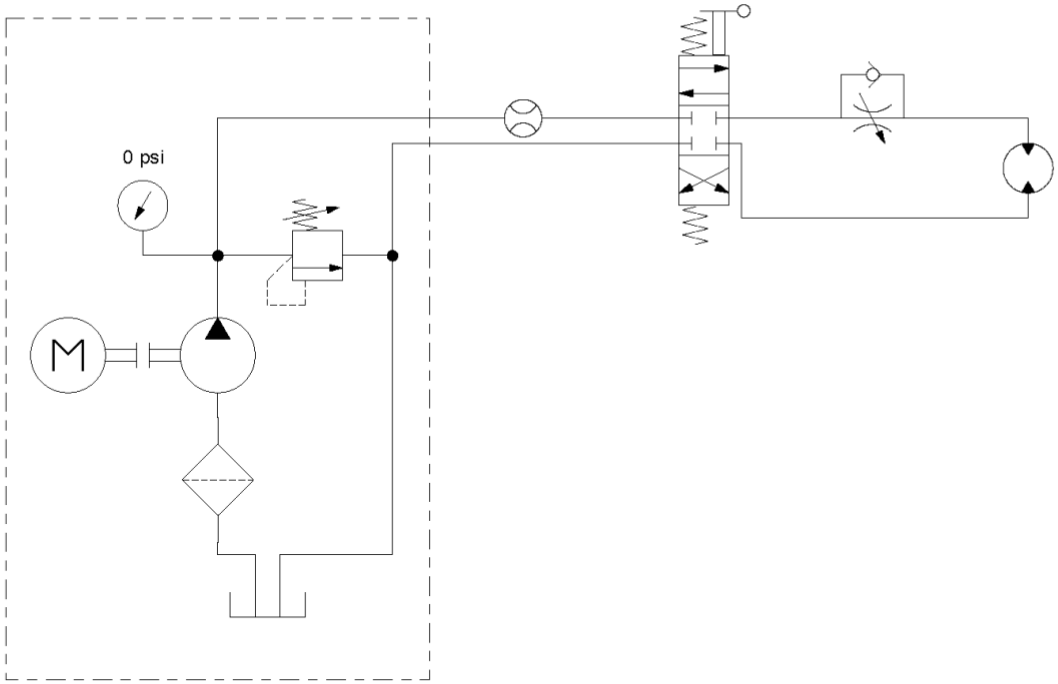


Figure 5. Flow Control Schematic

2. Turn the knob on the flow control meter counterclockwise so it is partially open at two turns.
3. Turn on the hydraulic unit.
4. Adjust the relief valve pressure to 500 psi.
5. Open the shutoff valve.
6. Move the lever on the DCV **towards** and **away** from you to activate the motor.
7. Record the following in Table 5.
    - Flow
    - System pressure
    - Motor speed
8. Close the shutoff valve.
9. Repeat Steps 2–8 for the following flow control settings in Table 4.
10. Answer *Part Four Analysis Questions*.

Conclusion

1. How is flow different than pressure?

2. How is flow changed in a system?

3. What happens to pressure when a valve reduces the flow?

4. What part of the system provides a constant fluid flow?

Name____

Activity 6.1.4 Student Observations

Table 1. ***Flow Rate Observations***

Needle Valve Setting	Relief Valve Pressure Reading (psi)	Flow Meter Reading (gpm)
7 turns		
3 turns		
2 turns		
1 turn		
0.8 turn		
0.6 turn		
0.5 turn		
0 turns		

Part One Analysis Questions

Q1 What happens to the flow as you adjust the needle valve? Why?

Q2 Why does the flow rate drop when you reduce the needle valve setting to zero?

Table 2. ***Needle Valve Observations***

Needle Valve Setting	Relief Valve Pressure	Upstream Pressure Gauge Reading	Downstream Pressure Gauge Reading	Tank Pressure
7 turns (system on)				0 psi
3 turns				0 psi
2 turns				0 psi
1 turn				0 psi
0 turns				0 psi

Table 3. Pressure Drop

Needle Valve Setting	US Pressure – DS Pressure	DS Pressure – Tank Pressure	Total Pressure Drop
7 turns (open)			
3 turns			
2 turns			
1 turn			
0 turns			

Part Two Analysis Questions

Q3 What is the relationship between pressure upstream and downstream of the needle valve?

Q4 What is the relationship between total pressure drop in Table 4 and the pressure reading at the relief valve?

Q5 What is the maximum pressure at any location in the system? Why?

Table 4. ***Cylinder Observations***

Needle Valve Setting	Actuator Speed	
	Lever Toward	Lever Away
1.0		
0.8		
0.5		
0.3		
0.2		
0.1		

Part Three Analysis Questions

Q6 How does the flow rate affect the speed of the actuator?

Q7 What would happen to the cylinder's speed if the cylinder had a larger volume? Why?

Table 5. ***Motor Observations***

Flow Control Setting	Lever Toward			Lever Away		
	Pressure Gauge Reading	Flow Rate	Actuator Speed	Pressure Gauge Reading	Flow Rate	Actuator Speed
2.0						
1.0						
0.5						
0						

Part Four Analysis Questions

Q8 How does a flow control valve differ from a needle valve?

Q9 What are the advantages of a flow control valve in this situation?

Q10 What other fluid power designs would require a flow control valve?

Name____ CASE

Activity 6.1.5 System Settings

Purpose

When a driver applies the brake in a car, they apply enough force to stop the wheels of a moving vehicle weighing thousands of pounds. How can the force applied with a foot halt the movement of a car?

Many brakes use a hydraulic system consisting of mechanical pistons that squeeze a rotating disk attached to the wheel. As the pistons compress the disk, friction slows the vehicle. A simple hydraulic system consists of fluid in a pump and cylinder. The pump pushes the fluid into the cylinder. The pressure exerted by the pump transfers to the cylinder's piston. This mechanical system is an application of Pascal's Law.

Pascal's Law states that the pressure exerted at any point on a liquid is equally transmitted to all surfaces. If you fill a bottle with water to the top and put a cork in the bottle, the cork can transfer force throughout the entire bottle. If ten pounds of force is applied to a cork with one square inch of surface area, the cork will transfer ten pounds per square inch of pressure to the bottle's entire surface. The following equation is the mathematical equation of Pascal's Law used to calculate a hydraulic system's pressure.

$$\text{pressure} = \frac{\text{force (lbs)}}{\text{area (in}^2\text{)}}$$

Pistons in hydraulic cylinders are circular in shape. To calculate the surface area of a circle, use the following equation.

$\pi = 3.14$

r = radius of the circle

$$\text{surface area} = \pi r^2$$

Once the force applied to a specific area in a hydraulic system is known, a technician can calculate the system's pressure.

How can you use Pascal's Law to calculate the settings and select components for a hydraulic system? What factors should you consider when troubleshooting a hydraulic system?

Materials

Per pair of students:

- Battery, 9V
- Dial caliper 6″/150mm
- LabQuest
- Plastic container, 10 oz
- Plastic tee, $^1/_8$″ O.D.
- (4) Plastic tubing, 1′ x $^1/_8$″ I.D.
- Positive displacement pump, 12V
- Pressure sensor 400
- Syringe, 10ml
- Syringe, 20ml
- Syringe, 60ml
- Wire with alligator clips, black
- Wire with alligator clips, red

Per student:

- *Agriscience Notebook*
- Calculator
- *Logbook*
- Pen
- Safety glasses

Per Class

- (5) Cooking spray

Procedure

Practice calculating the force in a model hydraulic system. Then use Pascal's Law to identify the potential cause of the problem in a hydraulic system.

Part One – Piston, Pressure, and Force

1. Use the following materials to assemble an open-loop positive displacement pump. Use your notes from your *Logbook* if needed.
    - Battery, 9V
    - Wire with alligator clips, black
    - Wire with alligator clips, red
    - Positive displacement pump, 12V
    - Plastic tee, $^1/_8$″ O.D.
    - (4) Plastic tubing, 1′ x $^1/_8$″ I.D.
    - Plastic container, 10 oz
2. Prepare the pressure sensor.
    - Attach the pressure sensor to CH1.
    - Turn on LabQuest.
    - Change the units to psi.
3. Turn on the pump with both hoses in the water container until water flows out of the output hose.
4. Connect the pressure sensor to the hose returning to the reservoir.
5. Remove the piston from each cylinder.
6. Use the dial caliper to measure each piston's diameter (inches) and record them in Table 1 of *Activity 6.1.5 Student* Observation.
7. Find the surface area of each piston (in^2) using the equation in the purpose and record it in Table 1.
8. Use cooking oil to lubricate the pistons in each syringe, so they move freely with little friction.
9. Retract all pistons to the port.
10. Attach the 10ml piston (syringe) to the output hose.
11. Turn on the pump.
12. Shut the pump off once 10ml of the liquid has filled the cylinder.
13. Record the system pressure in Table 1.
14. Use the caliper to measure the extension of the rod and record the extension in Table 1.
15. Repeat Steps 11–14 for the 20ml and 60ml syringes.
    - Fill each with 10ml of liquid.
16. Use Pascal's Law to calculate the pounds of force in each system and record it in Table 1.
17. Answer *Part One Analysis Questions*.

Part Two – System Situations

Review each customer complaint and use Pascal's Law to find the potential cause and correction. Then, record the complaint, cause, and correction on the student observations sheet.

Complaint 1
A customer's hydraulic cylinder with a 1-inch piston diameter cannot lift a 1000-lb implement. The system is an open-loop system with a maximum pressure of 500 psi.

Complaint 2
A customer has a loader tractor with a single 1.5-inch piston diameter cylinder. The loader is unable to lift a 1000-pound load. The relief valve pressure is 500 psi but can be increased to 600 psi.

Complaint 3
A customer has a loader tractor with two cylinders. Each cylinder has a 2-inch diameter piston but cannot lift a 500-pound load. The relief valve pressure setting is 100 psi.

Conclusion

1. What is the relationship between piston surface area and force in a hydraulic system?

2. Why should a technician understand Pascal's Law?

3. How would you explain Pascal's Law to a customer?

Name____

Activity 6.1.5 Student Observations

Table 1. ***System Measurements and Calculations***

Syringe	Piston Diameter	Surface Area	Pressure	Force	Extension
10ml					
20ml					
60ml					

Part One Analysis Questions

Q1 How did the piston diameter affect the pressure in the system?

Q2 What is the relationship between volume, piston diameter, and extension?

Q3 How does the piston diameter affect the lifting force of a cylinder?

Q4 Which cylinder has the largest potential force? Why?

Table 2. ***System Situations***

	Complaint	Cause	Correction
1			
2			
3			

Name____

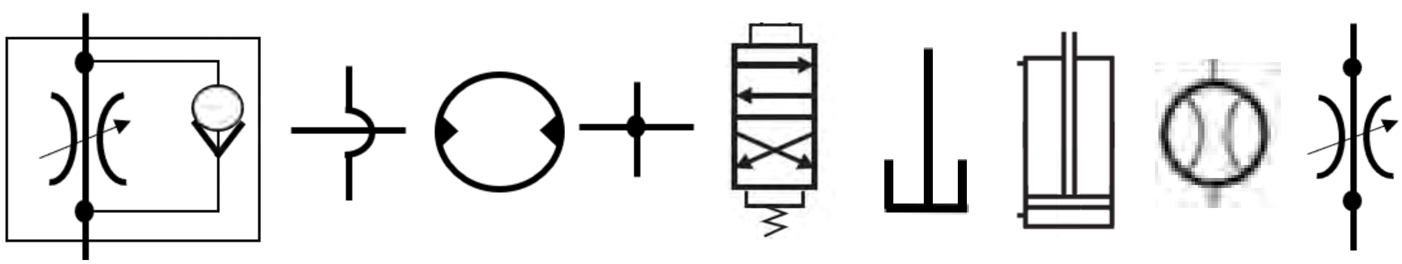
Lesson 6.1 Check for Understanding

1. List the five components found in all hydraulic systems.

2. Which of the following components controls hydraulic pressure? Circle all that are correct.
   a) Positive displacement pump
   b) Flow control valve
   c) Needle valve
   d) Directional control valve

3. Which system does not require a reservoir?
   a) A system with a positive displacement pump
   b) An open-loop system
   c) A system with a nonpositive displacement pump
   d) A closed-loop system

4. Match the schematic symbol to the correct component.



______ ______ ______ ______ ______ ______ ______ ______ ______

A.	Pump
B.	Flow control valve
C.	Needle valve
D.	Directional control valve
E.	Cylinder
F.	Connected line
G.	Crossed line
H.	Reservoir
I.	Flowmeter

5. Explain the difference between a positive and nonpositive displacement pump using the following terms: flow, pressure, rpm, and volume.

6. A customer brings a loader-tractor to the dealership and complains that the hydraulic pump is broken because there is no system pressure. Based on what you know about hydraulics, explain why the pump may not be the problem and what the cause may be.

7. What is the pressure in a system lifting a load of 200 lbs with a cylinder that has a 2” diameter piston?

8. A customer needs a hydraulic cylinder to lift a 550 lb implement. The system is an open-loop system with a maximum pressure of 500 psi. They need to decide whether to use a 1”, 1.5”, or 2” cylinder. Use Pascal’s Law to determine which cylinder the customer needs.

CASE

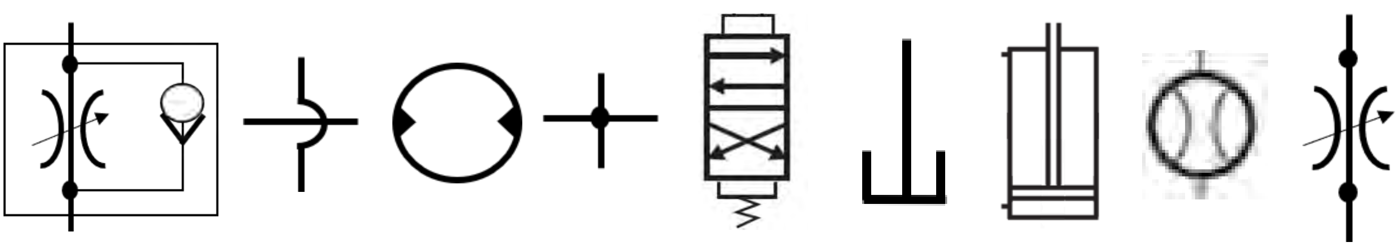
Lesson 6.1 Check for Understanding Answer Key

1. List the five components found in all hydraulic systems.
   - **Pump**
   - **Control valves**
   - **Actuators**
   - **Fluid**
   - **Hoses**

2. Which of the following components controls hydraulic pressure? Circle all that are correct.
   a) Positive displacement pump
   b) **Flow control valve**
   c) **Needle valve**
   d) Directional control valve

3. Which system does not require a reservoir?
   a) A system with a positive displacement pump
   b) An open-loop system
   c) A system with a nonpositive displacement pump
   d) **A closed-loop system**

4. Match the schematic symbol to the correct component.



B **F** **A** **G** **D** **H** **E** **I** **C**

A.	Pump
B.	Flow control valve
C.	Needle valve
D.	Directional control valve
E.	Cylinder
F.	Connected line
G.	Crossed line
H.	Reservoir
I.	Flowmeter

5. Explain the difference between a positive and non-positive displacement pump using the following terms: flow, pressure, rpm, and volume.

Positive displacement pumps provide a consistent fluid flow under varied pressure. A non-positive displacement pump will slip under pressure and not provide a consistent flow.

6. A customer brings a loader-tractor to the dealership and complains that the hydraulic pump is broken because there is no system pressure. Based on what you know about hydraulics, explain why the pump may not be the problem and what the cause may be.

Pumps produce flow and do not create pressure in a system. Therefore, lack of system pressure is more likely to be a problem with a component that causes pressure, such as a valve.

7. What is the pressure in a system lifting a load of 200 lbs with a cylinder that has a 2” diameter piston?

$$\text{Surface area} = \pi r^2$$

$$\textbf{3.14 square inches} = \pi 1^2$$

$$\text{Pressure} = \frac{\text{force}}{\text{area}}$$

$$\textbf{63.7 psi} = \frac{\textbf{200 lbs}}{\textbf{3.14 square inches}}$$

1. A customer needs a hydraulic cylinder to lift a 550 lb implement. The system is an open-loop system with a maximum pressure of 500 psi. They need to decide whether to use a 1”, 1.5”, or 2” cylinder. Use Pascal’s Law to determine which cylinder the customer needs.

$$\text{Force} = \text{pressure} \times \text{area}$$

Area = force ÷ pressure **1.1 square inches = 550 lb ÷ 500 psi**

The 1.5 in^2 cylinder has a radius of 0.75 inches.

Surface area = πr^2 **1.76 = $\pi 0.75^2$**

The 1.5 in^2 cylinder has enough surface area to provide enough force.

CASE

Lesson 6.2 Hydraulic Systems and Safety

Preface

When a technician repairs a hydraulic system, they need to know how the manufacturer designed the system and how it functions. In addition, hydraulic systems pose new and unseen dangers that a technician should be aware of before performing maintenance or repairs.

All hydraulic fluids provide lubrication, cooling, sealing, and pressure transfer in a hydraulic system. Specific physical and chemical properties of hydraulic fluids vary. A fluid's resistance to flow is called viscosity. The temperature impacts the viscosity of a liquid. A fluid's pour point is the lowest temperature at which a fluid will still flow. A fluids viscosity and pour point, along with other information, is found in a Safety Data Sheet (SDS). Technicians reference Safety Data Sheets for handling, usage, and safety information.

Hydraulic safety hazards include heat, fire, and pressure. Fluid traveling through a hydraulic system produces heat because of the friction with the internal Hose's surface. The fluid and components can become hot, causing potential burns. Flammable hydraulic fluids should be kept away from ignition sources. Fluid leaving the system under high pressure due to a leak or crack in a hose can puncture the skin. Before a technician works on any hydraulic system, they place the system in a zero-energy state where the fluid has cooled and is under no pressure.

Positive-displacement systems use two types of pumps for transferring fluid: fixed-displacement and variable-displacement. Gear pumps are a common fixed-displacement pump producing a constant fluid flow directly proportional to the pump's rpm. Variable-displacement pumps can increase and decrease the fluid flow while operating at the same rpm. Hydrostatic drive systems use variable-displacement pumps. Hydrostatic systems use the pump to adjust fluid flow and direction to eliminate the need for directional control valves.

Operators will find fluid power systems throughout mobile equipment. Steering, brake, drive, and power take-offs are examples of fluid power systems in a tractor. Electrical components, such as relays and solenoids, control these systems remotely. Students learn how to safely operate and identify components in fluid power systems they find on equipment during this lesson.

Concepts	**Performance Objectives**
Students will know and understand	*Students will learn concepts by doing*
1. Hydraulic fluids have specifications and properties that meet industry standards.	• Read an SDS and identify the ISO Standards for hydraulic fluids. (Activity 6.2.1) • Compare the physical properties of hydraulic fluids. (Activity 6.2.1)
2. Technicians need to be aware of the potential safety hazards when working with hydraulic equipment.	• Inspect a hydraulic system for safety hazards. (Activity 6.2.2) • Record and practice the steps to place a hydraulic system in a zero energy state. (Activity 6.2.2)
3. Hydrostatic transmissions use variable displacement pumps to transfer energy in a power train.	• Model and calculate the advantage of variable displacement pumps. (Activity 6.2.3)
4. Electro-hydraulic systems control cylinders in agricultural implements.	• Evaluate a solenoid and relay for functionality on electro-hydraulic components. (Activity 6.2.4)

5. Hydraulics provide power in agricultural equipment for steering, braking, drivetrains, and axillary equipment.	• Construct an electro-hydraulic system. (Project 6.2.5) • Inspect and document the physical characteristics of fluid power systems found on a tractor. (Activity 6.2.6)

National AFNR Common Career Technical Core Standards Alignment

Career Ready Practices
2. Apply appropriate academic and technical skills.
• CRP.02.01: Use strategic thinking to connect and apply academic learning, knowledge, and skills to solve problems in the workplace and community.
• CRP.02.02: Use strategic thinking to connect and apply technical concepts to solve problems in the workplace and community.
4. Communicate clearly, effectively and with reason.
• CRP.04.01: Speak using strategies that ensure clarity, logic, purpose and professionalism in formal and informal settings.
• CRP.04.02: Produce clear, reasoned and coherent written and visual communication in formal and informal settings.
• CRP.04.03: Model active listening strategies when interacting with others in formal and informal settings.
8. Utilize critical thinking to make sense of problems and persevere in solving them.
• CRP.08.01: Apply reason and logic to evaluate workplace and community situations from multiple perspectives.
• CRP.08.02: Investigate, prioritize, and select solutions to solve problems in the workplace and community.
• CRP.08.03: Establish plans to solve workplace and community problems and execute them with resiliency.
Agriculture, Food, and Natural Resources Career Cluster
3. Examine and summarize importance of health, safety, and environmental management systems in AFNR organizations.
• AG 3.1: Examine health risks associated with a particular skill to better form personnel safety guidelines.
• AG 3.4: Examine required regulations to maintain/improve safety, health and environmental management systems and sustainable business practices.
• AG 3.5: Enact procedures that demonstrate the importance of safety, health, and environmental responsibilities in the workplace.
• AG 3.6: Demonstrate methods to correct common hazards.
• AG.3.7: Demonstrate application of personal and group health and safety practices.
Power, Structural and Technical (AG-PST)
3. Service and repair mechanical equipment and power systems used in AFNR power, structural and technical systems.
• AG-PST 3.3: Service and repair hydraulic systems by evaluating performance using maintenance manuals.
• AG-PST 3.4: Service and repair steering, suspension, traction, and vehicle performance systems by checking performance parameters.

Next Generation Science Standards Alignment

Disciplinary Core Ideas
Engineering, Technology, and the Application of Science
ETS1: Engineering Design

Science and Engineering Practices	
Developing and Using Models	Modeling in 9–12 builds on K–8 experiences and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed world(s). • Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system. • Develop and/or use multiple types of models to provide mechanistic accounts and/or predict phenomena and move flexibly between model types based on merits and limitations. • Develop a complex model that allows for manipulation and testing of a proposed process or system.
	Planning and carrying out investigations in 9-12 builds on K-8 experiences and progresses to include investigations that provide evidence for and test conceptual, mathematical, physical, and empirical models.

Planning and Carrying Out Investigations	• Plan and conduct an investigation or test a design solution in a safe and ethical manner including considerations of environmental, social, and personal impacts. • Select appropriate tools to collect, record, analyze, and evaluate data. • Manipulate variables and collect data about a complex model of a proposed process or system to identify failure points or improve performance relative to criteria for success or other variables.
Analyzing and Interpreting Data	Analyzing data in 9–12 builds on K–8 experiences and progresses to introducing more detailed statistical analysis, the comparison of data sets for consistency, and the use of models to generate and analyze data. • Analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in order to make valid and reliable scientific claims or determine an optimal design solution.

Crosscutting Concepts	
Cause and Effect: Mechanism and Prediction	Events have causes, sometimes simple, sometimes multifaceted. Deciphering causal relationships, and the mechanisms by which they are mediated, is a major activity of science and engineering.
	• Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. • Cause and effect relationships can be suggested and predicted for complex natural and human designed systems by examining what is known about smaller scale mechanisms within the system. • Systems can be designed to cause a desired effect. • Changes in systems may have various causes that may not have equal effects.
Systems and System Models	A system is an organized group of related objects or components; models can be used for understanding and predicting the behavior of systems.
	• Systems can be designed to do specific tasks. • When investigating or describing a system, the boundaries and initial conditions of the system need to be defined and their inputs and outputs analyzed and described using models. • Models (e.g., physical, mathematical, computer models) can be used to simulate systems and interactions—including energy, matter, and information flows—within and between systems at different scales. • Models can be used to predict the behavior of a system, but these predictions have limited precision and reliability due to the assumptions and approximations inherent in models.
Energy and Matter: Flows, Cycles, and Conservation	Tracking energy and matter flows, into, out of, and within systems helps one understand their system's behavior.
	• The total amount of energy and matter in closed systems is conserved. • Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system. • Energy cannot be created or destroyed—only moves between one place and another place, between objects and/or fields, or between systems. • Energy drives the cycling of matter within and between systems.

Common Core State Standards for High School Mathematics

Modeling standards are indicated by the star symbol (*) throughout other conceptual categories.

CCSS: Conceptual Category – Functions	
Interpreting Functions	*Interpret functions that arise in applications in terms of the context.
Linear, Quadratic, and Exponential Models	*Interpret expressions for functions in terms of the situation they model.

Common Core State Standards for English Language Arts

CCSS: English Language Arts Standards » Science & Technical Subjects » Grade 11-12	
Key Ideas and Details	• **RST.11-12.3 –** Follow precisely a complex multistep procedure when carrying out experiments, taking measurements, or performing technical tasks; analyze the specific results based on explanations in the text.
Craft and Structure	• **RST.11-12.4 –** Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to grades 11-12 texts and topics.

Integration of Knowledge and Ideas	• **RST.11-12.7 –** Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem. • **RST.11-12.9 –** Synthesize information from a range of sources (e.g., texts, experiments, simulations) into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible.
Range of Reading and Level of Text Complexity	• **RST.11-12.10 –** By the end of grade 12, read and comprehend science/technical texts in the grades 11-CCR text complexity band independently and proficiently.

CCSS: English Language Arts Standards » Writing » Grade 11-12	
Text Types and Purposes	**WHST.11-12.2 –** Write informative/explanatory texts, including the narration of historical events, scientific procedures/experiments, or technical processes. • **WHST.11-12.2.A –** Introduce a topic and organize complex ideas, concepts, and information so that each new element builds on that which precedes it to create a unified whole; include formatting (e.g., headings), graphics (e.g., figures, tables), and multimedia when useful to aiding comprehension.
Production and Distribution of Writing	• **WHST.11-12.4 –** Produce clear and coherent writing in which the development, organization, and style are appropriate to task, purpose, and audience.
Research to Build and Present Knowledge	• **WHST.11-12.7 –** Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation.
Range of Writing	• **WHST.11-12.10 –** Write routinely over extended time frames (time for reflection and revision) and shorter time frames (a single sitting or a day or two) for a range of discipline-specific tasks, purposes, and audiences.

Essential Questions

1. What is the purpose of a Safety Data Sheet (SDS)?
2. What are the physical and chemical properties of hydraulic fluid?
3. How do technicians work with hydraulic systems safely?
4. What are the potential injuries caused by hydraulic systems?
5. What are the advantages of a variable displacement pump?
6. Why are piston pumps used in hydrostatic systems?
7. How are hydraulics controlled with electrical circuits?
8. How is a relay different from a solenoid?
9. What systems in a tractor use fluid power?
10. What should a technician know about the fluid power systems in an agricultural implement?

Key Terms

Aeration	**Additive**	**Asperities**
Barrel	**Cam ring**	**Chemical stability**
Demulsifier	**Electro-hydraulic system**	**Emulsify**
Friction	**Gear pump**	**Hydrostatic**
Hydrostatic drive	**International Standards Organization (ISO) viscosity grade**	**Oxidation**
Piston pump	**Piston shoes**	**Pour point**
Rotor	**Safety Data Sheet (SDS)**	**Shear force**

Solenoid	**Specific gravity**	**Swashplate**
Vane pump	**Viscosity**	**Viscosity index**
Zero-energy state		

Day-to-Day Plans
Time: 14 days

*Refer to the Teacher Resources section for specific information on teaching this lesson, in particular **Lesson 6.2 Teacher Notes**, **Lesson 6.2 Glossary**, **Lesson 6.2 Materials**, and other support documents.*

Day 1:

- Present **Concepts**, **Performance Objectives**, **Essential Questions**, and **Key Terms** to provide a lesson overview.
- Provide students **Presentation Notes** pages to be used throughout the presentation to record notes and reflections. Students add these pages to their *Agriscience Notebook*.
- Present LunchBox Session© **Fluid Basics Part 1**.
- Provide students with a copy of **Activity 6.2.1 Properties and Precautions**.
- Students work in pairs to complete Part One of *Activity 6.2.1 Properties and Precautions*.

Day 2:

- Present LunchBox Session© **Fluid Basics Part 2**.
- Students take notes using the *Presentation Notes* pages provided by the teacher.
- Students work in pairs to complete *Activity 6.2.1 Properties and Precautions*.

Day 3:

- Present LunchBox Session© **Fluid Power Safety**.
- Students take notes using the *Presentation Notes* pages provided by the teacher.
- Provide students with a copy of **Activity 6.2.2 Hydraulic Safety**.
- Students work in pairs to complete Part One of *Activity 6.2.2 Hydraulic Safety.*

Day 4:

- Students work in pairs to complete *Activity 6.2.2 Hydraulic Safety.*

Day 5:

- Provide students with a copy of **Activity 6.2.3 Pump Up the Volume**.
- Present LunchBox Session© **Introduction to Gear Pumps**.
- Students will work in pairs to complete Part One of *Activity 6.2.3 Pump Up the Volume*.

Day 6:

- Present LunchBox Sessions© **Introduction to Vane Pumps** and **Introduction to Piston Pumps**.
- Students diagram and label pump components in their *Logbooks*.
- Students work in pairs to complete Part Two of *Activity 6.2.3 Pump Up the Volume.*

Day 7:

- Students work in pairs to complete *Activity 6.2.3 Pump Up the Volume.*

Day 8:

- Provide students with a copy of **Activity 6.2.4 Electrical Controls**.
- Students work in pairs to complete *Activity 6.2.4 Electrical Controls*.

Day 9 – 11:

- Present LunchBox Session© **Hydrostatic Systems**.
- Provide students *Presentation Notes* pages to use throughout the presentation to record notes and reflections. Students add these pages to their *Agriscience Notebook*.
- Provide students with a copy of **Project 6.2.5 Electro-Hydraulics** and **Project 6.2.5 Evaluation Rubric**.
- Students work in pairs to complete *Activity 6.2.5 Electro-Hydraulics*.
- Use *Project 6.2.5 Evaluation Rubric* to assess *Project 6.2.5 Electro-Hydraulics*.

Day 12 – 13:

- Present LunchBox Session© **Hydraulic Steering**.
- Provide students with a copy of **Activity 6.2.6 Fluid Equipment** and two copies of the **Activity 6.2.6 Fluid Inspection Checksheet**.
- Students will work in pairs to complete *Activity 6.2.6 Fluid Equipment*.

Day 14:

- Distribute **Lesson 6.2 Check for Understanding**.
- Students will complete *Lesson 6.2 Check for Understanding* and submit it for evaluation.
- Use **Lesson 6.2 Check for Understanding Key** to evaluate student assessments.

Instructional Resources

LunchBox Sessions©

Fluid Basics Part 1

Fluid Basics Part 2

Fluid Power Safety

Introduction to Gear Pumps

Introduction to Vane Pumps

Introduction to Piston Pumps

Hydrostatic Systems

Hydraulic Steering

Student Support Documents

Lesson 6.2 Glossary

Presentation Notes

Activity 6.2.1 Properties and Precautions

Activity 6.2.2 Hydraulic Safety

Activity 6.2.3 Pump Up the Volume

Activity 6.2.4 Electrical Controls

Project 6.2.5 Electro-Hydraulic

Activity 6.2.6 Fluid Equipment

Activity 6.2.6 Fluid Inspection Sheet

Teacher Resources

Lesson 6.2 Hydraulic Systems and Safety PDF

Lesson 6.2 Teacher Notes

Lesson 6.2 Materials

Lesson 6.2 Check for Understanding

Answer Keys and Assessment Rubrics

Lesson 6.2 Check for Understanding Answer Key

Project 6.2.5 Evaluation Rubric

Student Project Development Template

Fluid Inspection Sheet

Reference Sources

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Dell, Timothy W. (2019). *Heavy Equipment Power Trains and System, 1st Edition.* Tinely Park, IL: The Goodheart-Willcox Company, Inc.

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LunchBox Sessions© (n.d.). *Fixed and variable displacement pumps*. **http://www.lunchboxsessions.com**

LunchBox Sessions© (n.d.). *Hydraulic steering*. **http://www.lunchboxsessions.com**

LunchBox Sessions© (n.d.). *Hydrostatic systems*. **http://www.lunchboxsessions.com**

FFA Connections

This lesson provides conceptual and procedural knowledge related to the following FFA awards, activities and educational resources.

- Agricultural Proficiency
  - **Agricultural Mechanics Repair and Maintenance –Placement**
  - **Agricultural Mechanics Repair and Maintenance –Entrepreneurship**
  - **Agriscience Research – Integrated Systems**
- Agriscience Fair
  - **Power, Structural and Technical Systems**
- Career Development Events
  - **Agricultural Technology & Mechanical Systems**
- Educational Resources
  - **SAE Idea Cards-Power, Structural and Technical Systems**
  - **Power, Structural and Technical System Careers**
  - **Power, Structural and Technical Systems Career Focus Area Resources**
  - Power, Structural and Technical Careers **(Word)**

Skills and knowledge from this lesson support the development and implementation of service-learning projects that address hydraulic systems and safety.

- **Service-Learning and Living to Serve Grants**
  - Service-learning projects focused on diagnosing hydraulic system issues in agricultural and other outdoor equipment.
  - Project ideas include hosting a spring tune-up or winterization event for local community members for lawnmowers and other equipment with hydraulic systems.

- Living to Serve Grants provide funding to FFA chapters to support service-learning and community service projects.

For more information, visit the **National FFA Organization** website.

SAE for All

Foundational SAE

All students in an agricultural education program are expected to have a Foundational SAE. Students completing the APP and extensions listed below will meet the Foundational SAE qualification for the *Advanced(Grades 11-12) level*. Students should place all documented evidence in the *FFA/SAE* section of their *Agriscience Notebook* along with the *SAE for All Foundational Checksheet*.

- Workplace Safety
  - Activity 6.2.1 Properties and Precautions
  - Activity 6.2.2 Hydraulic Safety

Immersion SAE

Students interested in this lesson's topics should explore the following related Immersion SAEs. An immersion SAE is optional and replaces the agricultural literacy component of the Foundational SAE.

- **Immersion SAE Learning Guides**

For more information on the guiding principles for implementing SAE programs, visit the **SAE for All: Evolving Essentials** site.

Critical Thinking and Application Extensions

Explanation

1. Students will develop a hydraulic safety demonstration to present at a farm safety day.

Application

2. Students will change the hydraulic fluid in a tractor.

CASE

Lesson 6.2 Teacher Notes

Lesson 6.2 Hydraulic Systems and Safety

In preparation for teaching this lesson, review Concepts, Performance Objectives, Essential Questions, and Key Terms, along with the PowerPoint® presentations. Also, review all activity and project directions, expectations, and work students complete.

Students start the lesson by learning how to work safely with hydraulic fluids and equipment. Then they construct model hydraulic pumps and compare how they each work. Next, students assemble model electro-hydraulic systems. Finally, to complete the lesson, students inspect and identify types of hydraulic systems on a tractor.

LunchBox Sessions©

Fluid Basics Part 1

Use the presentation to provide background knowledge about fluid viscosity.

Fluid Basics Part 2

Use the presentation to provide background knowledge about hydraulic fluid's makeup and physical characteristics.

Fluid Power Safety

Present and discuss hydraulic safety hazards during this presentation.

Introduction to Gear Pumps, **Introduction to Vane Pumps**, and **Introduction to Piston Pumps**

Use these presentations during *Activity 6.2.3 Pump Up the Volume* to introduce students to positive displacement pumps and their components.

Hydrostatic Systems

Use this presentation to introduce students to closed-loop hydrostatic systems. Students use the information from this presentation to design electrical controls operating a hydrostatic system.

Hydraulic Steering

This presentation provides graphical information about hydraulic steering and the valves used to direct fluid through the system.

Activities, Projects, and Problems

Activity 6.2.1 Properties and Precautions

Students work in pairs observing and collecting information about hydraulic fluids.

Teacher Preparation

Choose two fluids that vary in viscosity, such as a power steering and hydraulic fluid. Example fluids include **Chevron AW 68** and **Havoline Power Steering Fluid**. Print ten copies of the SDS and property sheets for each liquid. Pour a small amount of each fluid into 10 cups and label each with the fluid's name.

Student Performance

Part One

Student pairs acquire one cup of each fluid. Each student records information on the student observation sheet. Then they share their results with their partner and answer analysis questions.

Part Two

Students observe how hot and cold temperatures impact the fluids by placing them in hot and cold water. Once the fluid temperature changes, students pour it through a syringe to see how quickly it flows. Students graph the time it takes for each fluid to flow out of the syringe to compare the viscosity index of each.

Results and Evaluation

Students place their observation sheets in the *Safety* section of their *Agriscience Notebook*. Example answers to analysis questions are in Table 1.

Table 1. ***Analysis Questions and Potential Responses***

Part One		
Q1	Which product will float more easily on water?	*The hydraulic fluid with a lower density.*
Q2	What is the lowest temperature at which you can use each product?	*Hydraulic fluid – Pour Point = -22 + 18 = -4 F* *Power steering fluid – Pour Point = -48 +18 = -30F*
Q3	Which fluid's viscosity will vary more with a temperature change?	*Hydraulic fluid – Viscosity Index = 99* *Power steering fluid – Viscosity Index = 155*
Q4	Which fluid has a higher viscosity at room temperature?	*Hydraulic fluid – Viscosity = 64.6* *Power steering fluid – Viscosity = 41*
Part Two		
Q5	According to your graph, which fluid has a lower viscosity index?	*Answers will vary based on collected data. Most likely the hydraulic fluid.*
Q6	Which fluid has a lower viscosity?	*Answers will vary based on observations. Most likely, the power steering fluid.*
Q7	Could the fluid with lower viscosity have a higher viscosity index? Why?	*Yes, because it could have a stable viscosity.*
Q8	What was the relationship between the viscosity, sealability, and aeration of the two fluids?	*The more viscous fluid sealed better and did not foam as much when aerated.*

Activity 6.2.2 Hydraulic Safety

Students practice safely shutting down a virtual hydraulic system and inspecting hydraulic systems for safety hazards.

Teacher Preparation

Students need access to the Amatrol® hydraulic simulator. You also need equipment with two hydraulic systems for students to inspect. An example would be a tractor with a hydraulic loader and hydrostatic transmission.

Student Performance

Part One

Students work in pairs to set up and shut down a virtual system with multiple pressure gauges in place. The students observe the pressure gauges to see where pressure remains in the system after power has been shut off. Students then place the system in a zero-energy state and answer analysis questions.

Part Two

Students individually record potential safety concerns on the student observation sheet. The safety inspection includes the inspection of hoses, actions, and motions. They complete the inspection by documenting the process for placing the equipment in a zero-energy state.

Results and Evaluation

Students should place their observation sheets in the *Safety* section of their *Agriscience Notebook*. Example answers to analysis questions are in Table 2.

Table 2. *Analysis Questions and Potential Responses*

Q1	Where did fluid pressure remain after you reduced the pressure relief valve to zero?	*Pressure remained in the hydraulic cylinder, and hoses connected to the cylinder.*
Q2	Why is it important to move directional valves after turning off the system?	*To relieve the pressure in the cylinder and connected hoses.*

Activity 6.2.3 Pump Up the Volume

Students observe and construct models of positive displacement pumps.

Teacher Preparation

You need access to the LunchBox Sessions© to present to students throughout this activity. Have craft materials listed below for students to construct their model pumps. Students may require additional materials depending on their designs.

- Wooden dowels
- Tagboard
- Cups of various sizes
- Hot glue gun
- Paper plates
- Glue sticks
- Scissors

Student Performance

Part One

Present *LunchBox Session© Introduction to Gear Pumps* to students. Students then sketch an example of a gear pump in their Logbook and label components. Next, students mark the area on the sketch where they believe wear will occur in the pump.

Students work in pairs to assemble a fixed displacement pump with a variable resistor. They then change the pump's displacement by adjusting the variable resistor, which changes the pump's rpm. Next, students answer analysis questions.

Part Two

Students observe *LunchBox Session© Introduction to Vane Pumps* and *Introduction to Piston Pumps.* After each presentation, they sketch and identify components and wear locations on the pump. Students are assigned a partner to construct a vane or piston pump model.

Part Three

Student pairs work with another pair, so their group of four has a model of a piston pump and a vane pump. Then they calculate the displacement of each pump at different settings. The cam ring changes for the vane pump, and the swashplate changes for the piston pump. After students complete the calculations, they answer analysis questions.

Results and Evaluation

Use example data calculations and answers to analysis questions to assess student understanding.

Table 3. *Variable Displacement Calculations*

Cam Ring Position	Vane Volume	Total Volume per Rotation	RPM	Flow Rate ml/min
Closest to Output	**10 ml**	**60 ml**	**100**	**6000 ml/min**
Center	**20 ml**	**120 ml**	**100**	**12,000 ml/min**
Closest to Input	**30 ml**	**180 ml**	**100**	**18,000 ml/min**
Swashplate Position	**Piston Volume**	**Total Volume per Rotation**	**RPM**	**Flow Rate ml/min**

	5 ml	**30 ml**	**100**	**3000 ml/min**
Center	10 ml	**60 ml**	**100**	**6000 ml/min**
	20 ml	**120 ml**	**100**	**12,000 ml/min**

Table 4. ***Analysis Questions and Potential Responses***

Part One		
Q1	How can you change the flow rate in a fixed displacement pump?	*Change the flow rate by changing the pump rpm.*
Q2	Why would reducing or increasing the pump's rpm not be possible on some equipment with hydraulic systems?	*The pump is directly connected to a power device with a constant rpm.*
Part Two		
Q3	What is the flow range for this simulated vane pump?	*6000 – 12000 ml/min*
Q4	How is a piston pump different than a vane pump?	*Piston pumps have pistons that adjust fluid displacement, and vane pumps vary by changing the vanes' size.*
Q5	Why are variable pumps beneficial in equipment operating at a lower engine speed?	*The rpm of the engine does not impact the flow of the pump.*

Activity 6.2.4 Electrical Controls

Students wire, operate, and troubleshoot an electro-hydraulic system using a solenoid, switch, and relay.

Teacher Preparation

Review all electrical schematics before starting the activity, so you can help students assemble and test the components. Then, if needed, review using a digital multimeter with students, or instruct them to review activities and projects from Lesson 4.2.

Student Performance

Part One

Students assemble a battery and switch to activate a hydraulic solenoid. They operate the solenoid with the switch while recording observations. Students complete Part One by identifying the cause and correction for multiple scenarios where an electro-hydraulic system with solenoid fails.

Part Two

Students assemble a battery, relay, and switch to activate a hydraulic solenoid. Next, they operate the solenoid with the switch while recording observations. Finally, students complete Part Two by identifying the cause and correction for multiple scenarios where an electro-hydraulic system with a relay and solenoid fails.

Results and Evaluation

Answers to observations will vary based on the students' solenoid and relay. Table 5 includes example answers to analysis questions. Use Table 6 to assist students in identifying the cause and correction for each scenario.

Table 5. ***Analysis Questions and Potential Responses***

Q1	How can you use a DMM to determine if a solenoid is working correctly?	*By measuring the voltage when the switch is on and continuity of the solenoid when the switch is off.*
Q2	How can you use a DMM to identify a broken relay?	*A technician can use the DMM to check the voltage and continuity of the relay.*

Table 6. ***Cause and Corrections***

Solenoid		
Scenario	**Cause**	**Correction**
1	*The valve is stuck.*	*Clean or replace the valve.*

2	*The solenoid is broken and stuck in the open position.*	*Replace the solenoid on the valve.*
3	*The switch is broken and stuck in the closed position*	*Replace the electrical switch.*
4	*The switch is broken and stuck in the open position.*	*Replace the electrical switch.*
Relay		
Scenario	**Cause**	**Correction**
1	*The valve is stuck.*	*Clean or replace the valve.*
2	*The solenoid is broken and stuck in the open position.*	*Replace the solenoid on the valve.*
3	*The relay is broken and stuck in the closed position.*	*Replace the electrical relay.*
4	*The relay and/or switch are broken and stuck in the open position.*	*Replace the electrical relay and/or switch.*

Project 6.2.5 Electro-Hydraulics

Students use what they have learned about electrical circuits and hydraulics to design an electro-hydraulic system.

Teacher Preparation

Present *LunchBox Session© Hydrostatic Systems* before starting this project. Students use their knowledge from past activities and projects. Students should review Project 4.2.2 Directional Control and Activity 6.1.3 Positively Pumping if needed. In addition, have the following materials available for students to access during this project.

- Plastic containers
- Pumps
- Wire leads (red and black)
- 1 ft sections of 1/8" I.D. vinyl hose
- 9-volt batteries
- 10 ml syringes
- Couplers 1/8″ O.D.
- Tees 1/8″ O.D.
- Battery, 12V
- LED bulbs
- Normally Closed relays
- Potentiometer
- Switch, SPST

Student Performance

Students design and construct an electro-hydraulic system that meets the following criteria.

- The system is neat and orderly, with no loose wires, hoses, or leaks.
- The pump directs fluid through a flow sensor simulating a hydraulic motor in a closed-loop system.
- The system voltage is 12V with relays controlling the system.
- The system uses a positive fixed displacement pump.
- A potentiometer controls volume displacement by changing the amperage.

Results and Evaluation

Students submit their schematics and system for you to evaluate with **Project 6.2.5 Evaluation Rubric.**

Activity 6.2.6 Fluid Equipment

Students identify and inspect hydraulic systems found on a tractor.

Teacher Preparation

Present *LunchBox Session©* *Hydraulic Steering* before starting this activity. Have a tractor with multiple hydraulic systems for students to inspect and identify. Each student pair needs a copy of the maintenance manual for the tractor and a **Fluid Inspection Sheet.**

Student Performance
Students start the activity using a maintenance manual and visual observations to identify the hydraulic systems found on a tractor. Then they select two systems to inspect in detail. Students work in pairs to record fluid and system safety information on the *Fluid Inspection Sheet*.

Results and Evaluation
Review each system with the class at the end of the activity. Students place their *Fluid Inspection Sheets* in the *Safety* section of their *Agriscience Notebook*.

Assessment

Lesson 6.2 Check for Understanding

Lesson 6.2 Check for Understanding is included for you to use as an assessment tool for this lesson. Use **Lesson 6.2 Check for Understanding Answer Key** for evaluation purposes.

Name____

CASE

Activity 6.2.1 Properties and Precautions

Purpose

Hydraulic systems require fluid for lubricant, cooling, sealing, and pressure. What are the physical properties of hydraulic fluids, and how do you safely work with them?

All fluids have an International Standards Operation (ISO) viscosity grade, a fluid's resistance to flow. Fluids are composed of many flowing molecules. As the molecules flow, they put shear force on each other. Fluids with high viscosity have a high resistance to shear force and flow slowly. Fluids with low viscosity have a low resistance to shear force and flow quickly. Temperature influences viscosity. A fluid's change in viscosity at different temperatures is called a viscosity index. The higher the index number, the less the fluid's viscosity is affected by temperature.

A technician should also know a hydraulic fluids' specific gravity and pour point. The specific gravity is the weight of the fluid as compared to water. Any fluid with a specific gravity of less than one will float on top of the water because it has lower specific gravity than water. The pour point is the coldest temperature at which you can still pour the fluid. A technician should only use a fluid in a system if its coldest temperature is 18 degrees Fahrenheit higher than the pour point.

Hydraulic fluids must also lubricate, reduce heat, and provide a seal in a system. Hydraulic fluid lubricates all internal components to reduce wear and heat buildup due to friction. Hydraulic fluid coats the microscopic spikes and pits in the metal, called asperities, to reduce friction. Since friction will occur in a hydraulic system, the fluid needs cooling properties to transfer heat out of the system. Viscosity also becomes essential as a fluid sealant to prevent leaks between internal components.

Chemical stability is another important property of a fluid. Chemically stable fluids will not mix with air or water. Fluids that mix with air and water will reduce pressure in a system and cause parts to oxidize. Additives, known as emulsifying agents, prevent fluids from mixing with water.

Manufacturers of chemical materials provide their customers with Safety Data Sheets (SDS). Safety Data Sheets contain the proper procedures for workers and emergency personnel to handle a substance. Technicians working with hydraulic fluids need fluid information, including physical data, health effects, first aid, storage, disposal, required protective equipment, and spill procedures. In addition, all chemicals also have a property description sheet describing the purpose of the fluid, how it functions, and when to use it. Organizations store SDS and property description sheets in easily accessible workshop areas.

How can you use SDS and fluid properties to select the proper hydraulic fluid?

Materials

Per pair of students:

- (2) Beakers, 600ml
- (2) Cup filled with hydraulic fluid
- Device with timer
- Lab tape
- Permanent marker
- (2) Syringes, 60ml
- (4) Test tubes

Per student:

- *Agriscience Notebook*
- Device with internet access
- Nitrile gloves
- Pen
- Safety glasses
- SDS and property sheet

Per class:

- Ice
- Water

Procedure

Work with a partner to find and compare the SDS information for two hydraulic fluids. Then compare the two fluids' physical properties.

Part One – Safety and Property Data

1. Put on safety glasses and nitrile gloves, and tie back long hair.
2. Acquire two plastic cups of hydraulic fluid from your teacher. Each cup has the name of the fluid printed on it.
3. Acquire the SDS and property sheets for each fluid from your teacher.
4. Assign one fluid to yourself and the other to your partner.
5. Complete Table 1 on *Activity 6.2.1 Student Observation* for your assigned fluid.
6. Work with your partner to answer *Part One Analysis Questions* while comparing the fluids.

Part Two – Property Observations

1. Record the names of each hydraulic fluid in Table 2.
2. Fill one 600ml beaker with cold water and a handful of ice cubes.
3. Fill one 600ml beaker with hot water.
4. Use a permanent marker and laboratory tape to record the name of *Fluid 1* on two test tubes.
5. Fill the two test tubes half-full with *Fluid 1*.
6. Place one test tube in the cold beaker and one in the warm beaker.
7. Repeat Steps 5–7 for *Fluid 2*.
8. Leave fluids in the beakers for five minutes to cool down or warm up.
9. Use a 60ml syringe to aspirate the first hydraulic fluid by sucking in and dispensing 30ml of liquid three times into the cup.
10. Observe the fluid for physical changes and record them in Table 2.
11. Observe how well the fluid is sealed between the piston and cylinder and record it in the sealing properties row in Table 2.
12. Repeat Steps 10–12 for *Fluid 2* using a second syringe.
13. Remove the piston from the 60ml syringe you used for *Fluid 1*.
14. Hold the syringe cylinder over the original *Fluid 1* cup with the port facing downward.
15. Hold your finger over the port.
16. Pour 10ml from the warm *Fluid 1* test tube into the cylinder.
17. Remove your finger from the port and start the timer simultaneously.
18. Stop the timer once all fluid has flowed through the port.
19. Record the time in Table 2.
20. Repeat Steps 15–20 for the *Fluid 1* test tube in the cold beaker and room temperature fluid.
21. Repeat Steps 14–21 for *Fluid 2*.
22. Use a line graph to compare the time to temperature from Table 2.
    - Place the temperature on the X-axis and the time on the Y-axis.

23. Answer *Part Two Analysis Questions*.
24. Place a copy of the observation sheet in the *Safety* section of your *Agriscience Notebook*.

Conclusion

1. How does viscosity affect a hydraulic system?

2. Which fluid properties should a technician know when selecting a hydraulic fluid?

3. Why should a technician read the SDS information before working with a new fluid?

4. What is the relationship between ISO grade and pour point fluid specifications?

Name____

Activity 6.2.1 Student Observations

Table 1. ***SDS Review Form***

SDS Form 1	Observations
Name of Material	
Use(s) of Material	
First Aid Measures	
Eye Contact	
Skin Contact	
Inhalation	
Ingestion	
Fire and Explosion Hazards	
Product Flammability	
Fire Fighting Media	
Precautions for Safe Handling and Use	
Handling a Spill	
Handling and Storage Precautions	
Personal Protective Equipment Needed	
Physical and Chemical Properties	
Physical State and Appearance	
Specific Gravity	
ISO Grade	
Viscosity	
Viscosity Index	
Anti-wear Additives	
Emulsifying Additives	
Pour Point	

Part One Analysis Questions

Q1 Which product will float more easily on water?

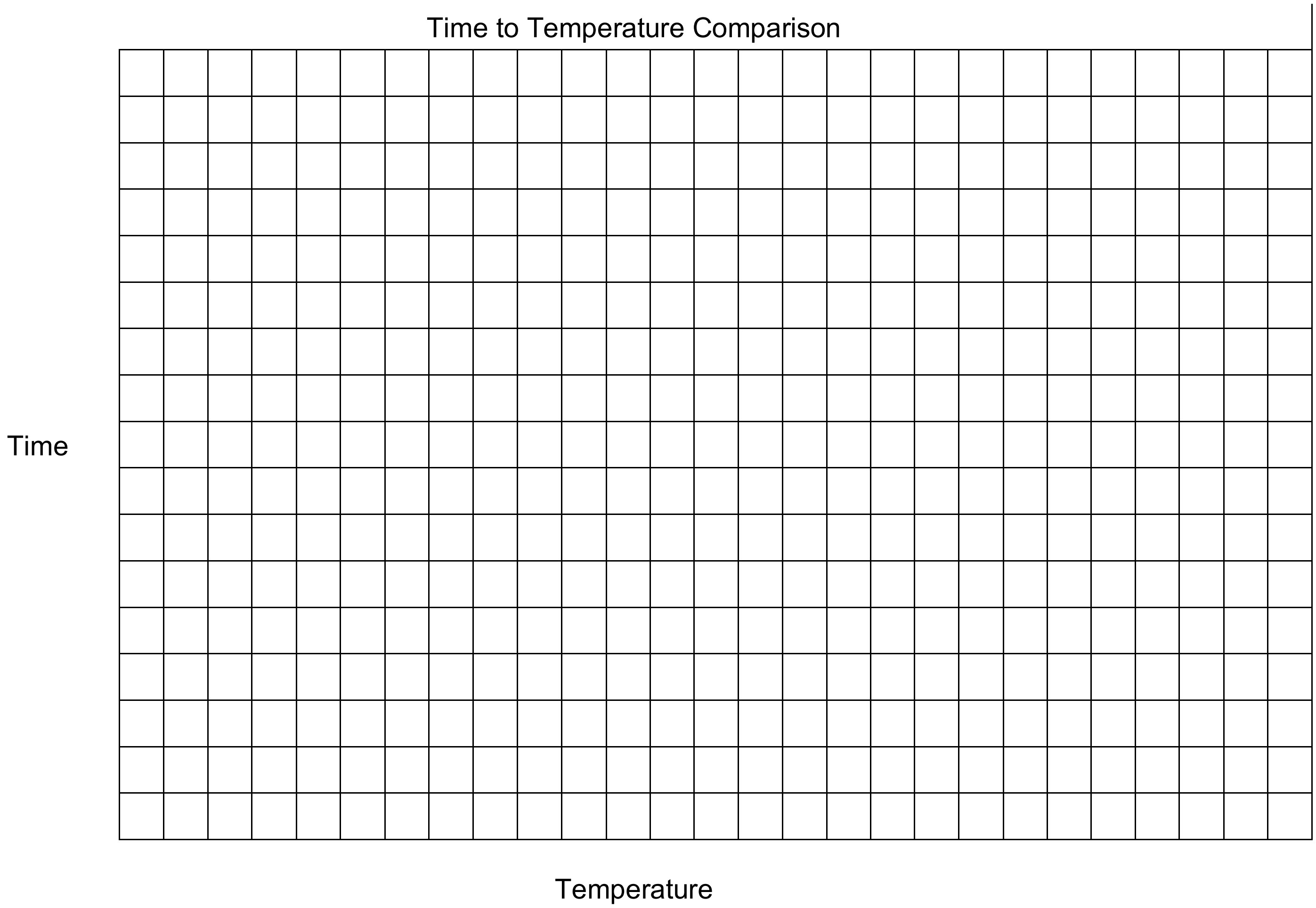
Q2 What is the lowest temperature at which you can use each product?

Q3 Which fluid's viscosity will vary more with a temperature change?

Q4 Which fluid has a higher viscosity at room temperature?

Table 2. ***Property Observations***

Fluid Number	#1	#2
Fluid Name		
Aeration Properties		
Sealing Properties		
Flow time at room temperature		
Flow time at a warm temperature		
Flow time at a cold temperature		



Part Two Analysis Questions

Q5 According to your graph, which fluid has a lower viscosity index?

Q6 Which fluid has a lower viscosity?

Q7 Could the fluid with lower viscosity have a higher viscosity index? Why?

Q8 What was the relationship between the viscosity, sealability, and aeration of the two fluids?

Name____ CASE

Activity 6.2.2 Hydraulic Safety

Purpose

Hydraulic systems pose safety hazards that a technician cannot directly view. So, what does a technician need to be aware of when working with hydraulic equipment?

Fluid moving through conductors produces friction between the fluid and the conductor's internal surface. Friction causes the fluid and hydraulic components to become hot enough to cause burns. Therefore, technicians should wear PPE such as insulated gloves when working with hot equipment or wait until the equipment has cooled down.

Hydraulic fluid creates extreme internal pressure in the system. This pressure can cause hoses and fittings to fail. In addition, hydraulic fluid exiting a system at high pressure can puncture the skin. Also, fluid leaking or spraying from the system can be flammable, causing a fire hazard. A technician should inspect all hoses and fittings to reduce the chance of hose or fitting failures.

Besides the hazards caused by friction and pressure, hydraulic systems produce the same actions and motions you observed in power trains. Technicians must be aware of all actions and motions, and all guards must be in place to prevent injury.

Technicians place hydraulic systems in a zero energy state before they maintain the equipment. A zero energy state means the equipment is in a resting position, has had all power turned off, and has no pressure in the system. To do this, a technician will take *Steps to Zero Energy State*.

Steps to Zero Energy State

- Lower hydraulic cylinders to resting positions.
- Turn off the engine or electric power supply.
- Open bleed-down valves, if available.
- Move directional handles back and forth to dissipate pressure.
- Confirm all gauges read zero.

What safety hazards should a technician look for after placing a hydraulic system in a zero energy state?

Materials

Per class:

- Agricultural implement

Per student:

- Pen
- Safety glasses
- Amatrol® hydraulic simulator
- *Agriscience Notebook*
- *Logbook*

Procedure

Practice proper setup and shutdown of a virtual hydraulic system. Then practice finding hydraulic safety hazards on an agricultural implement.

Part One – Start-Up and Shut-Down

1. Log in to the Amatrol© LMS and select **eLearning courses**.

2. Select **Amatrol-Main Library, Fluid Power,** and choose **Basic Hydraulics**.
3. **Launch** *Hydraulic Power Systems.*
4. Select **Skill 3** to open the hydraulic simulator on your computer.
5. Assemble a 4/3 DCV and hydraulic cylinder with three pressure gauges, as seen in Figure 1.

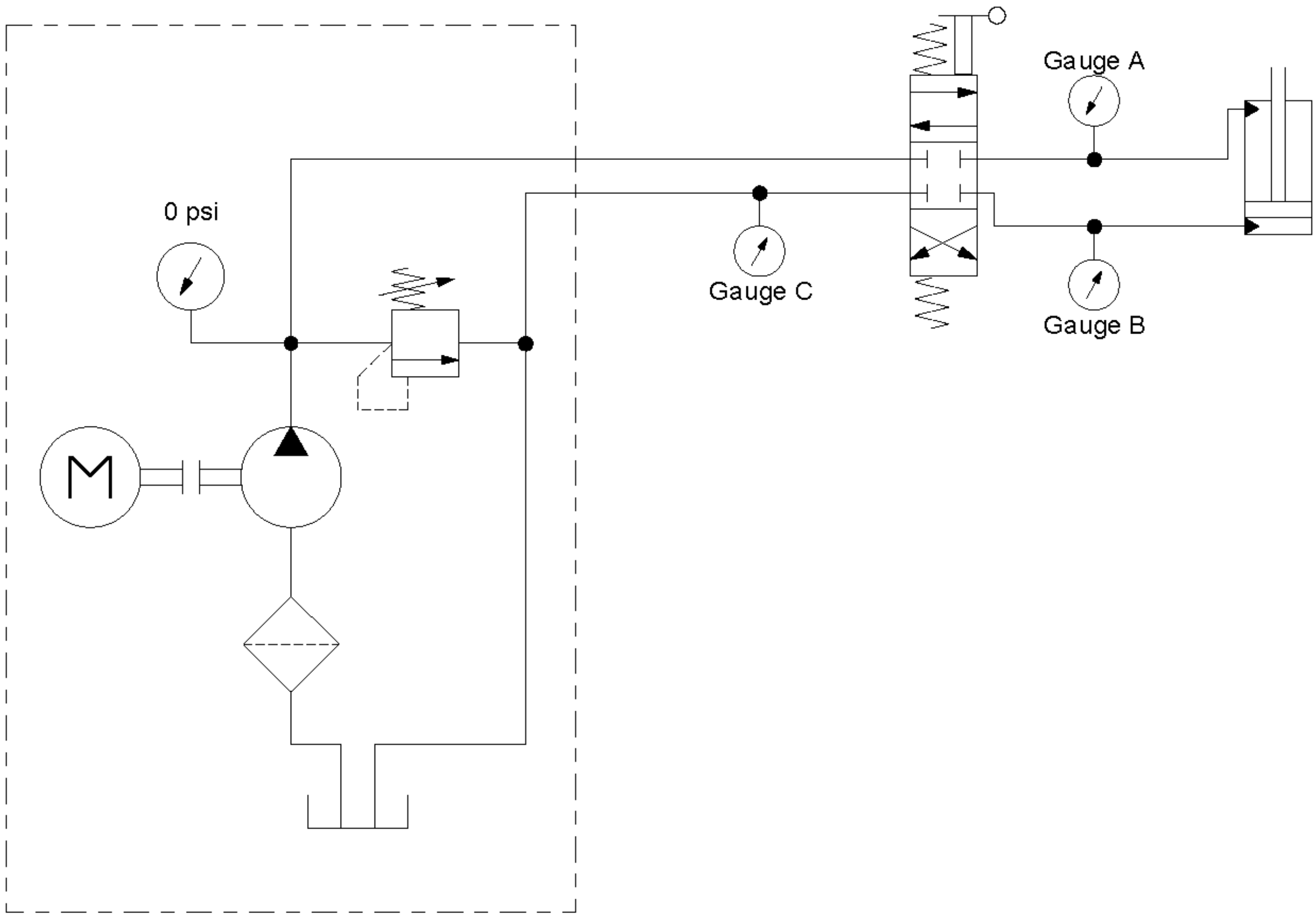


Figure 1. Three Gauge Schematic

6. Record the temperature and system pressures in the *Off* row of Table 1 on *Activity 6.2.2 Student Observation*.
7. Turn on the system.
8. Adjust the pressure relief valve to 200 psi.
9. Open the shutoff valve.
10. Record the temperature and system pressures in the *Running* row of Table 1.
11. Operate the actuator in the system by moving the handle of the DCV.
12. Fully extend and retract the cylinder three times.
13. Record the temperature and system pressures in the operation row of Table 1.
14. Take system to zero energy state.
    - Lower cylinder to simulate a resting position.
    - Adjust the pressure relief valve to zero.
    - Close the shutoff valve.
    - Turn off the motor.

15. Record the temperature pressures in the system in the *Off (before moving the DCV lever)* row.
16. Move directional handles back and forth to dissipate any pressure. Confirm that all gauges read zero.
17. Record the temperature and pressures in the system in the *Off (after moving the DCV lever)* row.
18. Answer *Part One Analysis Questions*.

Part Two – Equipment Inspection

1. Record the two hydraulic systems assigned by your teacher to inspect.
2. Put on your safety glasses and go to the shop with your teacher to inspect an implement with your assigned systems.
3. Inspect each system's hoses, fittings, and connections on the implement. Record your findings in Table 2.
4. Inspect each system for potential hazardous actions or motions and record them in Table 3.
    - Place a checkmark by each hazard or motion you observe.
    - Record the location of the action/motion and any guard in place to prevent injury.
5. In Table 4, record the steps you believe should be used to place each system in a zero energy state.
6. Review your safety inspection and zero-state instructions with your teacher.
7. Make any additions or corrections to your inspection sheet.
8. Place your observations sheet in the *Safety* section of your *Agriscience Notebook*.

Conclusion

1. Why are hydraulic leaks a safety concern?

2. How can pressure be in a hydraulic system that has no power?

3. What are the safety hazards associated with a hydraulic hose fitting failure?

Name____

Activity 6.2.2 Student Observations

Table 1. ***Hydraulic Trainer Observations***

State of System	Temperature	Relief Valve Pressure	Gauge A Pressure	Gauge B Pressure	Gauge C Pressure
Off					
Running					
Operation					
Off (Before moving DCV Lever)					
Off (After moving DCV Lever)					

Part One Analysis Questions

Q1 Where did fluid pressure remain after you reduced the pressure relief valve to zero?

Q2 Why is it important to move directional valves after turning off the system?

Table 2. ***Hose and Fitting Inspection***

System:			
Hose and Fitting Defects	**Location**	**Hazard/Safety Concerns**	**Correction**
Cracked			
Poorly fitted			
Leaky			
Bent or kinked			
System:			
Hose and Fitting Defects	**Location**	**Hazard/Safety Concerns**	**Correction**
Cracked			
Poorly fitted			
Leaky			
Bent or kinked			

Table 3. ***Action and Motion Observation***

Place a check by any motions or actions that are potential hazards for each hydraulic system. Record the location and the potential accident that could occur.

System	System 1:			System 2:		
Action or Motion		**Location**	**Potential Accident**		**Location**	**Potential Accident**
Rotating	☐			☐		
In-Running Nip Points	☐			☐		
Reciprocating	☐			☐		
Transversing	☐			☐		
Cutting	☐			☐		
Punching	☐			☐		
Shearing	☐			☐		
Bending	☐			☐		

Table 4. ***Zero Energy State Operation Instructions***

System 1	System 2

Name____

CASE

Activity 6.2.3 Pump Up the Volume

Purpose

All hydraulic systems require pumps to move the fluid through the system. Pumps vary in size, shape, and design. As a technician, you need to understand pump design and functionality to determine when a pump needs maintenance and repair. What are the various types of pumps found in hydraulic systems?

During *Lesson 6.1 Hydraulic Principles*, you used a positive fixed displacement pump. Fixed displacement pumps provide a constant flow rate that cannot change without increasing the pump's rpm speed. The engine controls the rpm on pumps found on mobile equipment. As the engine speed increases, so does the speed of the pump. If the pump's rpm is directly related to the engine speed, the operator will need to increase engine speed to increase hydraulic flow.

Some hydraulic systems require a varied flow without increasing rpm, such as a hydrostatic transmission. Hydrostatic transmissions are hydraulic systems controlling the travel speed of mobile equipment. For example, an operator can use a hydrostatic transmission to increase or decrease tractor travel speed without increasing or decreasing its engine speed. Hydrostatic transmissions with a variable displacement pump eliminate the direct correlation of pump rpm and flow.

Variable-displacement pumps have internal components adjusting the fluid volume displaced with each pump revolution. Vane and piston pumps are two standard variable-displacement pumps found in agricultural equipment.

How do variable and fixed displacement components differ in function and required maintenance?

Materials

Per pair of students:

- Battery, 9V
- Plastic container, 10 oz
- (2) Plastic tubing, 1′ x $^{1}/_{8}$″ I.D.
- Positive displacement pump, 12V
- Potentiometer, 10KΩ
- Switch, single-pole, single-throw
- Syringe, 20ml
- (3) Wire with alligator clips, black
- Wire with alligator clips, red

Per student:

- *Agriscience Notebook*
- *Logbook*
- Pen
- Red pen
- Safety glasses

Per group of students:

- Cups, 12 oz
- Cups of various sizes
- Device with timer
- Graduated cylinder, 100ml
- Hot glue gun
- Hot glue sticks
- Paper plates
- Permanent marker
- Poster board
- Scissors
- (6) Syringes, 20ml
- Wooden dowels, 12″ x $^{3}/_{4}$″ diameter

Procedure

Compare how fixed and variable displacement pumps change flow in a system by constructing a model and calculating displaced volumes.

Part One – Fixed Displacement

1. View the *LunchBox Session© Introduction to Gear Pumps* presented by your teacher.
2. Sketch an external gear pump in your *Logbook* and label the following.
    - Inlet
    - Outlet
    - Drive Gear
    - Driven Gear
3. Highlight where the fluid will be under high pressure in the pump.
4. Use a red pen to mark the areas of the pump that will wear.
5. Fill a plastic container with water.
6. Attach a hose to the inlet side of the pump and place it in the plastic container.
7. Use a hose to attach the pump to a 20ml syringe with no piston.
8. Review the schematic in Figure 1 to assemble the battery, switch, and potentiometer to the pump. Be sure the switch is in the off position.

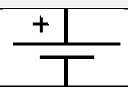
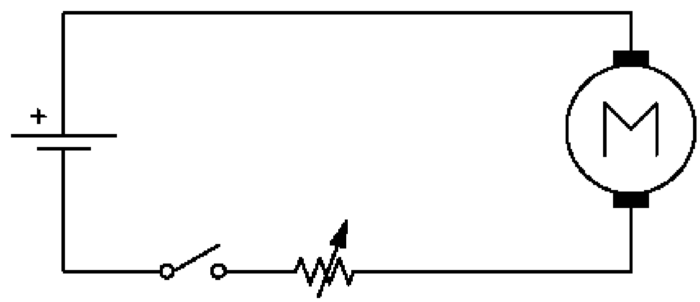
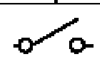
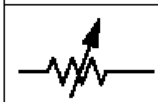
Key		Pump Schematic
	9V Battery	
	Switch	
	Potentiometer	
	Motor with Pump	

Figure 1. Electrical Schematic

9. Set the resistance at the lowest setting.
10. Turn on the system until the water reaches the syringe, and then shut it off.
11. Turn on the pump and start the timer.
12. Stop the timer when the syringe fills to 20ml.
13. Record the time to fill in Table 1 of *Activity 6.2.3 Student Data Sheet* .
14. Pour the water in the syringe back into the plastic container.
15. Find the flow rate in ml/sec by dividing the volume by the time.
16. Record the flow rate in Table 1.
17. Repeat Steps 10–16 at two other resistance levels.
18. Answer *Part One Analysis Questions*.

Part Two – Model Pumps

Vane Pump

1. View the *LunchBox Session© Introduction to Vane Pumps* presented by your teacher.
2. Sketch a vane pump in your *Logbook* and label the following parts.
   - Inlet
   - Outlet
   - Vanes
   - Cam Ring
   - Rotor
3. Highlight where the fluid will be under high pressure in the pump.
4. Use a red pen to mark the areas of the pump that will wear.

Piston Pump

5. View the *LunchBox Session© Introduction to Piston Pumps* presented by your teacher.
6. Sketch a piston pump in your *Logbook* and label the following parts.
   - Inlet
   - Outlet
   - Piston
   - Yoke
   - Swashplate
   - Barrel
   - Piston shoes
   - Rotor
7. Highlight where the fluid will be under high pressure in the pump.
8. Use a red pen to mark the areas of the pump that will wear.
9. Your teacher will assign you a vane or piston pump.
10. Use the materials listed under *per gourp of students* to construct a variable displacement vane pump or piston pump model with a high, medium, and low setting. The vane pump should have six vanes, and the piston pump should have six pistons. The models do not need to move water.

Part Three – Pump Calculations

Vane Pump Volume

1. Use a permanent marker to draw and label three lines on the plastic cup, one low, one medium, and one high.
2. Fill the cup to the first line with water to represent the lowest flow setting each vane displaces in the pump.
3. Set your group's model to the lowest setting.
4. In Table 2, describe the position of the cam ring in the pump.
5. Pour the volume into a graduated cylinder to measure the volume. Record the volume in Table 2 as the volume a single vane displaces.
6. Record the total volume displaced for each rotation if there are six vanes.
7. Calculate the volume dispersed each minute at a constant 100 rpm speed. Record the volumes in Table 2.
8. Repeat Steps 2–7 for the medium and high settings.

Piston Pump Volume

9. Fill the syringe to the 5ml line with water to represent the system's lowest flow setting.
10. Set the swashplate on the model pump to the lowest setting.
11. In Table 3, describe the position of the pump's swashplate.

12. Record the total volume displaced for each rotation if there are six pistons in the pump (multiply the volume of one piston by six).
13. Assuming the *Piston Volume* in Table 3 exiting the pump for each rotation, calculate the volume dispersed each minute at a constant 100 rpm speed.
14. Record the volumes in Table 3.
15. Repeat Steps 9–13 for the 10ml (medium) and 20ml (high settings).
16. Answer *Part Three Analysis Questions*.

Conclusion

1. How does a hydrostatic transmission with a piston pump increase the speed of a hydraulic motor?

2. What is the advantage of using a variable displacement pump in a hydrostatic transmission?

3. What component of a variable vane pump should a technician inspect if the operator cannot speed up or slow down a tractor's speed with a hydrostatic transmission?

Name____

Activity 6.2.3 Student Data

Table 1. ***Fixed Displacement Calculations***

Resistance	Motor Speed	Volume	Time	Flow Rate ml/sec
Low	Slow	20 ml		
Medium	Medium	20 ml		
High	Fast	20 ml		

Part One Analysis Questions

Q1 How can you change the flow rate in a fixed displacement?

Q2 Why would reducing or increasing the pump's rpm not be possible on some equipment with hydraulic systems?

Table 2. ***Variable Vane Displacement Calculations***

Cam Ring Position	Vane Volume	Total Volume per Rotation	RPM	Flow Rate ml/min

Table 3. ***Variable Vane Displacement Calculations***

Swashplate Position	Piston Volume	Total Volume per Rotation	RPM	Flow Rate ml/min
	5ml			
	10ml			
	20ml			

Part Three Analysis Questions

Q3 What is the flow range for this simulated vane pump?

Q4 How is a piston pump different than a vane pump?

Q5 Why are variable pumps beneficial in equipment operating at a lower engine speed?

Name____

CASE

Activity 6.2.4 Electrical Controls

Purpose

An operator in the cab of a tractor controls all systems. Most of those controls are not manual; electronic controls send signals to relays and solenoids, controlling hydraulic directional control valves. How are solenoids and relays used in an electro-hydraulic system?

Electro-hydraulic controls in a tractor cab are either a switch controlling the solenoid or activating a relay that controls the solenoid. A solenoid consists of a plunger with wire wrapped around it. When electrical current flows through the wire, it becomes magnetized. The magnetic field will then cause the plunger to move a poppet, blocking or allowing oil to flow into the valve. A switch, relay, or relay-switch combination directs electricity to the solenoid.

When equipment has an electro-hydraulic system, and an error occurs, a technician must determine whether the electrical or hydraulic component is the cause. Technicians use a digital multimeter (DMM) to test the system's electrical controls for voltage and resistance.

How are electrical controls wired to a solenoid? How can faulty electrical components in a hydraulic system be identified?

Materials

Per pair of students:

- Battery, 12V
- Battery, 9V
- Digital multimeter (DMM)
- Hydraulic solenoid valve
- Relay, single-pole, single-throw
- Switch, single-pole, single-throw
- (6) Wire with alligator clips

Per student:

- Pen
- Safety glasses
- *Agriscience Notebook*

Procedure

Use a switch and relay to operate a solenoid valve. Then apply your knowledge of hydraulics and electricity to identify the cause and correction of customer complaints. Record data and answers to analysis questions in your *Logbook*.

Part One – Solenoid Valve

1. Put on safety glasses and tie back long hair.
2. Inspect the solenoid valve and record the voltage, nmber of ports, number of positons, positon when power is on, positon when power is off in Table 3.
3. Wire the solenoid, switch, and battery using three wire leads, as seen in Figure 1. Be sure the switch is in the off position.

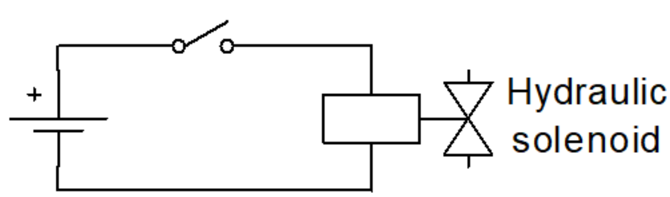


Figure 1. Solenoid Schematic

4. Turn the switch on and off, and listen for a click indicating the solenoid activating the valve.
    - Check the electrical connections if you hear no noise or see no light.
5. Use the DMM to measure the solenoid resistence and record in Table 3.
6. Answer *Part One Analysis Question*.
7. Review the scenarios in Table 1.

Each customer listed in Table 1 has the same complaint: *The hydraulic valve connected to the solenoid is not working correctly. The hydraulic valve should allow fluid flow when the switch is on and no flow when the switch is off.*

Table 1. *Solenoid and Switch Data*

Scenario	**Solenoid Resistance**	**Switch Resistance** switch is on	**Solenoid Voltage**		**Valve Position** switch is on	**Fluid Flow**
			Switch On	**Switch Off**		
1	24 ohms	0.3 ohms	12	0	Closed	No-flow
2	Infinite (OL)	0.3 ohms	12	0	Closed	No-flow
3	24 ohms	0.3 ohms	12	12	Open	Flow
4	24 ohms	Infinite (OL)	0	0	Closed	No-flow

8. Use each scenario's DMM readings and valve position to predict the cause and suggest a correction for each scenario.
9. Record the cause and correction in Table 4.

Part Two – Relay and Solenoid

1. Inspect the relay and complete Table 5.
2. Wire the solenoid, switch, relay, and battery, as seen in Figure 2.
    - Be sure the switch is in the off position.
3. Use the DMM to measure the voltage at the solenoid and the relay with the switch off.
4. Turn the switch on.
5. Use the DMM to measure the voltage at the solenoid and the relay.
6. Answer *Part Two Analysis Question*.
7. Review the scenarios in Table 2.

Each customer listed in Table 2 has the same complaint: *The hydraulic valve connected to the solenoid is not working correctly. The hydraulic valve should allow fluid flow when the switch is on and no flow when the switch is off.*

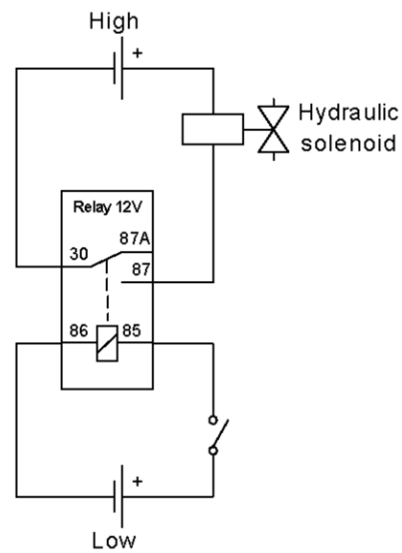


Figure 2. Relay Schematic

Table 2. *Solenoid and Relay Data*

Scenario	**Solenoid Resistance**	**Relay Voltage (Terminal 85 and 86)** switch is on	**Relay Voltage (Terminal 30 and 87)**		**Valve Position** switch is on	**Fluid Flow**
			Switch On	**Switch Off**		
1	24 ohms	12 Volts	12	0	Closed	No-flow
2	Infinite	12 Volts	12	0	Closed	No-flow
3	24 ohms	12 Volts	12	12	Open	Flow
4	24 ohms	0 Volts	0	0	Closed	No-flow

8. Use each scenario's DMM readings and valve position to predict the cause and suggest a correction.
9. Record the cause and correction in Table 6.

Conclusion

1. What are the advantages of using electricity to power hydraulic valves?

2. How do technicians troubleshoot electro-hydraulic systems?

3. How is a relay different from a solenoid?

Name____

Activity 6.2.4 Student Observations

Part One – Solenoid Valve

Table 3. ***Solenoid Observations***

Voltage	
Number of ports	
Number of positions	
Position when power is on	
Position when the power is off	
Solenoid resistance	

Part One Analysis Question

Q1 How can you use a DMM to determine if a solenoid is working correctly?

Table 4. ***Solenoid Cause and Corrections***

Scenario	Cause	Correction
1		
2		
3		
4		

Table 5. ***Relay Observations***

Voltage	
Maximum amperage	
Number of polls	
Number of throws	
Poll position when power is off	
Poll position when power is on	

Part Two Analysis Question

Q2 How can you use a DMM to identify a broken relay?

Table 6. ***Relay Cause and Corrections***

Scenario	Cause	Correction
1		
2		
3		
4		

Name____ CASE

Project 6.2.5 Electro-Hydraulics

Purpose

Today's equipment depends upon interacting electrical and hydraulic systems. In the previous activity, you learned how to connect and troubleshoot an electro-hydraulic system. Hydrostatic systems are a common type of electro-hydraulic system. How do hydrostatic systems work?

Hydrostatic systems are closed-loop hydraulic systems. Because they do not have a tank, trapped or "static" fluid is constant in the system. Fluid in a hydrostatic system can become hot quickly if the fluid is continually moving. Because of this, some technicians call hydrostatic systems "hot-loops." Hydrostatic systems have electrical controls connected to the pump. These controls precisely adjust fluid flow and direction, avoiding the need for additional valves in the system. Hydrostatic systems reduce the need for valves and a tank for excess fluid, keeping the system lightweight.

How are hydrostatic systems constructed?

Materials

Per pair of students:

- Electrical supplies
- Hydraulic supplies

Per student:

- Pen
- *Logbook*
- *Agriscience Notebook*
- *Project 6.2.5 Evaluation Rubric*

Procedure

Use your knowledge of electrical and hydraulic controls to design and construct a hydraulic system.

Inventory the materials provided by your teacher before designing and constructing a system that meets the *Hydraulic System Criteria*.

Hydraulic System Criteria

- The system is neat and orderly, with no loose wires, hoses, or leaks.
- The pump directs fluid through a flow sensor simulating a hydraulic motor in a closed-loop system.
- The system voltage is 12V with relays controlling the system.
- The system uses a positive fixed displacement pump.
- A potentiometer controls volume displacement by changing the amperage.

Once you have built the electro-hydraulic system, draw electrical and hydraulic schematics for your design. Submit your *Logbook* with schematics along with the system for your teacher to evaluate with *Project 6.2.5 Evaluation Rubric*.

Conclusion

1. How are relays used to control a hydrostatic system?

2. What component replaces the directional control valve in a hydrostatic system?

3. What type of pump does a hydrostatic system need to increase and decrease fluid flow?

Name____

CASE

Project 6.2.5 Evaluation Rubric

Areas with Room for Improvement	Criteria	Areas that Meet or Exceed Expectations
	Hydraulic System The system is neat and orderly, with no loose wires, hoses, or leaks.	
	Electrical Circuit The circuit functions to complete the following tasks: • The pump reverses direction when the switch is closed. • The potentiometer changes amperage, not voltage. • The potentiometer changes pump speed in both directions. • The system voltage is 12V. • Relays control the system.	
	Electrical Schematic The student recorded the schematic in the *Logbook* using the correct electrical symbols. The reader can easily follow the electrical path from the source to the load and back to the source throughout each branch.	
	Hydraulic Schematic The student recorded the schematic in their *Logbook* using the correct hydraulic symbols. The reader can easily follow the fluid path to the load and source.	
	Control Panel The students designed the system to keep all electrical controls and indicators organized. Controllers and indicator lights are appropriately labeled.	

fName____

CASE

Activity 6.2.6 Fluid Equipment

Purpose

Tractors have a variety of fluid systems. Fluid systems cool, lubricate, and transfer power. Hydraulic fluid in a tractor can power the steering, three-point hitch, brakes, power take-off (PTO) implements, and attached auxiliary equipment such as a loader. Although each system has one commonality of transferring fluid, the components and means of transfer vary.

What are those components in a tractor's fluid systems, and how do they transfer power?

Materials

Per pair of students:

- Device with internet access
- (2) *Fluid Inspection Sheet*
- Tractor maintenance manual

Per class:

- Tractor

Per student:

- Pen
- *Logbook*
- *Agriscience Notebook*

Procedure

Practice what you have learned about fluid power systems by identifying and inspecting components on a tractor.

1. Use a maintenance manual and inspect the tractor to identify and list all fluid systems in Table One.
2. In Table 1, record the characteristics of each system.

Table 1. ***System Identification***

System	Fluid Type	Pump Classification (Positive/Non-positive)	Pump Type (Gear/Vane/Piston)	System Classification (Open-Loop/Closed-Loop)

3. Your teacher will assign you and your partner two systems to inspect in detail. Circle the assigned systems in Table 1.
4. Record the name of the first circled systems at the top of a *Fluid Inspection Sheet* and enter the identification information.

5. Use the user manual, SDS, and property sheets to complete the fluid information in Table 1 of the *Fluid Inspection Sheet*.
    - Use the internet to find and print SDS and property sheets if needed.
6. Find the schematics for your system and record the valves, actuators, and electrical components in Table 2 of the *Fluid Inspection Sheet*.
7. Inspect the tractor for potential safety hazards and complete Tables 3 and 4 on the *Fluid Inspection Sheet*.
8. Repeat Steps 4–7 for the second assigned system.
9. Add to your inspection sheets as your teacher reviews each fluid system with the class.

Conclusion

1. What are three systems in a tractor that require fluid power?

2. Why do the components and design of fluid power systems vary on a single tractor?

3. How would a technician use the *Fluid Inspection Sheets* completed during this activity?

Name____

CASE

Activity 6.2.6 Fluid System Inspection Sheet

Fluid System: ______________________

Fluid Type	
Pump Classification	
Pump Type	
System Classification	

Table 1. *Fluid Information*

Fluid Name	
First Aid Measures	
Eye Contact	
Skin Contact	
Inhalation	
Ingestion	
Fire and Explosion Hazards	
Flammability of Product	
Fire Fighting Media	
Precautions for Safe Handling and Use	
Spillage	
Precautions for Handling and Storage	
Personal Protective Equipment Needed	
Physical and Chemical Properties	
Physical State and Appearance	
Specific Gravity	
ISO Grade	
Viscosity	
Viscosity Index	
Anti-wear additives	
Emulsifying additives	
Pour Point	

Table 2. ***Components***

Valves	Actuators	Electrical Controls

Table 3. ***Conductor and Fitting Inspection***

Conductor and Fitting Defects	Location	Hazard/Safety Concerns	Correction
Cracked			
Poorly fitted			
Leaky			
Bent or kinked			

Table 4. ***Action and Motion Observation***

Place a check by any motions or actions that are potential hazards for each hydraulic system. Record the location and the potential accident that could occur.

Action or Motion		Location	Potential Accident
Rotating	☐		
In-Running Nip Points	☐		
Reciprocating	☐		
Transversing	☐		
Cutting	☐		
Punching	☐		
Shearing	☐		
Bending	☐		

Name____ CASE

Lesson 6.2 Check for Understanding

1. How will an additive improve the functionality of hydraulic fluid?

2. What are four main properties of hydraulic fluid?

3. What factors should a technician consider when selecting a hydraulic fluid for a cold, moist environment?

4. What are three hydraulic safety hazards?

5. List the steps for placing a hydraulic system in a zero-energy state.

6. Why do smaller implements use hydrostatic systems?

7. Which statement is true about a variable-displacement pump?
   a) Variable-displacement pumps are only available as gear and vane pumps.
   b) Variable-displacement pumps include gear, piston, and vane pumps.
   c) Variable-displacement pumps have a variable rpm and variable displacement rate.
   d) Variable-displacement pumps have a fixed rpm and variable displacement rate.

8. Match the pump with its characteristics.

______ Variable displacement pump	A. Contains a swashplate
______ Vane pump	B. Volume displacement can be changed with a constant pump rpm
______ Piston pump	C. Contains a cam ring
______ Positive displacement pump	D. Volume displacement is directly related to pump rpm
______ Non-positive displacement pump	E. Does not contain internal seals causing volume displacement to vary.

9. Why are electrical controls used to operate hydraulic systems?

10. List three fluid power systems found on a tractor.

CASE

Lesson 6.2 Check for Understanding Answer Key

1. How will an additive improve the functionality of hydraulic fluid?

Additives prevent the hydraulic fluid from oxidizing with air and mixing with water, improving lubrication and reducing wear in the system.

2. What are four main properties of hydraulic fluid?

Lubrication, cooling, sealing, and applying pressure

3. What factors should a technician consider when selecting a hydraulic fluid for a cold, moist environment?

Fluids in a cold environment need to have a low viscosity with a pour point at a low temperature. Fluids in a high moisture environment need additives to prevent oxidation and emulsification.

4. What are three hydraulic safety hazards?

Answers may include the following examples:
High-temperature fluid causes burns.
Thin hydraulic fluid film causing a fire.
High-pressure fluid punctures the skin.

5. List the steps for placing a hydraulic system in a zero-energy state.

Lower machine to resting position
Turn off the engine or power supply
Open bleed-down valve if available
Move directional handles to dissipate pressure
Confirm all gauges read zero

6. Why do smaller implements use hydrostatic systems?

Hydrostatic systems have fewer components. The pump controls the fluid in a static state, eliminating the need for valves and reservoirs, which would take up valuable space in small implements.

7. Which statement is true about a variable-displacement pump?

   a) Variable-displacement pumps are only available as gear and vane pumps.
   b) Variable-displacement pumps include gear, piston, and vane pumps.
   c) Variable-displacement pumps have a variable rpm and variable displacement rate.
   d) Variable-displacement pumps have a fixed rpm and variable displacement rate.

8. Match the pump with its characteristics.

B Variable displacement pump

C Vane pump

A Piston pump

D Positive displacement pump

E Non-positive displacement pump

A.	Contains a swashplate
B.	Volume displacement can change with a constant pump rpm
C.	Contains a cam ring
D.	Volume displacement is directly related to pump rpm
E.	Does not contain internal seals causing volume displacement to vary.

9. Why are electrical controls used to operate hydraulic systems?

Small amounts of electricity can control high-powered equipment safely. Electricity activates solenoids in directional valves from a safe distance.

10. List three fluid power systems found on a tractor.

Steering
Brakes
Auxiliary equipment
Three-point hitch
Transmission
Power take-off

CASE

Lesson 6.3 Hydraulic Maintenance

Preface

Technicians have an in-depth understanding of hydraulic system maintenance. They properly fasten components, look for internal damage, and identify the root causes of system failure. Hydraulic fluid is the lifeblood of a hydraulic system that technicians can analyze to diagnose inner-wear or system malfunction. Hydraulic components have a set cleanliness standard for hydraulic fluids. Fluids not meeting that standard due to environmental conditions or internal wear must be flushed and replaced.

Core hydraulic components have internal seals and moving parts that wear and break down over time. A technician uses knowledge of those seals and moving parts to determine where a system is failing. When technicians make repairs, they may need to replace the fittings used to connect hoses to each component. Fittings have external and internal threads that must match perfectly to seal the system. The system may fail or leak if a technician does not know how to identify the system's fittings.

During this lesson, students identify the signs of wear found in cylinders, valves, and pumps. Next, students identify the fittings used in a system and complete a pick list. To finish the lesson, students inspect hydraulic fluid samples for system failure evidence and complete a work/repair order for a customer complaint.

Concepts	Performance Objectives
Students will know and understand	*Students will learn concepts by doing*
1. Hydraulic components must seal correctly and be free of air and contaminants to prevent wear and damage.	• Disassemble a hydraulic cylinder and valve to inspect for wear and damage. (Activity 6.3.1) • Disassemble a hydraulic pump and complete a work/repair order. (Project 6.3.2)
2. Technicians select fittings based on design and purpose.	• Identify the fittings needed for a hydraulic system. (Activity 6.3.3)
3. Routine repair of a hydraulic system includes flushing a system and inspecting for particulate matter.	• Inspect used hydraulic oil for potential causes of contamination. (Project 6.3.4) • Fill out a work/repair order for hydraulic parts damaged by contaminated oil. (Project 6.3.4)

National AFNR Common Career Technical Core Standards Alignment

Career Ready Practices
2. Apply appropriate academic and technical skills.
• CRP.02.01: Use strategic thinking to connect and apply academic learning, knowledge, and skills to solve problems in the workplace and community.
• CRP.02.02: Use strategic thinking to connect and apply technical concepts to solve problems in the workplace and community.
8. Utilize critical thinking to make sense of problems and persevere in solving them.
• CRP.08.02: Investigate, prioritize, and select solutions to solve problems in the workplace and community.
Agriculture, Food, and Natural Resources Career Cluster
3. Examine and summarize importance of health, safety, and environmental management systems in AFNR organizations.

• AG 3.6: Demonstrate methods to correct common hazards.
Power, Structural and Technical (AG-PST)
2. Operate and maintain mechanical equipment related to AFNR power, structural, and technical systems.
• AG-PST 2.1: Maintain machinery and equipment by performing scheduled service routines.
• AG-PST 2.2: Perform service routines to maintain power units and equipment.
3. Service and repair mechanical equipment and power systems used in AFNR power, structural and technical systems.
• AG-PST 3.3: Service and repair hydraulic systems by evaluating performance using maintenance manuals.

Next Generation Science Standards Alignment

Disciplinary Core Ideas	
Science and Engineering Practices	
Planning and Carrying Out Investigations	Planning and carrying out investigations in 9-12 builds on K-8 experiences and progresses to include investigations that provide evidence for and test conceptual, mathematical, physical, and empirical models. • Make directional hypotheses that specify what happens to a dependent variable when an independent variable is manipulated.
Analyzing and Interpreting Data	Analyzing data in 9–12 builds on K–8 experiences and progresses to introducing more detailed statistical analysis, the comparison of data sets for consistency, and the use of models to generate and analyze data. • Analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in order to make valid and reliable scientific claims or determine an optimal design solution. • Compare and contrast various types of data sets (e.g., self-generated, archival) to examine consistency of measurements and observations. • Analyze data to identify design features or characteristics of the components of a proposed process or system to optimize it relative to criteria for success.
Constructing Explanations and Designing Solutions	Constructing explanations and designing solutions in 9–12 builds on K– 8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories. • Construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future. • Apply scientific ideas, principles, and/or evidence to provide an explanation of phenomena and solve design problems, taking into account possible unanticipated effects. • Design, evaluate, and/or refine a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations.

Crosscutting Concepts	
Cause and Effect: Mechanism and Prediction	Events have causes, sometimes simple, sometimes multifaceted. Deciphering causal relationships, and the mechanisms by which they are mediated, is a major activity of science and engineering.
	• Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. • Cause and effect relationships can be suggested and predicted for complex natural and human designed systems by examining what is known about smaller scale mechanisms within the system. • Systems can be designed to cause a desired effect. • Changes in systems may have various causes that may not have equal effects.
Systems and System Models	A system is an organized group of related objects or components; models can be used for understanding and predicting the behavior of systems.
	• Systems can be designed to do specific tasks. • When investigating or describing a system, the boundaries and initial conditions of the system need to be defined and their inputs and outputs analyzed and described using models. • Models (e.g., physical, mathematical, computer models) can be used to simulate systems and interactions—including energy, matter, and information flows—within and between systems at different scales.

Common Core State Standards for English Language Arts

CCSS: English Language Arts Standards » Science & Technical Subjects » Grade 11-12	
Key Ideas and Details	• **RST.11-12.3 –** Follow precisely a complex multistep procedure when carrying out experiments, taking measurements, or performing technical tasks; analyze the specific results based on explanations in the text.
Craft and Structure	• **RST.11-12.4 –** Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to grades 11-12 texts and topics. •
Integration of Knowledge and Ideas	• **RST.11-12.7 –** Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem. • **RST.11-12.9 –** Synthesize information from a range of sources (e.g., texts, experiments, simulations) into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible.
Range of Reading and Level of Text Complexity	• **RST.11-12.10 –** By the end of grade 12, read and comprehend science/technical texts in the grades 11-CCR text complexity band independently and proficiently.

CCSS: English Language Arts Standards » Writing » Grade 11-12	
Text Types and Purposes	**WHST.11-12.2 –** Write informative/explanatory texts, including the narration of historical events, scientific procedures/experiments, or technical processes. • **WHST.11-12.2.A –** Introduce a topic and organize complex ideas, concepts, and information so that each new element builds on that which precedes it to create a unified whole; include formatting (e.g., headings), graphics (e.g., figures, tables), and multimedia when useful to aiding comprehension. • **WHST.11-12.2.B –** Develop the topic thoroughly by selecting the most significant and relevant facts, extended definitions, concrete details, quotations, or other information and examples appropriate to the audience's knowledge of the topic. • **WHST.11-12.2.C –** Use varied transitions and sentence structures to link the major sections of the text, create cohesion, and clarify the relationships among complex ideas and concepts. • **WHST.11-12.2.D –** Use precise language, domain-specific vocabulary and techniques such as metaphor, simile, and analogy to manage the complexity of the topic; convey a knowledgeable stance in a style that responds to the discipline and context as well as to the expertise of likely readers. • **WHST.11-12.2.E** – Provide a concluding statement or section that follows from and supports the information or explanation provided (e.g., articulating implications or the significance of the topic).
Production and Distribution of Writing	• **WHST.11-12.4 –** Produce clear and coherent writing in which the development, organization, and style are appropriate to task, purpose, and audience. • **WHST.11-12.6 –** Use technology, including the Internet, to produce, publish, and update individual or shared writing products in response to ongoing feedback, including new arguments or information.
Research to Build and Present Knowledge	• **WHST.11-12.7 –** Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation. • **WHST.11-12.8 –** Gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively; assess the strengths and limitations of each source in terms of the specific task, purpose, and audience; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and overreliance on any one source and following a standard format for citation. • **WHST.11-12.9 –** Draw evidence from informational texts to support analysis, reflection, and research.
Range of Writing	• **WHST.11-12.10 –** Write routinely over extended time frames (time for reflection and revision) and shorter time frames (a single sitting or a day or two) for a range of discipline-specific tasks, purposes, and audiences.

Essential Questions

1. How are cylinder and valve leaks prevented?
2. Why doing hydraulic fittings vary in size and shape?
3. What are some common causes of hydraulic system failure?
4. What are the internal components in a cylinder?
5. How does a hydraulic valve divert oil to specific ports?

6. What can cause a hydraulic pump to break?
7. How is hydraulic fluid kept clean?
8. What are the common contaminants found in hydraulic fluid?

Key Terms

Barrel	**Beta ratio**	**British Standard Pipe Standard (BSP)**
Cavitation	**Contaminant**	**Filter**
Gland	**ISO 446:1999**	**Micron**
National Pipe Thread (NPT)	**Nominal diameter**	**O-ring**
Pitch	**Pitch gauge**	**Pitting**
Polymer	**Port**	**Quick-connect coupler**
Rod	**Silica**	**Snap ring**
Spool		

Day-to-Day Plans
Time: 10 days

*Refer to the Teacher Resources section for specific information on teaching this lesson, in particular **Lesson 6.3 Teacher Notes**, **Lesson 6.3 Glossary**, **Lesson 6.3 Materials**, and other support documents.*

Day 1:

- Present **Concepts**, **Performance Objectives**, **Essential Questions**, and **Key Terms** to provide a lesson overview.
- Provide students **Presentation Notes** pages to use throughout the presentation to record notes and reflections. Students add these pages to their *Agriscience Notebook*.
- Present LunchBox Sessions© **Anatomy of a Cylinder** and **Directional Control Valves.**
- Provide students with a copy of **Activity 6.3.1 Hydraulic Dissection**.
- Students work with a partner on *Activity 6.3.1 Hydraulic Dissection*.

Day 2:

- Students complete *Activity 6.3.1 Hydraulic Dissection*.

Day 3 – 4:

- Provide students with a copy of **Project 6.3.2 Pump Damage**, **Work/Repair Order Template**, **Work/Repair Order Evaluation Rubric**, and **Pump Complaint Card**.
- Students work with a partner to complete *Project 6.3.2 Hydraulic Dissection* and submit a work/repair order.
- Use the *Work/Repair Order Evaluation Rubric* to assess student work.

Day 5 – 6:

- Present LunchBox Session© **Hydraulic Fittings: Threads** and **Quick Couplers: Maintenance and Faults**.
- Students take notes using the *Presentation Notes* pages provided by the teacher.
- Provide students with a copy of **Activity 6.3.3 Will it Fit?**
- Students work with a partner to complete Part One of *Activity 6.3.3 Will it Fit?*

Day 7:

- Students work with a partner to complete *Activity 6.3.3 Will it Fit?*

Day 8:

- Present LunchBox Session© **Filtration and Contamination**.
- Students take notes using the *Presentation Notes* pages provided by the teacher.
- Provide students with a copy of **Project 6.3.4 Filter and Flush**, **Work/Repair Order Template**, **Work/Repair Order Evaluation Rubric**.
- Students work in pairs to complete Part One of *Project 6.3.4 Filter and Flush*.

Day 9:

- Provide student pairs with an **Oil Complaint Card**.
- Students work in pairs to complete *Project 6.3.4 Filter and Flush* and submit a work/repair order.
- Use the *Work/Repair Order Evaluation Rubric* to assess student work.

Day 10:

- Distribute **Lesson 6.3 Check for Understanding**.
- Students will complete *Lesson 6.3 Check for Understanding* and submit it for evaluation.
- Use **Lesson 6.3 Check for Understanding Key** to evaluate student assessments.

Instructional Resources

Lunchbox Sessions©

Anatomy of a Cylinder

Directional Control Valves

Hydraulic Fittings: Threads

Quick Couplers: Maintenance and Faults

Filtration and Contamination

Student Support Documents

Lesson 6.3 Glossary

Presentation Notes

Activity 6.3.1 Hydraulic Dissection

Project 6.3.2 Pump Damage

Activity 6.3.3 Will it Fit?

Project 6.3.4 Filter and Flush

Teacher Resources

Lesson 6.3 Hydraulic Maintenance PDF

Lesson 6.3 Teacher Notes

Lesson 6.3 Materials

Lesson 6.3 Check for Understanding

Answer Keys and Assessment Rubrics

Lesson 6.3 Check for Understanding Answer Key

Work/Repair Order Evaluation Rubric

Student Project Development Template

Work/Repair Order Template

Reference Sources

Dell, Timothy W. (2017). *Hydraulic systems for mobile equipment, 1st Edition.* Tinely Park, IL: The Goodheart-Willcox Company, Inc.

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Casey, Brendan. (2022). *Symptoms of common hydraulic problems and their root causes*. **www.machinerylubrication.com/Read/531/hydraulic-root-causes#:~:text=Abnormal%20noise%20in%20hydraulic%20systems,air%20contaminates%20the%20hydraulic%20fluid.&text=Check%20the%20fluid%20level%20in,pump%20through%20its%20shaft%20seal**.

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Fluid Power Journal (2018). *Determine the cause of no flow, low flow, high flow*. **https://fluidpowerjournal.com/determine-cause-no-flow-low-flow-high-flow/**

Global Electronic Services. (2016). *Explaining directional valve repair - full dismantle and reassembly*. **www.youtube.com/watch?v=O3joll9Jkx4**

Hydraulics and Pneumatics (2011). *Fluid power glossary*. **www.hydraulicspneumatics.com/200/FPE/ReferenceMateri/Article/False/6465/FPE-ReferenceMateri**

LunchBox Sessions© (n.d.). *Anatomy of a cylinder*. **www.lunchboxsessions.com**

LunchBox Sessions© (n.d.). *Directional control valves*. **www.lunchboxsessions.com**

LunchBox Sessions© (n.d.). *Filtration and contamination*. **www.lunchboxsessions.com**

LunchBox Sessions© (n.d.). *Hydraulic fittings: threads*. **www.lunchboxsessions.com**

LunchBox Sessions© (n.d.). *Quick couplers maintenance and faults*. **www.lunchboxsessions.com**

Process Systems. (2021.) *Threads*. **www.valvesonline.com.au/references/threads/**

FFA Connections

This lesson provides conceptual and procedural knowledge related to the following FFA awards, activities and educational resources.

- Agricultural Proficiency
  - **Agricultural Mechanics Repair and Maintenance –Placement**
  - **Agricultural Mechanics Repair and Maintenance –Entrepreneurship**
  - **Agriscience Research – Integrated Systems**
- Agriscience Fair
  - **Power, Structural and Technical Systems**
- Career Development Events
  - **Agricultural Technology & Mechanical Systems**
- Educational Resources
  - **SAE Idea Cards-Power, Structural and Technical Systems**
  - **Power, Structural and Technical System Careers**
  - **Power, Structural and Technical Systems Career Focus Area Resources**
  - Power, Structural and Technical Careers **(Word)**

Skills and knowledge from this lesson support the development and implementation of service-learning projects that address hydraulic principles.

- **Service-Learning and Living to Serve Grants**
    - Service-learning projects focused on diagnosing hydraulic system issues in agricultural and other outdoor equipment.
    - Project ideas include hosting a spring tune-up or winterization event for local community members for lawnmowers and other equipment with hydraulic systems.
    - Living to Serve Grants provide funding to FFA chapters to support service-learning and community service projects.

For more information, visit the **National FFA Organization** website.

SAE for All

Immersion SAE

Students interested in this lesson's topics should explore the following related Immersion SAEs. An immersion SAE is optional and replaces the agricultural literacy component of the Foundational SAE.

- **Immersion SAE Learning Guides**

For more information on the guiding principles for implementing SAE programs, visit the **SAE for All: Evolving Essentials** site.

Critical Thinking and Application Extensions

Application

1. Students will collect hydraulic fluid samples and submit them for contamination testing.
2. Students will repair a damaged hydraulic cylinder or valve.

Lesson 6.3 Teacher Notes

Lesson 6.3 Hydraulic Maintenance

In preparation for teaching this lesson, review Concepts, Performance Objectives, Essential Questions, and Key Terms, along with the PowerPoint® presentations. Also, review all activity and project directions, expectations, and work students will complete.

The students teardown and reassemble a hydraulic cylinder, valve, and pump while identifying parts and looking for wear. Then they use measurement tools to determine the fittings needed for connecting components. Students use oil and component data to fill out a work/repair order to complete the lesson.

LunchBox Sessions©

Anatomy of a Cylinder

Use the presentation to provide information on the internal parts of a hydraulic cylinder.

Directional Control Valves

Students learn how directional control valves function while viewing this presentation.

Hydraulic Fittings: Threads

Use this presentation to explain how to measure internal and external fittings found in hydraulic systems.

Quick Couplers: Maintenance and Faults

Use the presentation to provide background knowledge related to using quick couplers.

Filtration and Contamination

Students learn the cause and effects of contaminated hydraulic oil and how it is filtered and rated for cleanliness.

Activities, Projects, and Problems

Activity 6.3.1 Hydraulic Dissection

Students disassemble and rebuild a cylinder and valve while identifying internal parts.

Teacher Preparation
LunchBox Sessions©
Present *Anatomy of a Cylinder* and *Directional Control Valves* before starting the activity.

Components and Tools
For a class of 20 students, five pairs will complete *Part One – Cylinders*, while the other five pairs complete *Part Two – Valves*. Student pairs complete both parts over two days. Examine the cylinder and valves to determine the specific tools needed for the activity. The tools needed will vary, depending upon the type and brand of cylinder and valve. The gland may need a spanner wrench, gland wrench, snap ring tool, or socket wrench. Most hydraulic valves will require a hex wrench or socket wrench for disassembly.

Student Performance

Assign half the class to complete Part One and the other half to complete Part Two. During Part One, students disassemble a hydraulic cylinder while recording the process in their *Logbooks*. Next, students identify the internal parts and look for wear, documenting the cause and correction. They then reassemble the cylinder. Students complete the same procedure for Part Two by disassembling, identifying parts, examining, and reassembling a valve.

Results and Evaluation
Review student *Logbooks* for clarity and conciseness upon completing the activity.

Project 6.3.2 Pump Damage

Students work in pairs to tear down and inspect a hydraulic pump and complete a work/repair order.

Teacher Preparation
Make a copy of **Project 6.3.2 Pump Complaint Cards** and cut them out. Print copies of a h**ydraulic pump troubleshooting chart** for each student pair. Inspect the pumps used for this activity to determine the needed tools. Table 2 lists an example pump and tools required for this activity. Students will need a hex wrench and/or socket wrench set to disassemble the pump.

Student Performance
Provide each student pair a *Pump Complaint Card* and a used hydraulic pump. Students tear down the pump while recording all procedures and observations in their *Logbooks*. Students use the information on the complaint card, troubleshooting chart, and pump observations to complete a work/repair order.

Results and Evaluation
Use the **Work/Repair Order Evaluation Rubric** and **Logbook Evaluation Rubric** to assess student work/repair orders and *Logbooks*. Examples of causes and corrections for the complaints are in Table 1. As an inquiry-based project, these are only examples, pump observations and the troubleshooting chart may lead students to different answers that are also correct.

Table 1. *Pump Cause and Corrections*

Complaint	Cause	Correction
The pump motor is working, but the pump is not pumping oil. The reservoir has the correct oil level.	*Vacuum in the reservoir because the breather is clogged.*	*Unclog the breather on the reservoir.*
The hydraulic pump is noisy with the correct oil level.	*Aeration or cavitation. Air has leaked through a seal and contaminated the hydraulic fluid, making banging or knocking noises.*	*Replace the seals to prevent air from entering the system.*
The pump does not develop full pressure.	*Faulty relief valve.*	*Replace the relief valve.*
Pump speed increases and decreases at random while working.	• *Air in system.* • *Dirty or damaged components.* • *Restrictions in filters or lines.*	• *Check the suction side of the system for leaks. Repair.* • *Clear or repair as necessary.* • *Clean and/or replace elements or line*
The oil flow from the pump is low.	*Broken teeth or internal wear in the gear pump is causing lower flow.*	*Replace gears or the entire pump.*

Activity 6.3.3 Will it Fit?

Students measure the size of hydraulic fittings and determine the correct fitting sizes for a hydraulic system.

Teacher Preparation
LunchBox Sessions©

Present *Hydraulic Fittings: Threads* and *Quick Couplers: Maintenance and Faults* before starting the activity.

Components and Tools
Student pairs need a dial caliper and pitch gauge to measure the threads. Each pair will need a male and female fitting. Below are recommended fittings that are available through **McMaster-CARR**. Mix male and female fittings, so students work with a set that does not fit together.

Table 2. *Recommended Fittings*

Standard	Male	Female
Metric	Compression Fitting for Stainless Steel Tubing, Straight Adapter, 8 mm Tube OD x 1/4 NPT Male	316 Stainless Steel Nut for 8 mm Tube OD High-Pressure Compression Fitting
BSP	37 Degree Flared Fitting for Stainless Steel Tubing, Adapter for 3/8" Tube OD x 3/8 BSPT Male	Nut for 3/8" Tube OD 37 Degree Flared Fitting for Stainless Steel Tubing
NPT	Precision Compression Fitting for Stainless Steel Tubing, Straight Adapter for 3/8" Tube OD x 1/8 NPT Male	Precision Compression Fitting for Stainless Steel Tubing, Straight Adapter for 3/8" Tube OD x 1/8 NPT Female

Use the components from *Activity 6.3.1* and *Activity 6.3.2* for students to practice measuring the female fittings. Review the schematic in Figure 1. Have all components shown in Figure 1, including hoses, for students to measure. Do NOT connect the components. Students measure component fittings and exchange them with another pair.

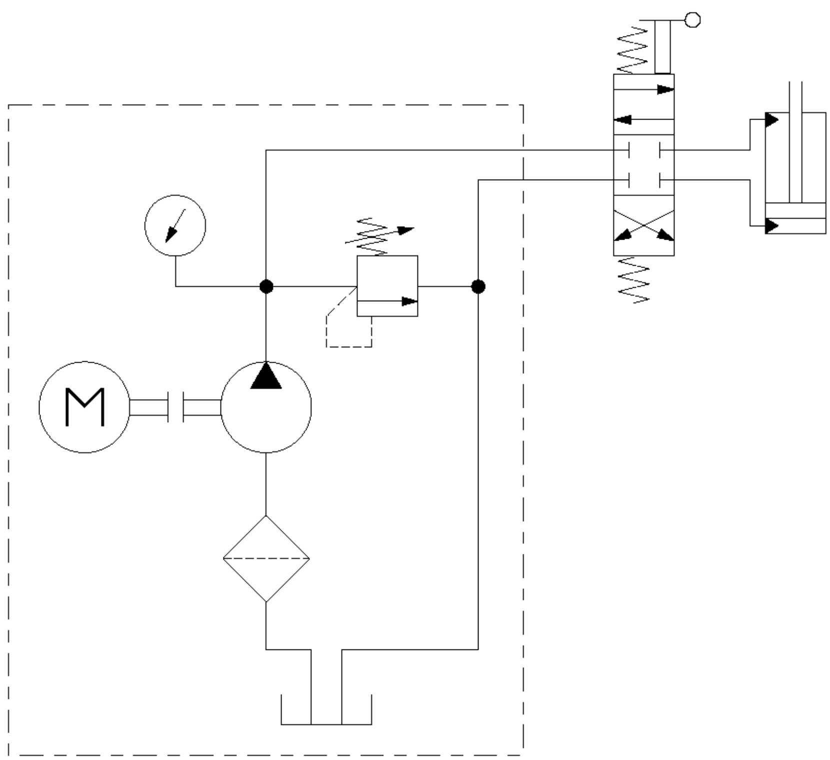

Figure 1. Hydraulic Schematic

Student Performance
Students measure and record identifying features for internal and external threads. They determine each thread's diameter, shape, gauge, and type, along with its industry name. Then students use a schematic

with physical examples of each component available to develop a pick list for ordering the needed fittings to assemble the system shown in the schematic.

Results and Evaluation
Review the fitting information and pick list students complete on *Activity 6.3.3 Student Observations* to assess student work.

Project 6.3.4 Filter and Flush

Students work in pairs to inspect the oil for contaminants and write a work/repair order for an oil sample.

Teacher Preparation
Make a copy of **Project 6.3.4 Oil Complaint Cards** and cut them out. Pour approximately 5ml of oil into ten plastic vials to make two sets of five vials. Use a permanent marker to number each set from 1–5. Make two sets of contaminated oil by placing the following contaminants in each vial, as shown in Table 3.

Table 3. *Oil Contamination*

Bag Number	Contaminant
1	Metal shavings
2	Dust or dirt
3	Cloth threads
4	Plastic or rubber shavings
5	Rust (scrape off a rusty nail)

LunchBox Sessions©
Present *Filtration and Contamination* before starting the activity.

Student Performance
Part One
Have two oil sample sets for students to view and exchange. Each student pair will use a microscope, pipet, and petri-dish to inspect the oil, determine the contaminant, and record the cause and correction in their *Logbook*.

Part Two
Provide each student pair an *Oil Complaint Card*. Students use the information on the complaint card to predict the cause and correction and then complete a work/repair order. They include the following on their completed work/repair order.

- ISO:446:1999 contamination code
- Number of contaminants per milliliter – use Figure 1
- Filter Beta Ratio
- Need for flushing
- Need for filter replacement

Results and Evaluation
Use the **Work/Repair Order Evaluation Rubric** to assess student work/repair orders.

Assessment

Lesson 6.3 Check for Understanding

Lesson 6.3 Check for Understanding is included for you to use as an assessment tool for this lesson. Use **Lesson 6.3 Check for Understanding Answer Key** for evaluation purposes.

Name____ CASE

Activity 6.3.1 Hydraulic Dissection

Purpose

Hydraulic equipment is exposed to dust, dirt, and debris while in working conditions. Protecting the internal working components is essential for preventing breakdowns and excessive wear. How are the inner workings of hydraulic equipment protected?

A rod extending and retracting into a barrel makes up a hydraulic cylinder. The rod connects to a piston with two O-rings preventing the hydraulic fluid from escaping inside the barrel. Hydraulic pressure on the piston causes linear movement. One O-ring seals the area between the piston and the inside of the wall of the barrel. A second O-ring seals the connection between the rod and piston. A gland containing O-rings surrounds the cylinder rod at the end of the barrel, preventing contaminants from entering. A snap ring holds the gland in place. O-rings and seals are made of plastics and rubber that break down over time and must be replaced.

If a seal breaks, oil can leak out of the system, causing the cylinder to drift and dirt to enter the system. Foreign material such as dirt will cause friction and wear of internal components. Even if contaminants enter a single location, debris travels throughout the system, causing component failures. For example, debris in a valve can cause the valve to leak or stick, resulting in a malfunction of the entire system.

A valve consists of a spool moved by mechanical actuators and springs. The spool diverts the fluid through specific ports depending on its position. Open-center and closed-center are two types of three-position valves. Closed-center valves do not circulate oil when in the center position, so there is no oil flow. Open-center valves will circulate oil through the valve and back to the reservoir when in the center position, so there is continuous oil flow.

How do you identify the worn seals and components in a cylinder and valve? How can you determine if a hydraulic component is faulty and needs to be replaced?

Materials

Per class:

- (5) Hydraulic cylinders
- (5) Hydraulic valves
- Shop rags
- Tools for disassembling the hydraulic cylinder and valve
- Wood block

Per student:

- *Agriscience Notebook*
- *Logbook*
- Nitrile gloves
- Pen
- Safety glasses

Procedure

Tear down a hydraulic cylinder and valve and identify internal components that prevent the part from wear and damage. Next, record the process for disassembly and reassembly of each component in your *Logbook* by recording the step, tools, and hardware. You and your partner will be assigned Part One or Part Two on the first day and finish the remaining part on the second day.

Part One – Cylinders

1. Put on safety glasses and nitrile gloves, and tie back long hair.
2. Draw the schematic of the cylinder and record the type in your *Logbook*.

3. Fasten the cylinder horizontally in a vice.
4. Use a snap ring pliers to remove the snap ring from the top of the barrel.
5. Use a blunt object, such as a wood block, to press the gland into the barrel.
6. Remove the retaining ring on top of the gland.
7. Remove the caps on the fittings to prevent a vacuum from occurring while removing the piston.
8. Place a bucket under the rod end of the piston to collect any excess oil, then remove the piston and gland by pulling on the rod.
9. Remove the barrel from the vice.
10. Fasten the rod horizontally in the vice.
11. Use a socket wrench to remove the nut from the piston stem.
12. Remove the rod and stem from the piston.
13. Sketch and identify the following components in your *Logbook*.
    - Rod
    - Barrel
    - Rod end port
    - Blind end port
    - Piston
    - Piston O-ring
    - Piston stem seal
    - Backup rings
    - Gland
    - Snap ring
    - Gland seal
    - Rod seal
14. Examine each component for contamination and wear. Record the cause and correction for each identified worn component.
15. Reassemble the hydraulic cylinder. Record the steps in your *Logbook*.

Part Two – Valves

1. Put on safety glasses and nitrile gloves, and tie back long hair.
2. Draw the schematic of the valve and record the type in your *Logbook*.
3. Use a socket wrench to remove the actuators from the valve.
    - The actuator will be a handle or a solenoid.
4. Use an adjustable wrench to remove the spools from the valve.
5. By hand, remove the O-ring, spring, and key from each tube.
6. Remove the spool from the directional valve.
    - Place the spool on a towel to prevent damage.
7. Sketch and identify the following components in your *Logbook*.
    - Actuator (type)
    - O-rings
    - Spring
    - Key
    - Tube
    - Spool
    - Valve
8. Examine each component for contamination and wear. Record the cause and correction for each identified worn component.
9. Reassemble the valve cylinder. Record the steps in your *Logbook*.

Conclusion

1. How can dirt and contaminants damage a spool?

2. Where can cylinder leaks occur that a technician cannot see?

3. What would be the cause and correction of a cylinder leak between the gland and cylinder rod?

Name____ CASE

Project 6.3.2 Pump Damage

Purpose

Technicians inspect hydraulic pumps just as you inspected cylinders and valves during *Activity 6.3.1 Hydraulic Dissection*. When a pump fails, the technician needs to identify the root cause of the failure before replacing the pump. If they do not recognize the root cause, the new pump may also fail and need replacement. What are the root causes of hydraulic pump failure?

If a gear pump is over-pressurized, pressurized oil may press the teeth together, causing additional wear or cracking. Dirt or debris in the fluid can cause internal components to be scored or seals to wear excessively. Air within the system can cause pits to form in the metal because of cavitation. Cavitation occurs when the oil demand is more than the supply. When there is not enough oil, a vacuum will produce bubbles of vapor that collapse under pressure. If the bubbles collapse near the metal, cavitation will cause pitting and damage to the pump.

Temperature is another factor causing pump failure. If the oil temperature is too high, heat breaks down seals causing the oil to become contaminated. In addition, high-temperature oil may have incorrect viscosity, which reduces the sealing property of the oil. Friction between shafts and worn bearings or bushings can also cause oil temperatures to increase. Discoloration and deformation of components are evidence of excess heat in a hydraulic system.

A technician can use a troubleshooting chart and perform a physical inspection to determine the root cause of a failed pump. A troubleshooting chart lists potential causes and corrections for customer complaints. Because the chart will have more than one possible cause, a technician must tear down and inspect the internal pump components. Before tearing down a pump, a technician marks each housing piece to ensure they can reassemble the pump in the correct order. Once they tear down the pump, the technician will inspect the following components.

- Internal house for scoring, pitting, and wear
- Plate seals for wear, deformation
- Shaft bearings and bushings for wear and discoloration
- Gears for scoring, wear, discoloration, and cracks

How would you identify the root cause of pump failure for a customer?

Materials

Per pair of students:

- Hydraulic pump, used
- *Project 6.3.2 Pump Complaint Card*
- Pump user manual
- Tools for disassembling the pump
- **Troubleshooting chart**

Per class:

- Shop rags

Per student:

- *Agriscience Notebook*
- *Logbook*
- *Logbook Evaluation Rubric*
- Nitrile gloves
- Pen
- Safety glasses
- *Work/Repair Order Evaluation Rubric*
- *Work/Repair Order Template*

Procedure

Put on safety glasses and nitrile gloves, and tie back long hair before starting. Your teacher will provide a hydraulic pump along with a *Activity 6.3.2 Pump Complaint Card*. Review the user manual for instructions on how to disassemble the pump. Then, tear down and inspect the pump while recording sketches, procedures, and notes in your *Logbook*. Inspect the following:

- Internal housing for scoring, pitting, and wear
- Port plate seals for wear and deformation.
- Shaft bearings and bushings for wear and discoloration.
- Gears for scoring, wear, cracks, or discoloration.

Next, review the inspection notes, **Troubleshooting chart** (https://www.carotek.com/userfiles/viking-pump/viking-pump-failure-troubleshooting-checklist.pdf), and *Activity 6.3.2 Pump Complaint Card* to determine the cause and correction. Then complete a *Work/Repair Order Template* for the pump. Finally, submit your *Work/Repair Order* and *Logbook* to your teacher to assess using the *Work/Order Evaluation Rubric* and *Logbook Evaluation Rubric*.

Conclusion

1. How does a customer complaint aid a technician in finding the root cause of hydraulic pump failure?

2. Why is it essential for a technician to identify the root cause of pump failure before replacing the pump?

3. What are the characteristics of a pump damaged by heat?

Name____

CASE

Project 6.3.2 Pump Complaint Cards

Customer Complaint Mark Marion brought this pump to the shop on September 20th. The pump motor is working, but the pump is not pumping oil. The reservoir has the correct oil level.	**Customer Complaint** Mark Marion brought this pump to the shop on September 20th. The pump motor is working, but the pump is not pumping oil. The reservoir has the correct oil level.
Customer Complaint Grace Worland brought in this pump on August 12th. The hydraulic pump is noisy with the correct oil level.	**Customer Complaint** Grace Worland brought in this pump on August 12th. The hydraulic pump is noisy with the correct oil level.
Customer Complaint Ron Nashua bought this pump last week, and it is still under warranty. The pump does not develop full pressure.	**Customer Complaint** Ron Nashua bought this pump last week, and it is still under warranty. The pump does not develop full pressure.
Customer Complaint Jamie Owattona brought in this pump on August 12th. Pump speed increases and decreases at random while working.	**Customer Complaint** Jamie Owattona brought in this pump on August 12th. Pump speed increases and decreases at random while working.
Customer Complaint Chris Cobble brought in this pump on July 12th. The oil flow from the pump is low.	**Customer Complaint** Chris Cobble brought in this pump on July 12th. The oil flow from the pump is low.

Name____ CASE

Activity 6.3.3 Will it Fit?

Purpose

A technician outfits a pump, DCV, and hydraulic cylinder with new hoses and fittings. After turning on the system, they find leaks at each fitting. What went wrong? What could the technician have done to prevent leaks in a new system?

As you learned during the *LunchBox Session*©, hydraulic fittings come in various shapes and sizes. If a technician does not understand how fittings differ, they may use the wrong fitting, damaging the equipment and costing more time and money. Fittings connect conductors such as hoses or rigid tubing to components. While quick-connect couplers are common throughout the industry, quick-connect couplers use threaded fittings to attach to components and conductors. Male fittings have threads on the outside, and female fittings have threads on the inside. Some fittings may have a combination of male and female threads.

Threads are defined by the standard and pitch. Common standard threads on hydraulic fittings include National Pipe Thread (NPT) and (British Standard Pipe (BSP). Both standards can be parallel or tapered. Tapered threads require a liquid sealant or tape to prevent leaks. The pitch is the number of threads per inch for imperial measurements or the distance between threads if it is metric. A technician uses a pitch gauge to find a fittings' pitch and standard.

Once a technician knows the pitch and standard, they must find the fittings' diameter. Technicians use a caliper to find the diameter of internal and external fittings. The nominal size of an internal pipe fitting equals a $^{1}/_{4}$″ subtracted from the actual diameter. Technicians use charts, as seen on the student observation sheet, to convert a fitting's external diameter to a nominal size.

After a technician collects the needed information, they can select a fitting based on its official name. The name of a fitting is listed in the order of thread diameter, pitch, and standard. For example, a 1-11 BSP is a British Standard fitting with a 1-inch nominal diameter and 11 threads per inch.

What tools will you use to find the correct fittings for a hydraulic system?

Materials

Per pair of students:

- Dial caliper
- Female hydraulic fitting
- Male hydraulic fitting
- Pitch gauge

Per class:

- Shop rags
- Components for a hydraulic system

Per student:

- *Agriscience Notebook*
- *Logbook*
- Nitrile gloves
- Pen
- Safety glasses

Procedure

Measure and identify internal and external threads. Then make a fitting pick list for connecting components in a schematic.

Part One – Internal Threads

1. Put on safety glasses and nitrile gloves, and tie back long hair.
2. Use your dial caliper to measure the distance between the female fitting's first, fourth, and last full internal thread to determine if the fitting is parallel or tapered. Record each measurement in Table 1 on the *Activity 6.3.3 Student Observations*.
    - Record the threads as tapered or parallel in Table 1.
3. Use the pitch gauge to find and record the following about the threads in Table 1.
    - Metric or non-metric
    - Thread pitch
        - Metric – measured in mm between two peaks
        - Non-metric – measured in threads per inch
    - Thread standard (NPT or BSP)
4. Subtract $^{1}/_{4}''$ from the inside diameter to find the nominal diameter of the fitting.
5. Record whether the threads require sealant.
6. Record the official size of the fitting in Table 1.

Part Two – External Threads

1. Use your dial caliper to measure the distance between the female fitting's first, fourth, and last full internal thread to determine if the fitting is parallel or tapered. Record each measurement in Table 1 on the student observations sheet.
2. Record the threads as tapered or parallel in Table 1.
3. Use the pitch gauge to find and record the following about the threads in Table 1.
    - Metric or non-metric
    - Thread pitch
        - Metric – measured in mm between two peaks
        - Non-metric – measured in threads per inch
    - Thread standard (Metric, NPT, or BSP)
4. Find the fitting's nominal size by measuring the major diameter and recording it in Table 1.
    - For BSP and NPT, use the dial caliper and the size charts in Figures 2 and 3.
    - For metric, measure the major diameter of the threads.
5. Record whether the threads require sealant.
6. Record the official size (nominal diameter, pitch, and thread standard) of the fitting in Table 1.

Part Three – Pick List

Find the fittings to connect hoses to the components seen in Figure 1. Use your knowledge to measure the example components and determine the needed fittings. Then make a pick list for ordering the fittings from a selected online supplier. Record the pick list in Table 2.

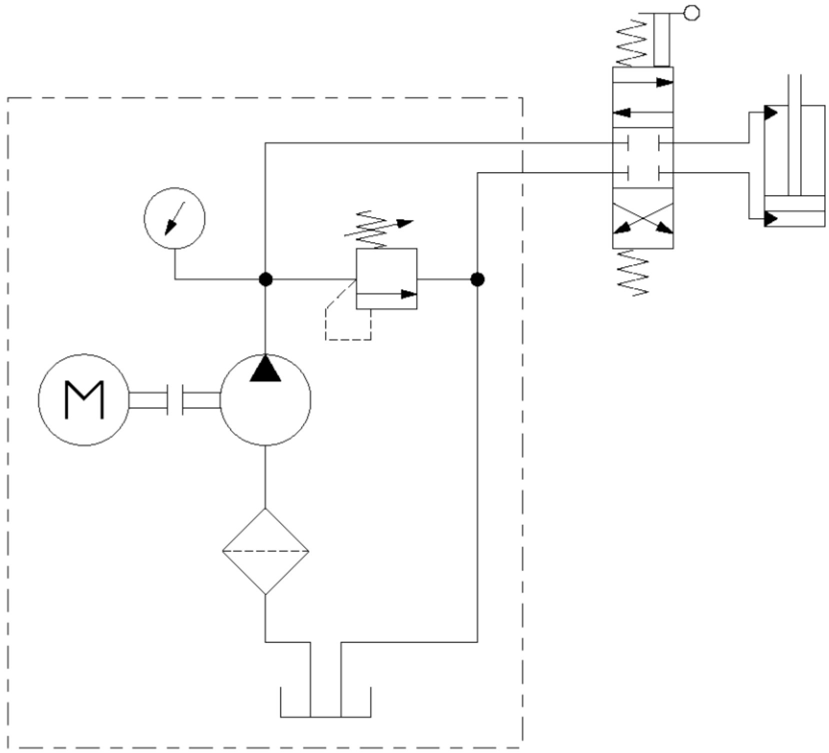

Figure 1. Hydraulic Schematic

Conclusion

1. Why should a technician measure the fitting before using it?

2. What information does a technician need when ordering a hydraulic fitting?

3. When should a technician use sealant with the fitting?

Name____

Activity 6.3.3 Student Observations

Table 1. ***Fitting Information***

Characteristics	Internal Threads	External Threads
First thread diameter		
Forth thread diameter		
Last thread diameter		
Tapered or parallel		
Metric or non-metric		
Thread pitch (mm or threads per in.)		
Thread standard (Metric, NPT or BSP)		
Nominal diameter		
Sealant or no sealant		
Official size		

Trade Size	Threads per inch	Pitch		Major Diameter		Minor Diameter		Gage Length	
		Inch	mm	Inch	mm	Inch	Mm	Inch	mm
1/8	28	0.0357	0.907	0.383	9.728	0.3372	8.565	0.1563	3.97
1/4	19	0.0526	1.337	0.518	13.157	0.4506	11.445	0.2367	6.012
3/8	19	0.0526	1.337	0.656	16.662	0.5886	14.95	0.25	6.35
1/2	14	0.0714	1.814	0.825	20.955	0.7336	18.633	0.3214	8.164
3/4	14	0.0714	1.814	1.041	26.441	0.9496	24.12	0.375	9.525
1	11	0.0909	2.309	1.309	33.249	1.1926	30.292	0.4091	10.391
1 ¼	11	0.0909	2.309	1.65	41.91	1.5336	38.953	0.5	12.7
1 ½	11	0.0909	2.309	1.882	47.803	1.7656	44.846	0.5	12.7
2	11	0.0909	2.309	2.347	59.614	2.2306	56.657	0.625	15.875
2 ½	11	0.0909	2.309	2.96	75.184	2.8436	72.227	0.6875	17.463
3	11	0.0909	2.309	3.46	87.884	3.3436	84.927	0.8125	20.638
4	11	0.0909	2.309	4.45	113.03	4.3336	110.073		

*Chart from https://www.valvesonline.com.au/references/threads/

Figure 2. NPT Standard Chart

Trade Size	Threads per inch	Pitch		Major Diameter (O.D)	
		Inch	mm	Inch	mm
1/8	27	0.03704	0.94082	0.405	10.29
1/4	18	0.05556	1.41122	0.54	13.72
3/8	18	0.05556	1.41122	0.675	17.15
1/2	14	0.07143	1.81432	0.84	21.34
3/4	14	0.07143	1.81432	1.05	26.67
1	11 ½	0.08696	2.20878	1.315	33.4
1 ¼	11 ½	0.08696	2.20878	1.66	42.16
1 ½	11 ½	0.08696	2.20878	1.9	48.26
2	11 ½	0.08696	2.20878	2.375	60.33
2 ½	8	0.125	3.175	2.875	73.03
3	8	0.125	3.175	3.5	88.9
4	8	0.125	3.175	4.5	114.3

https://www.valvesonline.com.au/references/threads/

Figure 3. BSP Standard Chart

Table 2. ***List of Parts***

Part Name	Reference Number	Part Number	Quantity Needed

Name____

CASE

Project 6.3.4 Filter and Flush

Purpose

A customer uses a cloth rag to clean a fitting before fastening it to a valve. After operating the hydraulic system, the directional control valve becomes stuck. After bringing the stuck valve to the dealership, the technician tells them that the cloth rag was the problem. How can cleaning a fitting cause a valve to stick?

Precisely manufactured valves have very close tolerances, with the smallest contaminant causing a valve to stick. Therefore, technicians are cautious when working with internal hydraulic components exposed to the outside environment. Common contaminants such as metals, polymers, rust, silica, and fibers can cause hydraulic systems to fail. Metals and plastics will break away from worn parts. If water enters the system, metal components will rust. Silica from dirt and dust can enter broken seals or open areas through a vent or reservoir cap. Finally, fibers from towels and rags used for cleaning can also cause system failures.

All hydraulic systems have standard cleanliness represented by an ISO 446:1999 contamination code. The standard depends upon how sensitive a component is to contaminants. The oil must meet the standard of the most sensitive component in the system for it not to be flushed and replaced. The three-number code defines the contamination rate in microns per milliliter. The first number represents the number of particles greater than or equal to four microns. The second number is greater than or equal to six microns, and the third number is greater than or equal to 14 microns. The chart seen in Figure 1 matches the code with the number of particles per milliliter.

Hydraulic systems contain filters to remove oil contaminants. Filters have a Beta Ratio describing the percentage of contaminants that the filter removes. Figure 2 shows the relationship between the Beta Ratio and filtration. Once a filter becomes clogged, dirty oil will bypass the filter through a valve to prevent the filter from bursting. If dirty oil flows through the system, causing valves to stick, the technician may need to flush the system with low viscosity fluid and replace the filter and hydraulic oil.

How does a technician determine the source of oil contamination and when to flush a system?

Materials

Per class:

- (10) Oil sample
- Shop rags

Per pair of students:

- Microscope
- Petri dish
- Pipet, plastic
- *Project 6.3.4 Oil Contamination Card*
- *Work/Repair Order Evaluation Rubric*
- *Work/Repair Order Template*

Per student:

- *Agriscience Notebook*
- *Logbook*
- Nitrile gloves
- Pen
- Safety glasses

Procedure

Work with your partner to inspect hydraulic fluid for contaminants. Then work with your partner to determine the cause and correction for a contaminated hydraulic system.

Part One – Inspection and Calculation

Your teacher will give you and your partner an oil sample. Use a microscope, pipet, and petri dish with your partner to inspect the sample for contamination. Record the contaminant, possible cause, and correction in your *Logbook,* and then swap samples with another pair of students. Continue exchanging until you have inspected the five different samples. Wear proper safety glasses and nitrile gloves, and make sure long hair is tied back during your inspection.

Part Two – Component Complaint

A Chris Cobbel has brought you damaged components from a failing hydraulic system for inspection. The parts should be repaired or replaced. The service department took a fluid sample, submitted it for an ISO 446:1999 contamination code, and collected information about the filter. Use the collected information on the *Project 6.3.4 Oil Contamination Card* to complete a *Work/Repair Order Template*. Include the following information on the *Work/Repair Order* to explain the cause and recommended correction.

- ISO:446:1999 contamination code
- Number of contaminants per milliliter – use Figure 1
- Filter Beta Ratio
- Need for flushing
- Need for filter replacement

Submit your work/repair order for your teacher to assess using the *Work/Repair Order Evaluation Rubric*.

Conclusion

1. What are some root causes of oil contamination?

2. How is oil contamination measured?

3. How does a technician determine when to flush a hydraulic system?

Project 6.3.4 Figures

ISO 4406:1999 - Allocation of Scale Numbers

Number of particles per millilitre			Number of particles per millilitre		
More than	Up to & including	Scale Number	More than	Up to & including	Scale Number
0.00	0.01	0	160	320	15
0.01	0.02	1	320	640	16
0.02	0.04	2	640	1 300	17
0.04	0.08	3	1 300	2 500	18
0.08	0.16	4	2 500	5 000	19
0.16	0.32	5	5 000	10 000	20
0.32	0.64	6	10 000	20 000	21
0.64	1.3	7	20 000	40 000	22
1.3	2.5	8	40 000	80 000	23
2.5	5	9	80 000	160 000	24
5	10	10	160 000	320 000	25
10	20	11	320 000	640 000	26
20	40	12	640 000	1 300 000	27
40	80	13	1 300 000	2 500 000	28
80	160	14	2 500 000		>28

https://www.lunchboxsessions.com/materials/hydraulic-accessories/filtration-and-contamination-lesson

Figure 1. Scale Numbers

Beta Value	Efficiency (%)	Particles Upstream	Particles Downstream
2	50.0000	100,000	50,000
4	75.0000	100,000	25,000
10	90.0000	100,000	10,000
20	95.0000	100,000	5,000
40	97.5000	100,000	2,500
60	98.3333	100,000	1,667
75	98.6667	100,000	1,333
100	99.0000	100,000	1,000
125	99.2000	100,000	800
150	99.3333	100,000	667
200	99.5000	100,000	500
300	99.6667	100,000	333
500	99.8000	100,000	200
1,000	99.9000	100,000	100
2,000	99.9500	100,000	50
4,000	99.9750	100,000	25
5,000	99.9800	100,000	20
10,000	99.9900	100,000	10
20,000	99.9950	100,000	5
50,000	99.9980	100,000	2

https://ppp.purdue.edu/engine-oils-and-their-filters/

Figure 2. Beta Ratio

CASE

Project 6.3.4 Oil Complaint Cards

Oil Complaint Card

Contamination Code

- 18/16/13

Type of contaminants found

- Silica

Filter Information

- Beta Ratio – 4

Component Information

- Cylinder – Not moving when a solenoid activates the DCV
    - Cleanliness Requirement - 21/17/14
- Pump – Has correct flow and pressure
    - Cleanliness Requirement - 22/18/13
- Valve – Stuck in the center position
    - Cleanliness Requirement - 18/16/13

Oil Complaint Card

Contamination Code

- 18/16/13

Type of contaminants found

- Rust

Filter Information

- Beta Ratio – 4

Component Information

- Cylinder – Not moving when a solenoid activates the DCV, quick-connects are rusty
    - Cleanliness Requirement - 21/17/14
- Pump – Has correct flow and pressure
    - Cleanliness Requirement - 22/18/13
- Valve – Stuck in the center position
    - Cleanliness Requirement - 18/16/13

Oil Complaint Card

Contamination Code

- 20/16/15

Type of contaminants found

- Metal

Filter Information

- Beta Ratio – 10

Component Information

- Cylinder – Not moving when a solenoid activates the DCV
    - Cleanliness Requirement - 21/17/14
- Pump – Has correct flow and pressure
    - Cleanliness Requirement - 22/18/13
- Valve – Stuck in the center position
    - Cleanliness Requirement - 18/16/13

Oil Complaint Card

Contamination Code

- 25/16/13

Type of contaminants found

- Metal

Filter Information

- Beta Ratio – 10

Component Information

- Cylinder – Not moving when a solenoid activates the DCV
    - Cleanliness Requirement - 21/17/14
- Pump – Makes noise and has pitted interior
    - Cleanliness Requirement - 22/18/13
- Valve – Stuck in the center position
    - Cleanliness Requirement - 18/16/13

Oil Complaint Card

Contamination Code

- 18/16/13

Type of contaminants found

- Polymer

Filter Information

- Beta Ratio – 100

Component Information

- Cylinder – Not moving when a solenoid activates the DCV – oil leaking around the gland
  - Cleanliness Requirement - 21/17/14
- Pump – Has correct flow and pressure
  - Cleanliness Requirement - 22/18/13
- Valve – Stuck in the center position
  - Cleanliness Requirement - 18/16/13

Oil Complaint Card

Contamination Code

- 18/16/13

Type of contaminants found

- Polymer

Filter Information

- Beta Ratio – 100

Component Information

- Cylinder – Not moving when a solenoid activates the DCV
  - Cleanliness Requirement - 21/17/14
- Pump – Has correct flow and pressure
  - Cleanliness Requirement - 22/18/13
- Valve – Stuck in the center position – oil leaking around the tube's O-ring
  - Cleanliness Requirement - 18/16/13

Oil Complaint Card

Contamination Code

- 20/16/13

Type of contaminants found

- Fiber

Filter Information

- Beta Ratio – 2

Component Information

- Cylinder – Not moving when a solenoid activates the DCV
  - Cleanliness Requirement - 21/17/14
- Pump – Has correct flow and pressure
  - Cleanliness Requirement - 22/18/13
- Valve – Stuck in the center position
  - Cleanliness Requirement - 18/16/13

Oil Complaint Card

Contamination Code

- 18/18/13

Type of contaminants found

- Fiber

Filter Information

- Beta Ratio – 2

Component Information

- Cylinder – Moves erratically when a solenoid activates the DCV
  - Cleanliness Requirement - 21/17/14
- Pump – Has correct flow and pressure
  - Cleanliness Requirement - 22/18/13
- Valve – Moves erratically
  - Cleanliness Requirement - 18/16/13

Oil Complaint Card

Contamination Code

- 25/16/13

Type of contaminants found

- Silica
- Polymer

Filter Information

- Beta Ratio – 200

Component Information

- Cylinder – Not moving when a solenoid activates the DCV
  - Cleanliness Requirement - 21/17/14
- Pump – Has correct flow and pressure
  - Cleanliness Requirement - 22/18/13
- Valve – Stuck in the center position – valve leaks – valve used in a dry, dusty environment
  - Cleanliness Requirement - 18/16/13

Oil Complaint Card

Contamination Code

- 22/18/13

Type of contaminants found

- Rust
- Polymer

Filter Information

- Beta Ratio – 100

Component Information

- Cylinder – Not moving when a solenoid activates the DCV – seal leaks – cylinder is used in a high moisture environment
  - Cleanliness Requirement - 21/17/14
- Pump – Has correct flow and pressure
  - Cleanliness Requirement - 22/18/13
- Valve – Stuck in the center position -
- Cleanliness Requirement - 18/16/13

Name____

CASE

Lesson 6.3 Check for Understanding

1. What evidence on a hydraulic cylinder would indicate a worn gland seal?

2. Match the gear pump damage with the cause.

   ______ Discolored bearings and bushings

   ______ Leaking seals

   ______ Cracked gear

   ______ Internal scoring

   ______ Pitted metal

A.	Dirt and debris
B.	Cavitation
C.	High-temperature oil
D.	Excessive pressure
E.	Friction

3. List three identifying characteristics of a fitting.

4. What type of fitting threads require a sealant?
   a) Tapered threads
   b) Parallel threads
   c) Imperial threads
   d) Metric threads

5. List three hydraulic oil contaminants and the cause for each.

6. Which of the following fluids used with a component having an 18/16/13 standard needs to be flushed?
   a) 18/16/12
   b) 15/10/8
   c) 16/14/13
   d) 22/16/13

7. Explain how a technician could use contaminated oil to identify a broken part.

CASE

Lesson 6.3 Check for Understanding Answer Key

1. What evidence on a hydraulic cylinder would indicate a worn gland seal?

   Oil will be leaking from the cylinder between the barrel and gland on the rod end.

2. Match the gear pump damage with the cause.

   __**E**__ Discolored bearings and bushings
   __**C**__ Leaking seals
   __**D**__ Cracked gear
   __**A**__ Internal scoring
   __**B**__ Pitted metal

   A. Dirt and debris
   B. Cavitation
   C. High-temperature oil
   D. Excessive pressure
   E. Friction

3. List three identifying characteristics of a fitting.

   Tapered or Parallel
   Thread pitch
   Type of threads
   Diameter

4. What type of fitting threads require a sealant?

   a) **Tapered threads**
   b) Parallel threads
   c) Imperial threads
   d) Metric threads

5. List three hydraulic oil contaminants and the cause for each.

   Silica – Dirt and Dust
   Polymer – Broken seals
   Rust – Water
   Metal – Internal wearing and scoring
   Fiber – Rags from cleaning

6. Which of the following fluids used with a component having an 18/16/13 standard needs to be flushed?

   a) 18/16/12
   b) 15/10/8
   c) 16/14/13
   d) **22/16/13**

7. Explain how a technician could use contaminated oil to identify a broken part.

Technicians use the type of contamination to determine the source or root cause. If a technician knows the root cause is a broken part, they can fix the problem.

CASE

Lesson 7.1 Practical Evaluation

Preface

Agricultural producers have high expectations for the technicians working on their equipment. Because agricultural production is seasonal and weather-dependent, producers have a short time frame to grow and harvest their crops. Therefore, technicians must be aware of their customers' needs and prepared to work within those seasonal time frames.

Use Lesson 7.1 Practical Evaluation to assess student comprehension and technical skill development. Students begin the lesson by inspecting a tractor and implement needing repair and maintenance. Next, students demonstrate diagnostic skills learned during the course. Finally, students take an end-of-course assessment and compile a portfolio of work.

Concepts	Performance Objectives
Students will know and understand	*Students will learn concepts by doing*
1. Technicians work with producers to periodically maintain equipment for optimum agricultural production.	• Assess the mechanical systems of a tractor and implement and write a work/repair order for recommended maintenance. (Project 7.1.1)
2. Troubleshooting and service procedures are essential for long-term equipment performance.	• Complete service procedures for hydraulic, electrical, and power train systems. (Activity 7.1.2)
3. Practical experiences are essential when preparing for a technical career.	• Compile a work portfolio of technical skill competencies. (Foundational SAE Checklist)

National AFNR Common Career Technical Core Standards Alignment

Career Ready Practices
2. Apply appropriate academic and technical skills.
• CRP.02.01: Use strategic thinking to connect and apply academic learning, knowledge, and skills to solve problems in the workplace and community.
• CRP.02.02: Use strategic thinking to connect and apply technical concepts to solve problems in the workplace and community.
4. Communicate clearly, effectively and with reason.
• CRP.04.02: Produce clear, reasoned and coherent written and visual communication in formal and informal settings.
8. Utilize critical thinking to make sense of problems and persevere in solving them.
• CRP.08.01: Apply reason and logic to evaluate workplace and community situations from multiple perspectives.
• CRP.08.02: Investigate, prioritize, and select solutions to solve problems in the workplace and community.
10. Plan education and career path aligned to personal goals.
• CRP.10.04: Identify, prepare, update and improve the tools and skills necessary to pursue a chosen career path.
11. Use technology to enhance productivity.
• CRP.11.01: Research, select and use new technologies, tools, and applications to maximize productivity in the workplace and community.
Agriculture, Food, and Natural Resources Career Cluster
5. Describe career opportunities and means to achieve those opportunities in each of the AFNR career pathways.

• AG.5.1: Locate and identify career opportunities that appeal to personal career goals.
• AG.5.2: Match personal interest and aptitudes to selected careers.
Power, Structural and Technical (AG-PST)
1. Apply physical science principles and engineering applications related to mechanical equipment, structures, and biological systems to solve problems and improve performance in AFNR power, structural, and technical systems.
• AG-PST 1.2: Use hand and power tools commonly required in power, structural, and technical systems
• AG-PST 1.3: Investigate solutions to AFNR power, structural, and technical systems.
2. Operate and maintain mechanical equipment related to AFNR power, structural, and technical systems.
• AG-PST 2.1: Maintain machinery and equipment by performing scheduled service routines.
• AG-PST 2.2: Perform service routines to maintain power units and equipment.
3. Service and repair mechanical equipment and power systems used in AFNR power, structural and technical systems.
• AG-PST 3.1: Service and repair the components of internal combustion engines using procedures for troubleshooting and evaluating performance.
• AG-PST 3.2: Service and repair power transmission systems following manufacturer's guidelines.
• AG-PST 3.3: Service and repair hydraulic systems by evaluating performance using maintenance manuals.
• AG-PST 3.4: Service and repair steering, suspension, traction, and vehicle performance systems by checking performance parameters.
• AG-PST 3.6: Service electrical systems by troubleshooting from schematics.

Common Core State Standards for English Language Arts

CCSS: English Language Arts Standards » Science & Technical Subjects » Grade 11-12	
Key Ideas and Details	• **RST.11-12.3 –** Follow precisely a complex multistep procedure when carrying out experiments, taking measurements, or performing technical tasks; analyze the specific results based on explanations in the text.
Craft and Structure	• **RST.11-12.4 –** Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to grades 11-12 texts and topics.
Integration of Knowledge and Ideas	• **RST.11-12.7 –** Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem.
Range of Reading and Level of Text Complexity	• **RST.11-12.10 –** By the end of grade 12, read and comprehend science/technical texts in the grades 11-CCR text complexity band independently and proficiently.

CCSS: English Language Arts Standards » Writing » Grade 11-12	
Production and Distribution of Writing	• **WHST.11-12.4 –** Produce clear and coherent writing in which the development, organization, and style are appropriate to task, purpose, and audience.
Research to Build and Present Knowledge	• **WHST.11-12.9 –** Draw evidence from informational texts to support analysis, reflection, and research.
Range of Writing	• **WHST.11-12.10 –** Write routinely over extended time frames (time for reflection and revision) and shorter time frames (a single sitting or a day or two) for a range of discipline-specific tasks, purposes, and audiences.

Essential Questions

1. How does a technician determine if equipment is ready to use?
2. What technical skills does a technician need to move into the workforce?
3. How has Technical Applications in Agriculture prepared you for technical careers?

Key Terms

Portfolio

Supervised agricultural experience (SAE)

Day-to-Day Plans
Time: 6 days

*Refer to the Teacher Resources section for specific information on teaching this lesson, in particular **Lesson 7.1 Teacher Notes**, **Lesson 7.1 Glossary**, **Lesson 7.1 Materials**, and other support documents.*

Day 1 – 2:

- Present **Concepts**, **Performance Objectives**, **Essential Questions**, and **Key Terms** to provide a lesson overview.
- Provide students with a copy of **Project 7.1.1 Routine Maintenance**, **Work/Repair Order Template**, and **Project 7.1.1 Evaluation Rubric**.
- Students complete *Project 7.1.1 Routine Maintenance*.
- Use *Project 7.1.1 Evaluation Rubric* to assess *Project 7.1.1 Routine Maintenance*.

Day 3 – 4:

- Provide students with a copy of **Activity 7.1.2 Technical Practice**.
- Students complete *Activity 7.1.2 Technical Practice*.

Day 5:

- Students complete the *TAA End of Course Assessment*.

Day 6:

- Students use the **SAE for All Foundational Checksheet** to document their accomplishments and complete their Foundational SAE.

Instructional Resources

Student Support Documents

Lesson 7.1 Glossary

Project 7.1.1 Routine Maintenance

Activity 7.1.2 Technical Practice

SAE for All Foundational Checksheet

Teacher Resources

Lesson 7.1 Practical Evaluation PDF

Lesson 7.1 Teacher Notes

Lesson 7.1 Materials

TAA End of Course Assessment

Answer Keys and Assessment Rubrics

Project 7.1.1 Evaluation Rubric

Work/Repair Order Evaluation Rubric

Student Project Development Template

Work/Repair Order Template

Reference Sources

FFA Connections

This lesson provides conceptual and procedural knowledge required for participation in the following FFA activities:

- Agricultural Proficiency
    -
- Agriscience Fair
    -
- Career Development Events
    -

For more information, visit the **National FFA Organization** website.

SAE for All

Foundational SAE

All students in an agricultural education program are expected to have a Foundational SAE. Students completing the APP and extensions listed below will meet the Foundational SAE qualification for the *Advanced (Grades 11-12) level*. Students should place all documented evidence in the *FFA/SAE* section of their *Agriscience Notebook* along with the *SAE for All Foundational Checksheet*.

- Authentic Experience
    - Project 7.1.1 Routine Maintenance
    - Activity 7.1.2 Technical Practice

Immersion SAE

Students interested in this lesson's topics should explore the following related Immersion SAEs. An immersion SAE is optional and replaces the agricultural literacy component of the Foundational SAE.

- Ownership/Entrepreneurship
    -
- Placement/Internship
    -
- Research
    -
- Service Learning
    -
- School Based Enterprise
    -

For more information on the guiding principles for implementing SAE programs, visit the **SAE for All: Evolving Essentials** site.

Lesson 7.1 Teacher Notes

Lesson 7.1 Practical Evaluation

In preparation for teaching this lesson, review Concepts, Performance Objectives, Essential Questions, and Key Terms. Also, review all activity, project, and problem directions, expectations, and work students will complete.

Students complete the *Technical Applications in Agriculture* course with performance and written assessments. First, students complete *Project 7.1.1 Routine Maintenance* and *Activity 7.1.2 Technical Practice* as performance assessments. During these APPs, students inspect the equipment, complete a *Work/Repair Order*, identify electrical components, complete precision measurements, and analyze a hydraulic schematic. Students complete a written end-of-course assessment for certification and document completion of a Foundational SAE to conclude the course.

Activities, Projects, and Problems

Project 7.1.1 Routine Maintenance

Students work individually to inspect a tractor and an attached implement for routine seasonal maintenance.

Teacher Preparation

1. Obtain a tractor and attach an implement. Implements can range from various applications, such as agricultural production, landscaping, sports turf management, or construction. Provide students with SDS sheets and maintenance manuals for the tractor and equipment.
2. Prepare documents and samples.
    - Print the maintenance manual for the tractor and implement.
    - Place a sample of hydraulic oil in a 10ml plastic vial for inspection. Consider using a vial from *Project 6.3.4 Filter and Flush*.
    - Place a sample of coolant in a 10ml plastic vial for inspection.
3. Provide various measurement and diagnostic tools. Throughout the course, students have used diagnostic tools. Students should be able to obtain the following tools for the tasks in this project:
    - Digital multimeter (DMM)
    - Microscope
    - Petri dish
    - Pipet, 1ml
    - Refractometer
4. Post the **Work/Repair Order Template** on your local LMS platform for student access.

Student Performance

Part One

Demonstrate proper use and operation of the tractor and attached implement. During the demonstration, raise or lift any machine components to exhibit the machine's function and hydraulic implements. Afterward, park the tractor, lower the implement, and disconnect the PTO shaft from the tractor. After the demonstration, students inspect the tractor and implement and complete the *Equipment Safety Checklist*.

Part Two

Students inspect the hydraulic system, describing the pump, system, and state in the *Hydraulic Information* sheet. Next, they observe the hydraulic fluid and SDS and record the following information in Table 2:

- First-aid measures
- Fire and explosion hazards
- Precautions for safe handling and use
- Physical and chemical properties

Next, students inspect hydraulic components and fittings in Tables 3–4.

Part Three
During Part Three, students inspect the drive train. First, they record the tire sizes of the rear tractor tire and the implement tire. Next, students sketch the tractor and implement and label the location of each grease fitting. Then, they inspect bearings. They label bearings on the drawing using the following marks below:

- *F* – Friction bearing
- *N* – Non-friction bearing
- *X* – Worn-bearing

Part Four
Students inspect the fuel and electrical system in Part Four. It is important for this process that the engine is cold. First, they describe the fuel system and check all fluids. Then, inspect the quality of fluids using the sample coolant and hydraulic oil provided. Then, they read the battery voltage and inspect for any parasitic current draw.

Part Five
Students work individually to complete a Work/Repair Order using diagnostics from Parts One through Four. Within the order, they include fluids in *Key Parts* and record procedures for replacing parts of fluids under *Correction*. Lastly, they record how they will *Confirm* equipment operation.

Results and Evaluation
Assess equipment safety, maintenance information, and the *Work/Repair Order Template* using the **Project 7.1.1 Evaluation Rubric**.

Activity 7.1.2 Technical Practice

Students work independently to rotate through electrical, measurement, and hydraulic stations. They practice diagnostic techniques to complete a routine technician skill at each station.

Teacher Preparation
Set up three stations. Provide sufficient equipment and supplies at each station for students to complete tasks individually.

Station 1: Electrical

1. Place the following components on a separate table.
    - Relay
    - Resistor
    - (2) Batteries
    - Potentiometer
    - Fuse
2. Create a key for the questions listed in Table 2 of *Activity 7.1.2 Student Diagnostics*. Save the key for assessing students.
3. Arrange EETC Electrical Training Boards and DMMs on tables. Provide five wires with alligator clips at each board.

Station 2: Measurement

1. Place the following parts on tables at Station 2. Create a key for each measurement and save it for assessing students.
    - Piston and sleeve – Place a hydraulic cylinder with a piston on the table.
    - Gear system – Gearbox, transmission, or assembly from *Activity 2.1.1 Manual Transmission*.
    - Wheel hub – Set the assembly shaft of a wheel hub in a vise. Remove the dust cap from the bearing assembly. Tighten a lug nut on a stud of the idler hub to 60 in-lbs.
2. Supply the following tools on tables at Station 2.
    - Dial caliper
    - Dial indicator
    - Torque-wrench (in-lbs.)

Station 3: Hydraulics
Students use the schematic in the *Activity 7.1.2 Student Diagnostics* page at this station.

Student Performance
Students work individually to rotate through three stations. At each station, they complete routine technician tasks. Split students between each rotation and provide directions on how to flow through the stations.

Station 1: Electrical
Part One has three components. First, students review the first electrical schematic to complete Table 1. They use the schematic to identify the circuit type, total voltage, resistance, and current. Next, students review a table with electrical components to answer the diagnostic questions. Then, students assemble the fuel solenoid branch of the circuit shown in Figure 1.

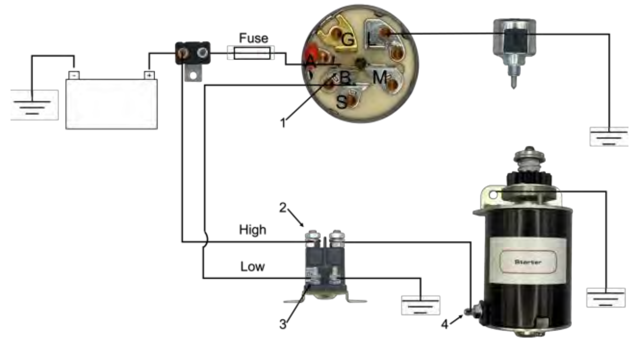

Figure 1. Electrical Schematic

Station 2: Measurement
Students use the provided tools to measure parts on a table. They measure the following components and answer the diagnostic questions on the student diagnostics page.

- Piston and sleeve diameter
- Gear backlash
- Wheel hub endplay
- Lug nut torque
- Bolt size and grade

Station 3: Hydraulics
Students use the schematic in *Activity 7.1.2 Student Diagnostics* page to answer the *Part Three Hydraulic Questions*.

Results and Evaluation
Review the *Activity 7.1.2 Student Diagnostics* page to assess student competency. Table 1 includes example responses to electrical diagnostics and *Part Three Hydraulic Questions*. Compare the student schematics for completeness and accuracy. Then, compare student responses to electrical components and measurement diagnostic questions to keys prepared during *Teacher Preparation*.

Table 1. *Keys for Assessing Activity 7.1.2 Student Diagnostics*

Electrical Diagnostics			
Circuit Type (Circle One)	**Series**	Parallel	Series/Parallel
Total Voltage	**12 V**		
Total Resistance	**8Ω**		
Total Current	**1.5 A**		

Part Two Measurement Questions		
Q1	What are the piston and sleeve diameters?	*Provide local keys for these questions using precision measurement equipment.*
Q2	What is the backlash of the following gear system?	
Q3	What is the endplay of the wheel hub?	
Q4	What is the torque of the bolt on the wheel hub?	
Q5	What is the bolt size and grade on the wheel hub?	

Part Three Hydraulic Questions		
Q6	Is the system an open loop or closed loop?	*Closed loop system.*
Q7	How is the directional control valve operated?	*Spring activated lever*
Q8	Where is the check valve located?	*The speed that the cylinder extends.*
Q9	How does the flow control valve impact the extension of the cylinder rod?	*It controls the fluid flow into the rod end.*
Q10	How does the flow control valve impact the retraction of the cylinder rod?	*It controls flow of fluid into the base end.*
Q11	What is the minimum system pressure needed to lift a 2000 lb object if the cylinder diameter is 2.5″?	*The pressure must be greater than 408 lbs.* *Cylinder area =* πr^2 *Cylinder area =* $\pi 1.25^2$ *Cylinder area = 4.9* in^2 *2000 lbs/ 4.9* in^2 *= 408* lbs/in^2

SAE for All Foundational Checksheet

Students place past work into a portfolio as evidence of preparedness for an agricultural technician career.

Assessment

TAA End of Course Assessment

Students complete the *TAA End of Course Assessment* to obtain industry certification from the Associated Equipment Distributors (AED) Foundation.

Name____ CASE

Project 7.1.1 Routine Maintenance

Purpose

Just as agricultural production is seasonal, the demand for technician services is also seasonal. A producer's equipment may have dirt, debris, and wear and tear from the past season. As an agricultural technician, you will need to be prepared to inspect and repair equipment before seasonal production begins. What should you inspect when preparing equipment for the field?

Materials

Per class:

- Coolant sample
- SDS sheets
- Maintenance manuals for tractor and implement
- Measurement and diagnostic tools
- Oil sample
- Shop towels
- Tractor and attached implement

Per student:

- Clipboard
- Nitrile gloves
- Safety glasses
- *Agriscience Notebook*
- *Logbook*
- *Work/Repair Order Template* with complaint
- *Project 7.1.1. Evaluation Rubric*

Procedure

Your teacher will provide you with a maintenance manual and a brief description of a customer's complaint about a tractor and the attached implement. Complete a safety and maintenance inspection for the tractor and attached implement provided by your teacher. Then write a *Work/Repair Order* for any needed repairs and maintenance.

Part One – Equipment Safety Checklist

1. Put on safety glasses and nitrile gloves, and tie back long hair.
2. Observe your teacher start and operate the tractor and attached implement.
3. Complete the *Equipment Safety Checklist.*
4. Obtain a *Work/Repair Order Template* with complaint from your teacher.

Part Two – Hydraulic System

1. Complete Table 1 on the *Hydraulic System* sheet by circling the terms that best describe the hydraulic system.
2. Observe the hydraulic fluid and SDS sheet provided by your teacher and complete Table 2.
3. Inspect the hydraulic components and complete Tables 3 and 4.

Part Three – Drive Train

4. Record the tire information for the rear tractor tire and implement tire in Table 5 of the *Drive Train* sheet.
5. Sketch the tractor and implement and place a circle by the location of each grease fitting in Figure 1.

6. In the sketch, label friction bearings with an *F* and non-friction bearings with an *N*.
7. Place an *X* where bearings are worn.

Part Four – Fuel and Electrical System

1. Complete Table 6 on the *Fuel and Electrical System* sheet by circling the terms best describing the fuel system.
2. Check the fluids listed in Table 6 and record if it is low.
    - Do not check the radiator if the engine is hot.
    - Use the sample coolant provided by your teacher.
3. Use the appropriate tools to determine the quality of each fluid. Record in Table 6.
4. Measure the tractors' battery voltage while off and idling. Record in Table 7.
5. Check the tractor for parasitic current draw. Record the current draw in Table 7.

Part Five – Work/Repair Order

Complete a *Work/Repair Order*. Start by using the information collected during Parts One through Four and the maintenance manuals to record the Cause of any customer concerns. Next, record the *Key Parts,* including any fluids needing replacement. Then record the procedure for replacing the parts and/or fluids under *Correction*. Finally, record how you will *Confirm* the equipment is operating properly. Your teacher will use *Project 7.1.1 Evaluation Rubric* to assess your equipment safety and maintenance information and your *Work/Repair Order*.

Conclusion

1. What tools and resources did you use to inspect the tractor and equipment?

2. Why would an agricultural producer want a technician to inspect their equipment periodically?

Name____

CASE

Equipment Safety Checklist

Equipment Name:

Non-Mechanical Hazards

Is there a potential noise hazard?	**Yes**	**No**	If yes, what PPE is needed?
Does the equipment produce harmful substances?	**Yes**	**No**	If yes, what PPE is needed?

Mechanical Inspection

Power Sources			**Power Transmission**			**Points of Operation**		
Place a check by all observed sources:			Place a check by all observed components:			Describe the work observed at the operation points.		
Electrical	☐		Belt and pully	☐				
Mechanical (Power take-off)	☐		Chain and sprocket	☐				
Combustion engine	☐		Gears	☐				
Hydraulic	☐		Hoses	☐				
Pneumatic	☐		Cylinders and rods	☐				
Are all power sources connected properly?	**Yes**	**NO**	Are any power transmission components exposed?	**Yes**	**NO**	Is there point of operation safeguards for the equipment?	**Yes**	**NO**
Are all power sources safeguarded?	**Yes**	**NO**	Do any power transmission components need maintenance?	**Yes**	**NO**	Have safeguards been tampered with or removed?	**Yes**	**NO**
What maintenance do you recommend?			What maintenance do you recommend?			What maintenance do you recommend?		

Mechanical Hazards

Place a check by any motions or actions that are potential hazards for each equipment area. Record the type of guard preventing injury from that action or motion.

Action or Motion	**Power Source**		**Power Transmission**		**Point of Operation**	
		Type of Guard in Place		**Type of Guard in Place**		**Type of Guard in Place**
Rotating	☐		☐		☐	
In-Running Nip Points	☐		☐		☐	
Reciprocating	☐		☐		☐	
Transversing	☐		☐		☐	
Cutting	☐		☐		☐	
Punching	☐		☐		☐	
Shearing	☐		☐		☐	
Bending	☐		☐		☐	

**** Types of guards: Fixed, Interlocked, Adjustable, Self-adjusting***

Hazard Prevention

Where are the operating controls located?
How is the equipment isolated (locked out) from its energy source before a technician performs maintenance?
What hazards should the operator be aware of before using the equipment?
What PPE should an operator wear to prevent injuries from mechanical hazards?

Hydraulic System

Table 1. ***Hydraulic System Information***

Pump Classification	Positive Pump		Non-positive Pump
Pump Type	Gear	Vane	Piston
System Classification	Closed Loop		Open Loop
Zero Energy State	Yes		No

Table 2. ***Hydraulic Fluid Information***

Fluid Name	
First Aid Measures	
Eye Contact	
Skin Contact	
Inhalation	
Ingestion	
Fire and Explosion Hazards	
Flammability of Product	
Fire Fighting Media	
Precautions for Safe Handling and Use	
Spillage	
Precautions for Handling and Storage	
Personal Protective Equipment Needed	
Physical and Chemical Properties	
Physical State and Appearance	
Specific Gravity	
ISO Grade	
Viscosity	
Viscosity Index	
Anti-wear additives	
Emulsifying additives	
Pour Point	

Table 3. ***Components***

Valves	Actuators	Electrical Controls

Table 4. ***Conductor and Fitting Inspection***

Conductor and Fitting Defects	Location	Hazard/Safety Concerns	Correction
Cracked			
Poorly fitted			
Leaky			
Bent or kinked			

Drive Train

Table 5. ***Tire Size***

Tire Information	Rear Tractor Tire	Implement Tire
Tire size		
Width		
Sidewall height		
Rim diameter		
Ply Type		
Load index		
Speed rating		
Inflation		
Manufacturing date		
Metric/Imperial		

Figure 1. Grease Fittings and Bearings

Fuel and Electrical Systems

Table 6. ***Fuel System Information***

Fuel Type	Gas		Diesel
Air Filter Type	Oil		Dry
Number of Pistons			
Fluid	**Specifications**	**Level**	**Quality**
Coolant			
Def (If Applicable)			
Engine Oil			

Table 7. ***Electrical Information***

Battery Voltage (off)	
Battery Voltage (idle)	
Parasitic Current Draw	

Name____

CASE

Project 7.1.1 Evaluation Rubric

Areas with Room for Improvement	Criteria	Areas that Meet or Exceed Expectations
	Safety The student uses proper PPE and safety procedures while inspecting the equipment	
	Tool Usage The student uses the proper tools while inspecting the equipment.	
	Completeness The Work/Repair order addresses all safety and system concerns identified by the student.	
	Grammar The work/repair order uses proper grammar throughout the document.	
	Concisely Written The student wrote the work/repair order concisely, using only the necessary wording and jargon.	
	Correct Terminology The work/repair order uses the correct terminology to communicate parts, failures, and procedures during diagnosis and correction.	
	Professional The order is professional and appropriate to file with employers and provide to the customer. The complaint, cause, key part, correction, and confirm sections are communicated clearly.	

Name____ CASE

Activity 7.1.2 Technical Practice

Purpose

You have learned many diagnostic skills throughout the *Technical Applications in Agriculture* course. A technician utilizes these skills each day on the job. They use diagnostic and measurement tools for solving electrical, mechanical, hydraulic, and engine problems. In addition, technicians read schematics associated with mechanical components. Practice what you have learned to show you have the skills to be a technician.

Materials

Per student:

- Safety glasses
- Pen
- *Agriscience Notebook*
- *Logbook*

Per class:

- Three stations

Procedure

Use what you have learned in this course to practice diagnostic techniques.

Put on safety glasses and tie back long hair. Your teacher will assign you a station. Rotate to the next station when instructed by your teacher. Turn in the *Activity 7.1.2 Student Diagnostic* sheet after you have completed all stations and steps. Refer to your *Logbook* and *Agriscience Notebook* when needed.

Station One – Electrical

1. Complete Table 1 on the *Activity 7.1.2 Student Diagnostics* sheet.
    - Use the example circuit and schematic in Figure 1.
2. Find the voltage drop for each component in Figure 1.
3. Record the voltage drop at each component in Figure 1.
4. Find the electrical components listed in Table 2 at your station and answer the diagnostic question for each.
5. Use the schematic in Figure 2 to wire the fuel solenoid circuit using the provided components.

Station Two – Measurement

Use the appropriate tools to answer *Station Two Measurement Questions*.

Station Three – Hydraulic

Review the schematic in Figure 3 of the diagnostic sheet. Then, answer the *Station Three Hydraulic Questions*.

Conclusion

Why are schematics and diagnostic tools essential for a technician's job?

Name____

Activity 7.1.2 Student Diagnostics

Station One – Electrical

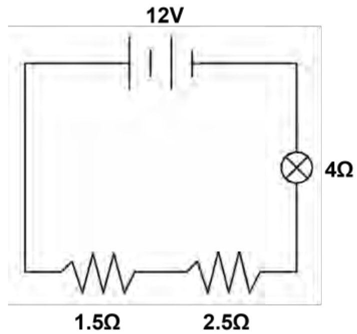

Figure 1. Electrical Schematic

Table 1. ***Electrical Diagnostic***

Circuit Type (Circle One)	Series	Parallel	Series/Parallel
Total Voltage			
Total Resistance			
Total Current			

Table 2. ***Electrical Components***

Component	**Diagnostic Questions**
Diode	Which end is the positive and which is the negative?
Relay	Is the relay normally open or normally closed?
Resistor	What is the resistor's resistance?
Batteries	What is the total voltage of these batteries when wired in series?
Potentiometer	What is the range of resistance?
Fuse	How much electrical current will it take to damage the fuse?

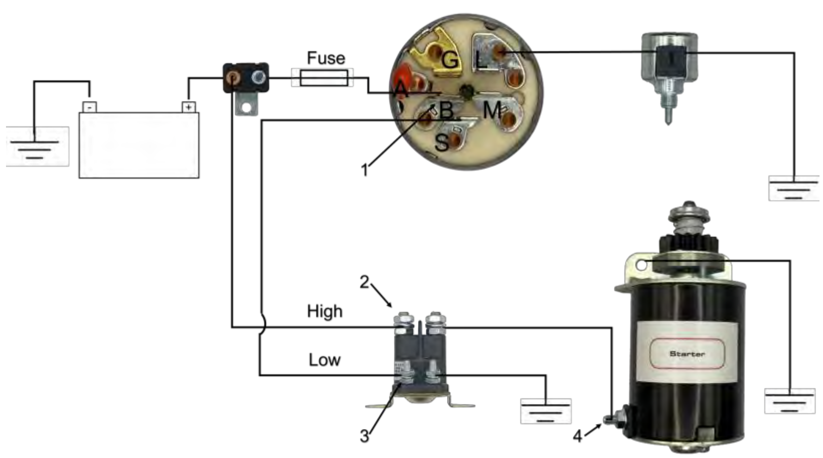

Figure 2. Electrical Schematic

Station Two – Measurement

Station Two Measurement Questions

Q1 What are the piston and sleeve diameters?

Q2 What is the backlash of the following gear system?

Q3 What is the endplay of the wheel hub?

Q4 What is the torque of the bolt on the wheel hub?

Q5 What is the bolt size and grade on the wheel hub?

Station Three – Hydraulic

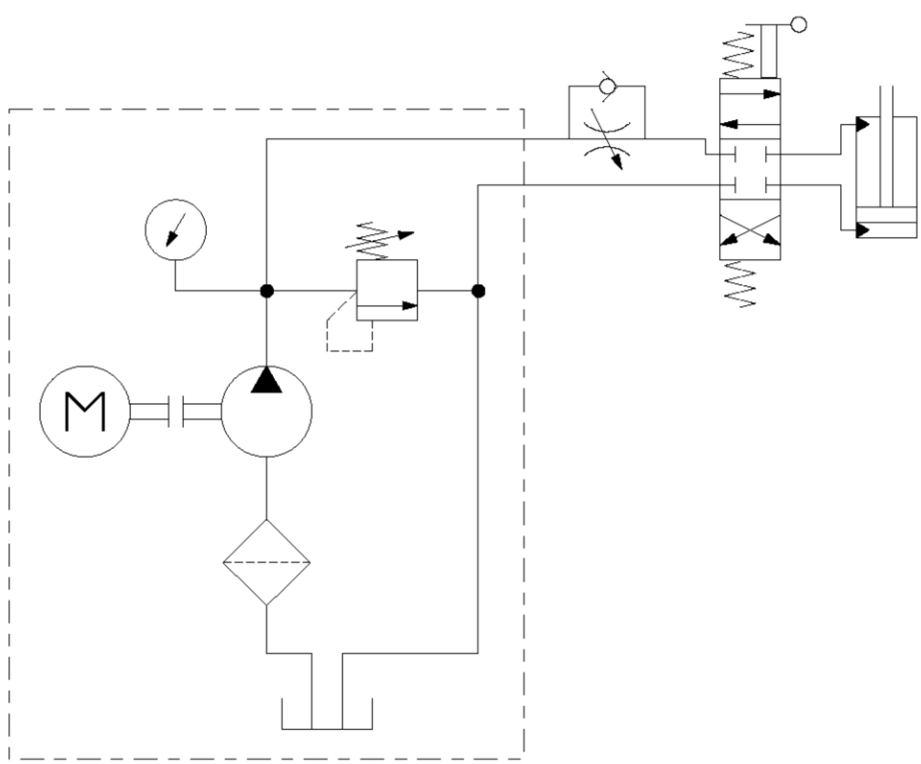

Figure 3. Hydraulic Schematic

Station Three Hydraulic Questions

Q6 Is the system an open loop or closed loop?

Q7 How is the directional control valve operated?

Q8 Where is the check valve located?

Q9 How does the flow control valve impact the extension of the cylinder rod?

Q10 How does the flow control valve impact the retraction of the cylinder rod?

Q11 What is the minimum system pressure needed to lift a 2000 lb object if the cylinder diameter is 2.5″?