Unit	1083
Title	Describe Heavy Equipment Mechanical Systems
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BC **Forest Safety**

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Feedback is welcome and may be sent to training@bcforestsafe.org

Table of Contents

Unit Introduction

What you will learn in this unit

By the end of this unit, you will be able to demonstrate knowledge of:

- Engines
- Hydraulic systems
- Powertrain systems
- Track systems
- Braking systems
- Electrical systems
- Ground engaging tool systems

Why it's important for you to learn this unit

Heavy equipment and machinery is used in all aspects of harvesting. Keeping that equipment operating correctly can optimize its efficiency, longevity and the safety of workers.

Are you ready to take this unit?

To take this unit, you need to have completed the following unit:

- 1002 – Describe Forestry Industry

Does this unit apply to you?

This unit applies to:

- All Road Building Equipment occupations
- All Mechanized Harvesting Equipment occupations

Section 1083-01: Engines

What you need to know about this section

By the end of this section, you will be able to demonstrate knowledge of the following key points:

1.1 Basic engine theory including parts and functions

1.2 Lubrication theory systems and functions

1.3 Cooling systems and functions

1.4 Fuel systems and functions

1.5 Air induction and exhaust systems and functions

Key Point 1.1: Basic Engine Theory including Parts and Functions

Combustion Engine Overview

A combustion engine is an engine that generates mechanical power by burning fuel, for example, gasoline or diesel. Most heavy forestry equipment machines use diesel engines because they require greater torque. Diesel engines also consume less fuel as compared to gasoline engines.

Both gasoline and diesel engines are types of internal combustion engines. For heavy equipment machines such as skidders, feller bunchers, excavators and front loaders, a diesel engine supplies the necessary power.

Both diesel and gasoline engines operate by the chemical process of combustion. This is achieved by igniting compressed fuel in the combustion chambers or cylinders.

For a gasoline engine, this process is ignited from a spark plug. For diesel engines, ignition is achieved by injecting the right mixture of fuel and air into the combustion chamber and compressing this mixture with very high pressure until it explodes, driving the piston downwards. Glow plugs in diesel engines use electric current to pre-heat the air-fuel mixture in order to help cold engines start more easily.

Watch the video below to learn why diesel engines have more torque than gasoline-powered engines.

Video 6:42

YouTube—Engineering Explained
Five Reasons Diesel Engines Make More Torque Than Gasoline
https://www.youtube.com/watch?v=D6YmAecTolQ

When you are finished, continue in this section.

Diesel engines have the following differences compared to gasoline powered engines:

- A longer stroke length. The bore width of the piston is also longer. By using the formula “Torque = Force x Distance”, a longer stroke length, or greater travel distance, means diesel engines have more torque when compared to a gasoline engine

- A higher compression ratio and are usually turbo-charged
- Heavier components, such as iron blocks, heavy duty pistons, crank shafts and connecting rods, and are built to handle an increased amount of torque
- A leaner air to fuel ratio (18:1 up to 70:1). Burning lean means there is more air to expand and this creates more useful work, which then leads to efficiency gains

Furthermore, diesel fuel has the following advantages over gasoline:

- The energy density of diesel fuel is greater than gasoline which translates into more potential power that is stored in diesel than gasoline
- Diesel fuel is safer to transport to remote work sites and transfer into equipment because the fuel will not ignite easily when not pressurized. Gasoline vapors will ignite very easily and cause explosions, even when not pressurized

4-Stroke vs. 2-Stroke Engines

Engines can operate using a 4-stroke or 2-stroke process. Most heavier engines are 4-stroke and smaller hand-held equipment such as power tools and chainsaws use the 2-stroke system. As a result, they are lighter and easier to hold.

The difference between 2-stroke and 4-stroke engines are discussed in the referenced link. The steps are summarized below.

Reference
Diesel Engine Registry
2-Stroke vs. 4-Stroke Engines
https://dieselengineregistry.wordpress.com/2-stroke-vs-4-stroke-engines/
When you are finished, continue in this section.

4-stroke steps

Step 1: Intake

Step 2: Compression

Step 3: Power

Step 4: Exhaust

2-stroke steps

Step 1: Compression

Step 2: Power

In a 2-stroke engine, each step is performed in a stroke of the piston - either up or down.

- The intake and exhaust steps are combined
- A supercharger pressurizes the air

Note: A 4-stroke engine is more fuel efficient because the burned air-fuel mixture is fully pushed out of the combustion chamber before the new unburned air-fuel mixture enters. A 2-stroke engine always has some residual burned fuel in the cylinder during the next power stroke, making the burn less efficient.

However, a 2-stroke engine can apply power more quickly to the crankshaft and rev to a higher rpm than a 4 stroke engine.

Reference

HowStuffWorks

How Diesel 2-stroke Engines Work
https://auto.howstuffworks.com/diesel-two-stroke1.htm

When you are finished, continue in this section.

Learning Point

Diesel engines ignite when the air and fuel mixture in the cylinder is compressed to the point of explosion. Whereas, gasoline engines ignite from the spark plug which allows the ignition to take place at a much lower compression. The ignition process in diesel engines is sometimes aided by the use of glow plugs to increase the starting temperature of the air-fuel mixture in colder weather conditions.

Basic Engine Theory—Self-Quiz

1. Diesel engines have more torque than gasoline engines.

   ☐ True

   ☐ False

2. Two-stroke engines are always more efficient than four-stroke engines.

   ☐ True

   ☐ False

3. In 2-stroke engines the intake and exhaust steps are combined.

   ☐ True

   ☐ False

Now check your answers on the next page.

Basic Engine Theory—Self-Quiz Answers

1. Diesel engines have more torque than gasoline engines.

   Answer: **True**

2. Two-stroke engines are always more efficient than four-stroke engines.

   Answer: **False**

3. In 2-stroke engines the intake and exhaust steps are combined.

   Answer: **True**

Key Point 1.2: Lubrication Theory Systems and Functions

Function of Lubrication

Lubrication allows engine parts to move past one another, reducing wear and friction. Insufficient lubrication will cause the engine to seize up due to metal-to-metal contact, which results in friction and melting of engine parts.

Diesel engines use an oil recirculating system. The base oil alone cannot provide all of the lubricating oil functions required in modern engines, therefore additives are used.

Lubricating oils perform a number of important functions in the diesel engine. These functions include:

- Reducing wear of components such as bearings, pistons, piston rings, cylinder liners, and the valve train
- Reducing friction of lubricated components
- Cooling pistons
- Preventing corrosion from acids and moisture
- Cleaning pistons and preventing sludge build-up on internal surfaces
- Keeping seals lubricated and controlling swelling to prevent leakage due to seal failure
- The lubricant also protects the engine from the acid caused by sulfur contained in diesel fuel
- The lubricant also protects the engine from the acid caused by sulfur contained in diesel fuel

The article below explains about the purpose of oil as a lubricant.

Reference
Engineers Edge
Diesel Engine Lubrication Systems
https://www.engineersedge.com/power_transmission/engine_lubrication.htm
When you are finished, continue in this section.

Typical Components of a Lubrication System

Typical components of a lubrication system include the following:

- **Oil pan** - provides adequate capacity and a sump, which helps supply flow even when machine is at an angle
- **Gear or rotor style pump** - supplies flow of lubrication
- **Oil filters** - removes contaminants from oil which reduces wear
- **Bypass valve** - allows oil to bypass filter as it becomes dirty
- **Oil cooler** - acts to dissipate heat from the oil (small internal tubes contain coolant which carries away the heat)
- **Pressure monitoring system** - senses pressure and sends a signal to a gauge
- **Crankcase venting** - allows for venting of unburned fuel and water vapour

The following reference explains how oil lubricants works to protect diesel engines.

Forestry equipment machines operate in extremely dust-contaminated environments. Therefore, because this dust is abrasive to the engine, lubricant is important for diesel engines.

CAUTION!
Insufficient lubrication will cause the engine to seize up.

Lubrication Systems—Self-Quiz

1. Diesel engines use recirculated engine oil as the lubricant.
   - ☐ True
   - ☐ False
2. Too much friction can cause engine parts to seize up due to:
   - ☐ Over-heating of parts
   - ☐ Metal-to-metal contact of parts
   - ☐ Wear creating improper movement of engine parts
   - ☐ All of these answers

Now check your answers on the next page.

Lubrication Systems—Self-Quiz Answers

1. Diesel engines use recirculated engine oil as the lubricant.

   Answer: **True**

2. Too much friction can cause engine parts to seize up due to:

   Answer: **All of these answers**

Key Point 1.3: Cooling Systems and Functions

The engine cooling system is important as it prevents the engine from overheating. This is accomplished by circulating engine oil and engine coolant throughout the system.

Engine oil is cooled in the oil pan below the engine before being pumped back around the engine – this helps in cooling the engine.

The engine coolant is pumped by the water pump, and is regulated by the thermostat.

All large engines are cooled by liquid coolant circulating around the engine block, then being moved out to a radiator for cooling, and back again to the engine block.

Some small engines are air cooled because they are lighter weight, and have no coolant and no radiator. An example would be on a chainsaw or a small engine on a cable yarding carriage, or small hydraulic pump on a low-bed trailer.

Cooling System Parts

Cooling System Parts include the following:

- Radiator function
- Thermostat function
- Water pump function
- Fan function

Radiator function

The radiator is a type of heat exchanger:

- Coolant flows to the radiator, which has many small air passages
- These passages provide for easy flow of air over a large surface area to absorb the heat from the liquid
- Air flow is improved by a large fan that is attached to the end of the crankshaft with the water pump
- To cool down the engine, a coolant is passed through the engine block, where it absorbs heat from the engine. The hot coolant is then fed into the inlet tank of the radiator (located either on the top of the radiator, or along one side), from which it is distributed across the radiator core through tubes to another tank on the opposite end of the radiator

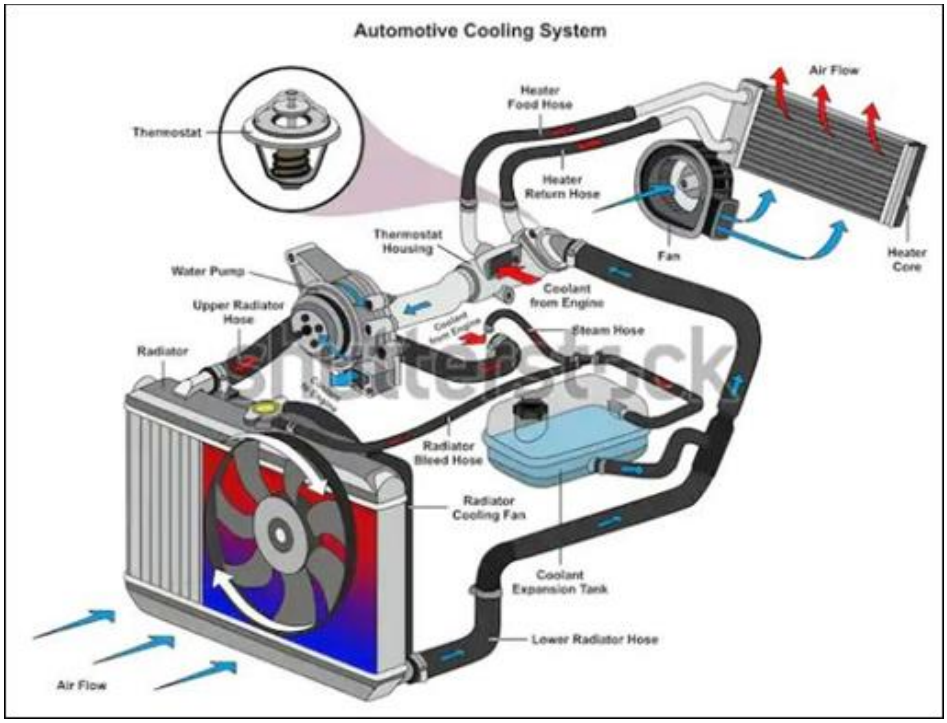
Thermostat function

The thermostat helps to control the engine temperature:

- It is a valve that helps regulate temperature.
- When liquid is cool, the thermostat is closed which restricts flow to the radiator. This causes the coolant to circulate only through the engine which speeds up the warming time.
- When the coolant reaches the thermostat's activation temperature, it begins to open, allowing water into the radiator. The thermostat will open as far as needed to maintain the ideal operating temperature, by metering the amount of water going to the radiator.

Water pump function

The water pump forces engine coolant to flow through the system (which includes the engine block, hoses and radiator) in order to remove heat. It is attached to the engine crankshaft and is driven by the pulley.



Automotive Cooling System: Engine block includes passages to bring coolant to the cylinder walls (water jacket), and other “hot” areas

Fan function

The fan automatically switches on to cool the engine or coolant. It keeps air moving through the radiator core, helping to dissipate heat and cool the machine or vehicle, at all times.

Heavy equipment used in forestry have radiator cooling fans that turn on when the engine reaches a certain temperature.

The following video explains about the fan, wax pellets, thermostat function and how the engine coolant cycles or flows around the engine cylinder.

Video 6:09

YouTube—Automotive Basics
How Car Cooling System Works
https://www.youtube.com/watch?v=V7inC4lOpGs
When you are finished, continue in this section.

CAUTION!
Do not open the radiator cap when the engine is hot!

Learning Point
Without a functional cooling system, parts would overheat and the engine would seize.

Cooling Systems—Self-Quiz

1. What is engine coolant made up of?

   - ☐ Antifreeze (ethylene glycol) and water
   - ☐ Water
   - ☐ Soap and water

2. The function of the water pump is to:

   - ☐ Drain excess coolant
   - ☐ Pressurize coolant so it will flow throughout the engine cooling system
   - ☐ Expel hot water from the engine
   - ☐ Flow coolant throughout the engine system

3. The thermostat is closed when the engine is cold.

   - ☐ True
   - ☐ False

Now check your answers on the next page.

Cooling Systems—Self-Quiz Answers

1. What is engine coolant made up of?

   Answer: **Antifreeze (ethylene glycol) + water**

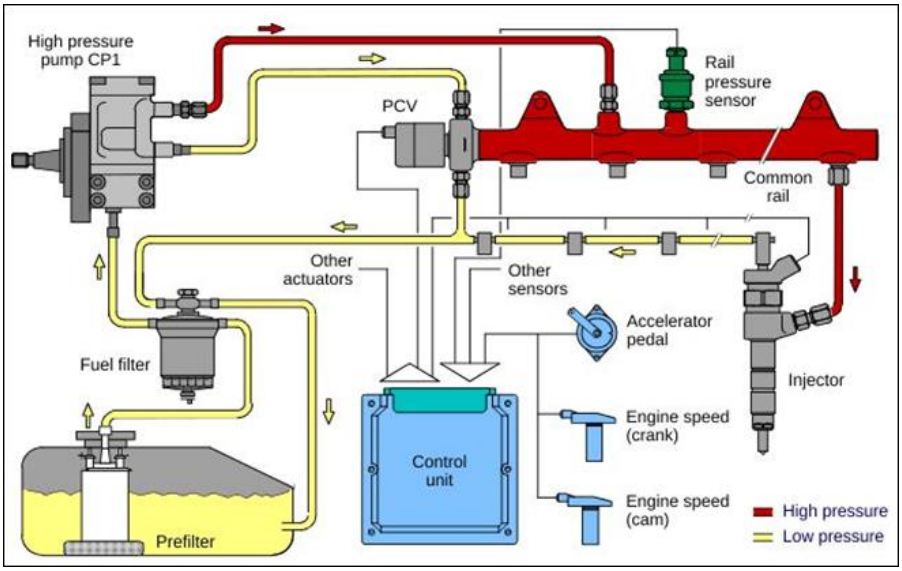
2. The function of the water pump is to:

   Answer: **Flow coolant throughout the engine system**

3. The thermostat is closed when the engine is cold.

   Answer: **True**

Key Point 1.4: Fuel Systems and Functions



The fuel system of logging trucks and forestry equipment consists of a fuel tank, filter, transfer pump, and injection pump.

The fuel filter system itself is designed to trap very fine particles, and often includes three levels of protection: a basic sump, water separator with sediment bowl, and a fuel filter.

Other parts of the fuel system include an injection pump, transfer pump and filter, and fuel tank. The fuel tank provides a reservoir of fuel and connections for outlet lines.

Fuel injectors or a carburetor work to vaporize the fluid into air inside the engine compartment so that combustion can occur.

Fuel Air Mixture

For an engine to work efficiently the fuel must be vaporized into the incoming air in what is commonly referred to as a fuel air mixture.

Carburetor vs. fuel injection – both are used to vaporize fuel into air, however carburetors are no longer used in forestry equipment.

Diesel engines always use fuel injection.

Injection Pump

The injection pump is designed to send a precisely metered amount of fuel under very high pressure to each cylinder.

Diesel Fuel

Diesel fuel has different grades. Two common grades of diesel fuel are 1-D and 2-D. Diesel fuel also labelled as clear or marked. Diesel fuel that is marked is intended for use in heavy equipment and other uses that are off highway and has some road taxes omitted.

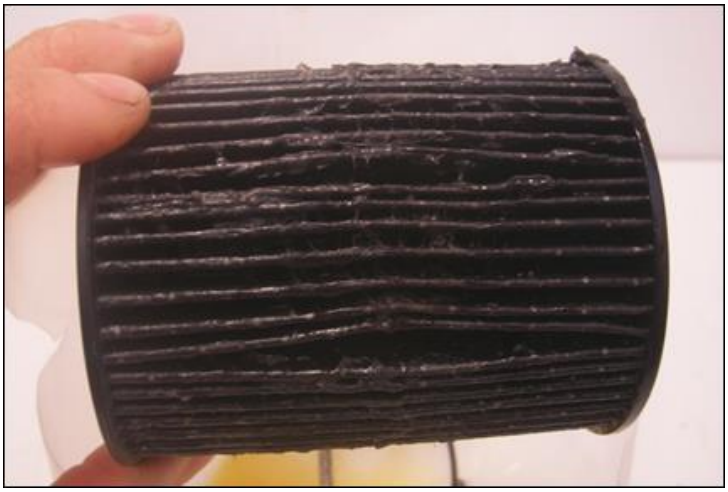
The following reference outlines some challenges when handling diesel fuel.

- Diesel fuel has a greater energy density (and is commonly used as the fuel for heavy machinery)
- Fuel filter can become clogged with contaminants: dirt, water, algae, asphaltene

These are special things that you need to do when dealing with diesel fuel – review the following article from Tigercat.

Reference

Tigercat
Dealing with Diesel Fuel
https://www.tigercat.com/service-tips/dealing-with-diesel/
When you are finished, continue in this section.



A fuel filter clogged with algae

The following reference discusses fuel efficiency and how modern diesel engines demand more attention to fuel quality and filtration than in the past. This is because modern diesel engines operate at much higher temperatures and pressures than in the past.

Reference

Tigercat Forestry Equipment
Fuel Economy Counts
https://www.tigercat.com/service-tips/fuel-economy-counts/
When you are finished, continue in this section.

Starting Fluid

Another type of fuel that is used for diesel engines is starting fluid.

Starting fluid, or ether, is a highly volatile (flammable/explosive) gas that is injected by spraying into the air intake (air filter). It is important to use it sparingly – only a quick squirt of a second to perhaps three seconds is necessary. Excessive quantities will cause damage.

It is also crucial that starting fluid be sprayed only after cranking has started, and is continuing. In other words, the starter must be engaged before and during the spray of starting fluid. It must be used sparingly, correctly, and only if necessary. It is not to be used for gasoline engines or any other applications.

Fuel Systems—Self-Quiz

1. What are some common contaminants that find their way into the fuel filter?

   - ☐ Dirt
   - ☐ Water
   - ☐ Algae
   - ☐ All of these answers

Now check your answers on the next page.

Fuel Systems—Self-Quiz Answers

1. What are some common contaminants that find their way into the fuel filter?

   Answer: **All of these answers**

Key Point 1.5: Air Induction and Exhaust Systems and Functions

How the Air Induction System Works

The function of an air induction system is to supply the correct amount of air needed to increase the combustion and the efficiency of an engine. On a diesel engine, the air intake system cleans the intake air, silences the intake noise, and provides air for turbocharging.

Air filter

The air filter removes particles and allows adequate flow of clean intake air to ensure efficient combustion. This is important to prevent contaminants from entering the engine. For some vehicles such as articulated haul trucks, there is a pre cleaner to remove larger particles.

Watch the following video to watch an air filter change on an excavator.

Video 6:09
YouTube—Tom Brueggen
Link Belt 3400 Excavator Air Filter Replacement
https://www.youtube.com/watch?v=gRavhFG3FIc
When you are finished, continue in this section.

An air flow restriction indicator shows visually how plugged the air filter is and when it needs to be replaced.

Air intake restriction indicator – photo by Chris Cole, RPF, PEng

The following reference describes the importance of dust control for modern diesel engines. Here are some key points:

- Modern diesel engines require extremely clean fuel and air to function properly
- Air filters do not have to be changed as often as oil filters
- A visual indicator will pop up when the air filter has reached its maximum restriction

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Reference

Equipment World
Dust Control: Know how your air filters work and how to change them to avoid big repair bills
https://www.equipmentworld.com/dust-control-know-how-your-air-filters-work-and-how-to-change-them-to-avoid-big-repair-bills/
When you are finished, continue in this section.

Turbochargers **compress** the air flowing into the engine. The advantage of compressing the air is that it lets the engine squeeze more air into a cylinder which allows for more fuel to be used which produces more power from each explosion in each cylinder. In a diesel engine this compression is needed to create the explosion as there are no spark plugs to ignite the fuel and air mixture.

Reference

Cummins
How a Turbocharger Works
https://www.cummins.com/components/turbo-technologies/turbochargers/how-a-turbocharger-works
When you are finished, continue in this section.

The following reference discusses about exhaust systems of diesel engines. Here are some key points:

- The exhaust system is connected to the exhaust manifold which collects gases from engine cylinder exhaust ports

- Parts include: catalytic converter, particulate filter, muffler, decoupling elements, piping, and hangers

Reference

Burkett Oil Company Inc.
What You Need to Know About Diesel Exhaust Systems
http://www.burkettoil.com/what-you-need-to-know-about-diesel-exhaust-systemss
When you are finished, continue in this section.

If you piece of equipment has a diesel exhaust after treatment system, refer to the following video for the basics on diesel exhaust fluid. These systems have been introduced to reduce pollutants from diesel engine exhaust emissions.

Video 2:43

Cat® Tier 4 Final Diesel Exhaust Fluid (DEF) | Overview
https://www.youtube.com/watch?v=4BrTy71QuVM
When you are finished, continue in this section.

Air Induction and Exhaust Systems—Self-Quiz

1. The function of the air induction system is to:

   ☐ Provide air to air conditioning unit

   ☐ Increase the combustion efficiency of the engine

   ☐ Supply current to the electrical system

   ☐ Decelerate the machine (or vehicle)

2. Engine exhaust brakes are only found on diesel engines, and are not found on gasoline engines.

   ☐ True

   ☐ False

Now check your answers on the next page.

Air Induction and Exhaust Systems—Self-Quiz Answers

1. The function of the air intake system is to:.

   Answer: **Increase the combustion efficiency of the engine**

2. Engine exhaust brakes are only found on diesel engines, and are not found on gasoline engines.

   Answer: **True**

Section 1083-02: Hydraulic Systems

What you need to know about this section

By the end of this section, you will be able to demonstrate knowledge of the following key points:

2.1 Hydraulic theory including basic parts

Key Point 2.1: Hydraulic Theory Including Basic Parts

Most heavy equipment machines used in forestry are powered by the main hydraulic system, which is comprised of a primary and secondary system. Generally, a primary high flow, high pressure system is used to “do the work” such as moving the machine and its components.

The secondary, or pilot system, is lower pressure and is used in controlling machine functions. It is connected to the operator controls, also known as joysticks, and they are in turn connected to the valve bank which opens and closes the valves to the main systems that do the work of the machine.

This secondary hydraulic system is designed to aid the operator in controlling the machine and its functions smoothly, and with minimal physical effort inside the cab. Rather than having an electrical “on/off” switch to move the machine, the operator precisely move a control like a joystick which can feather a little oil through the system allowing for greater control and precision to machine movements.

These functions include lifting and manipulating the blade on a grader or bucket on an excavator. On a track skidder, the joysticks control movements of the track and grapple. On a front loader, they act to raise and lower the lift arm assembly, curl the bucket, and dump the bucket.

Let’s take a look at how hydraulics are used in an excavator.

The main hydraulic parts of an excavator include:

- Boom cylinders
- Swing drive
- Cooler fan
- Track drive

Hydraulic systems are needed for heavy equipment because these machines are required to move extremely heavy loads. Hydraulics provide for this kind of lifting power due to the pressure exerted by the fluid onto a large cylinder, which is then able to produce a great amount of force. The fluid is controlled directly or automatically by control valves and distributed through hoses and tubes.

This great amount of force is translated into power which is used to do useful work.

Hydraulic Parts and Functions

Hydraulic parts and their functions include the following:

- Reservoir
- Pump
- Control valve
- Cylinder
- Actuator
- Filter
- Check and relief balves
- Hydraulic cooling system
- Rotary manifold

Reservoir

- Provides storage capacity
- There will be a fluid level indicator for this reservoir

Pump

- Supplies fluid to the components in the system
- Piston pumps vs. gear pumps
- Swash plate (part of an axial piston pump design) allows oil pressure to be converted into mechanical movements at a variable rate of speed

Control Valve

- Directional control valves route the fluid to the desired actuator

Cylinder

- Hydraulic cylinders get their power from pressurized hydraulic fluid, which is typically oil. The hydraulic cylinder consists of a cylinder barrel, in which a piston connected to a piston rod moves back and forth. The barrel is closed on one end by the cylinder bottom and the other end by the cylinder head where the piston rod comes out of the cylinder. The piston has sliding rings and seals

Actuator

- Translates fluid power into mechanical power

Filter

- Used to filter out any metal or other particles before they enter the pump and other components

Check and Relief Valves

- Check valves prevent backflow; relief valves regulate pressure

Hydraulic Cooling System

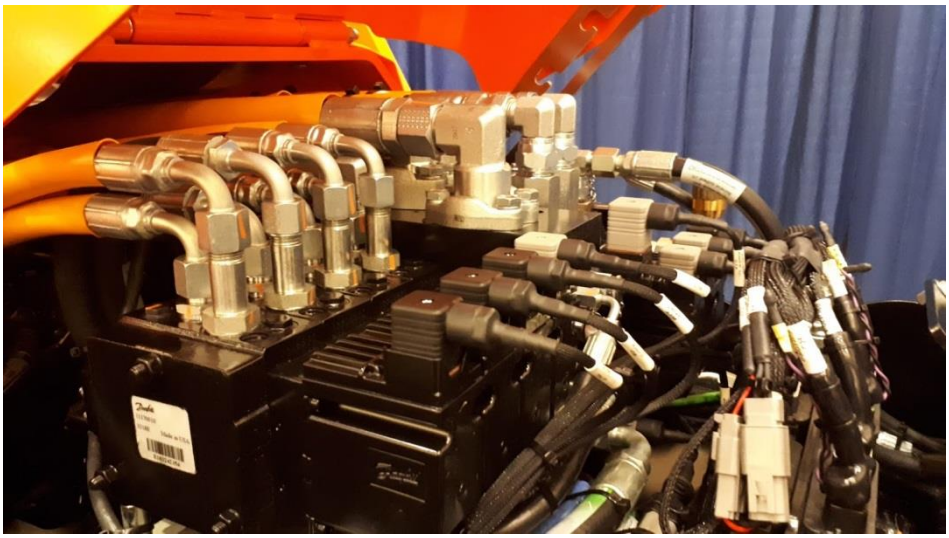
- Some of the hot oil is sent through a cooling system that usually includes a pressurized radiator stacked in front of the engine coolant radiator, with air flow assisted by the same fan

Rotary Manifold

- Used in excavators to conduct oil to the lower drive section while allowing independent rotation or swing of the upper section

Reference

Wikipedia – Hydraulic Machinery
Refer to this article for further information:
https://en.wikipedia.org/wiki/Hydraulic_machinery
When you are finished, continue in this section.



Main lines and labeled pilot lines (inside a log processing attachment)

The following reference is a safety bulletin about an accident that happened in November 2015, when a supervisor and maintenance mechanic were working on large hydraulic cylinder.

Reference

BC Forest Safety
Read Safety Alert: Hydraulics Safety
https://www.bcforestsafe.org/node/2743
When you are finished, continue in this section.

CAUTION!

Exercise caution when working with hydraulic cylinders and hose as they are under substantial amounts of pressure.
Small leaks can cause oil to be released at a pressure high enough to penetrate human skin.

Hydraulic Theory—Self-Quiz

1. What does a hydraulic actuator do?

   - ☐ Preheats hydraulic oil
   - ☐ Filters hydraulic oil
   - ☐ Translates fluid power into mechanical power
   - ☐ Cools hot hydraulic oil

2. What is the function of the secondary hydraulic system?

   - ☐ Moves the main hydraulic cylinders
   - ☐ Helps the operator to control the machine
   - ☐ Provides electrical power
   - ☐ Controls the tracks

Now check your answers on the next page.

Hydraulic Theory—Self-Quiz Answers

1. What does a hydraulic actuator do?

   Answer: **Translates fluid power into mechanical power**

2. What is the function of the secondary hydraulic system?

   Answer: **Helps the operator to control the machine**

Section 1083-03: Powertrain Systems

What you need to know about this section

By the end of this section, you will be able to demonstrate knowledge of the following key points:

3.1 Drive systems theory including basic parts and function

Key Point 3.1: Drive Systems Theory Including Basic Parts and Function

Heavy equipment will usually have a mechanical drive train or a hydrostatic drive train.

Mechanical Drive Train

The mechanical drive train found in construction equipment is similar to that of the automatic transmission in that a transmission is used in conjunction with a torque converter and shifting is accomplished hydraulically when the operator moves the range selector lever.

The powertrain is the system that transmits power from the engine to the drive wheel.

The powertrain has four functions:

- Connect and disconnect power
- Provide variable speed
- Allow for reverse movement as well as forward
- Provide turning ability and propel power simultaneously

Gear Basics

There are a series of mechanical gears and a clutch system that shifts the machine into the appropriate speed.

First gear uses a smaller gear to rotate a larger gear (usually with a 2:1 gear size ratio). This gives the vehicle greater power at a lower speed due to the torque exerted by the smaller gear onto the larger gear which is connected to the driveline.

Mid-range gears use two gears of similar sizes and higher gears use either two gears of the same size, or an or overdrive gear system that has a larger gear rotating a smaller driven gear on the driveline end of the system.

In automatic transmissions, the gear is selected without operator input, by a process of hydraulic pressure and a torque converter which engages the transmission. In manual drive systems, this gear is selected by the operator.

Definitions

- **Clutch**: used to engage the transmission and connect and disconnect power between two rotating shafts.

- **Differential**: a series of intermeshed gears that are used to allow each wheel to turn at different rates, as when going around a corner.
- **Torque converter**: a fluid coupling system, using vortex movement of oil to connect two sections of a sealed turbine

Hydrostatic Drive Train

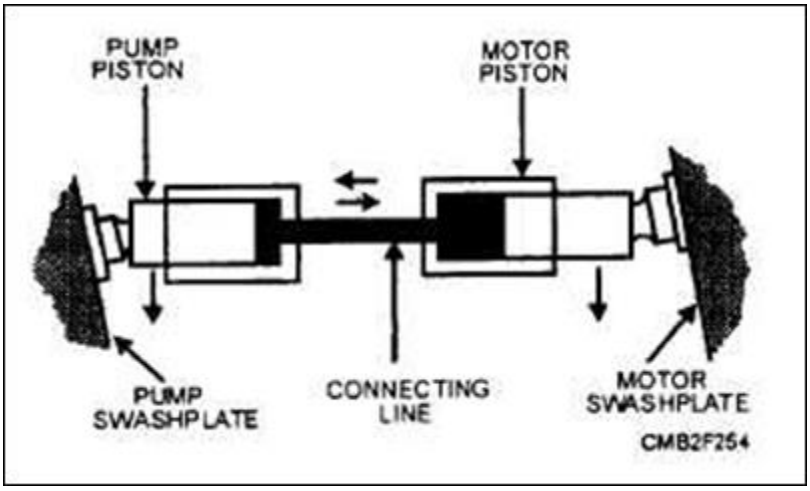
Some heavy equipment machines use a hydrostatic drive train. This system uses a variable displacement pump and hydraulic motor.

The hydrostatic drive is an automatic fluid drive that uses fluid under pressure to transmit engine power to the drive wheels or tracks. Mechanical power from the engine is converted to hydraulic power by a pump-motor team.

The hydrostatic drive functions as both a clutch and transmission. The final gear train then can be simplified with the hydrostatic unit supplying infinite speed and torque ranges as well as reverses speeds.

The pump's displacement is changed by a moveable swash plate, which allows oil pressure to be converted into mechanical movements at a variable rate of speed. This is as compared to mechanical gears, chain drives, or belt drives.

The pistons ride against the swash plates. The angle of the swash plates can be varied, so the volume and pressure of oil pumped by the pistons can be changed or direction of the oil reversed.



The direction of output shaft rotation can be reversed in variable setups by shifting either the pump or the swash plate of the motor over center.

Remember three factors control the operation of a hydrostatic drive:

- Rate of oil flow - gives the speed
- Direction of oil flow - gives the direction
- Pressure of the oil - gives the power

The pump is driven by the engine of the machine and is linked to the speed set by the operator. It pumps a constant stream of high-pressure oil to the motor. Since the motor is linked to the drive wheels or tracks of the machine, it gives the machine its travel speed.

The advantages of hydrostatic drive are as follows:

- Infinite speeds and torque
- Easy one-lever control
- Smooth shifting
- Shifts "on the go"
- High torque available for starting up
- Flexible location - no drive lines
- Low maintenance and service
- Reduces shock loads
- Compact size
- Eliminates clutches and large gear trains

The term travel motor refers to motors that provide propulsion, as opposed to swing motors that enable equipment to rotate. Travel motors are used on a variety heavy equipment.

The term final drive and travel motor are sometimes used interchangeably. However, the final drive either refers to the combined hydraulic motor and planetary gear hub, or to the gear hub only. The travel motor refers to the hydraulic motor.

View the following video for some more information on final drives.

Video 3:54

Excavator Final Drive Parts, A Basic View - ConEquip 101
https://youtu.be/CqdVQdzYWaE
When you are finished, continue in this section.

Section 1083-04: Track Systems

What you need to know about this section

By the end of this section, you will be able to demonstrate knowledge of the following key points:

4.1 Track systems theory including basic parts and function

Key Point 4.1: Track Systems Theory Including Basic Parts and Function

Track system (inside view). Photo credit: Chris Cole, RPF, P.Eng.

Track systems allow heavy equipment to work on varied terrain and soil conditions, including on ice and snow. Where steel tracked machines are required to operate on ice, ice lugs are usually welded to the steel tracks so the machine will not slide across icy surfaces.

Tracks work better than tires on varied terrain conditions because tires can puncture; whereas tracks are less likely to get stuck in soft ground, mud, or snow. Tracks distribute the heavy weight of the machine over a much greater area as compared to rubber tires. Lower ground pressure contributes to decreased soil and site disturbance and increased traction in all conditions except for on ice. Ice “lugs” are usually welded to the steel tracks so the machine will not slide across icy surfaces.

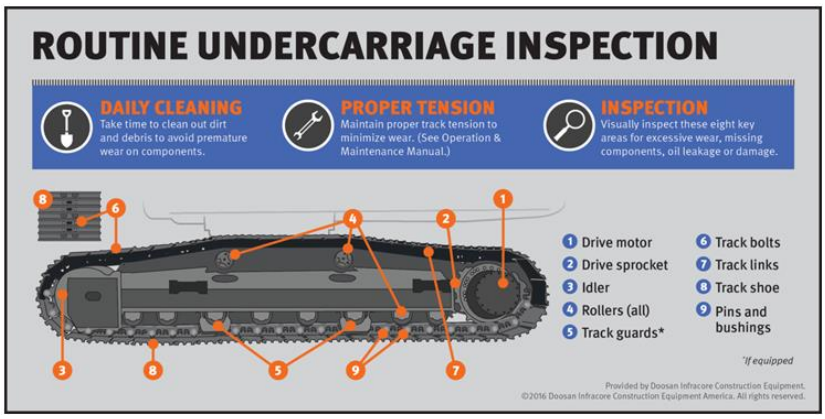
The track system is made up of the undercarriage which includes various parts.

Undercarriage parts include the following:

- Sprocket
- track pads
- track chain (rails)

- track adjuster
- bottom rollers
- carrier rollers (top rollers)
- sprockets
- idlers
- recoil mechanism

Photo showing inside of track rail and pads. Photo credit: Chris Cole, RPF, PEng



Watch the following video for some good tips on undercarriage inspection and maintenance.

Video 5:21

Cat® Excavator Undercarriage Maintenance Tips
https://youtu.be/pho0H1742lM?list=PL75EDB9654FEC4694
When you are finished, continue in this section.

Track Systems—Self-Quiz

1. The track system works better than rubber tires on varied terrain because:

   ☐ Rubber Tires may puncture or tear on sharp surfaces

   ☐ Tracked systems create less damage to the forest floor because ground pressure is reduced and spread over a greater area

   ☐ Tracks provide greater wear life on off road conditions, than rubber tires and require less frequent replacement

   ☐ All of these answers

Now check your answers on the next page.

Track Systems—Self-Quiz Answers

1. The track system works better than rubber tires on varied terrain because:

   Answer: **All of these answers**

Section 1083-05: Braking Systems

What you need to know about this section

By the end of this section, you will be able to demonstrate knowledge of the following key points:

5.1 Braking systems theory including basic parts and function

Key Point 5.1: Braking Systems Theory including Basic Parts and Function

The braking system on some heavy equipment machines make use of hydraulic brakes.

Heavy equipment used in forestry may have air brakes or hydraulic over air brakes, which is a combination of hydraulic and air systems.

Off highway road sanding trucks. Photo by Chris Cole, RPF, PEng

Due to the size and weight, some heavy equipment has auxiliary braking systems are required to decrease wear on the main braking system and to give extra braking power.

These systems all rely on a build-up of back pressure, to provide braking to the vehicle rather than relying on the foundation brakes or wheel brakes for all the braking power. These systems include compression or Jake brakes, that are a form of exhaust brakes that act to slow the vehicle.

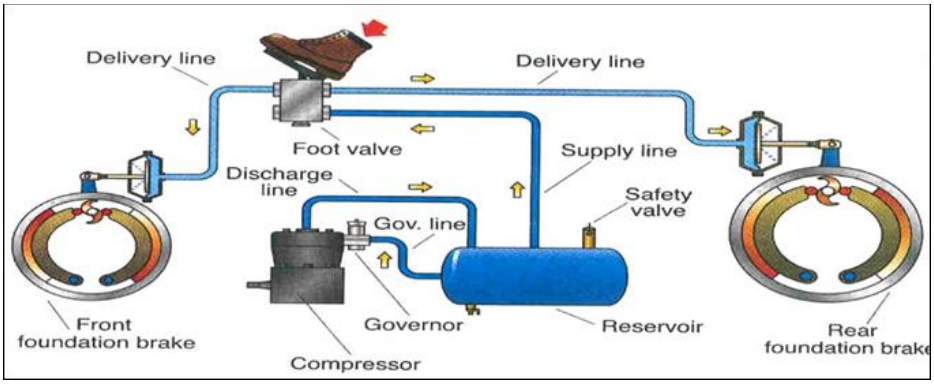
The following video explains about wet disk brakes, which are oil cooled hydraulic brakes often found in Cat products. They are used in elevated sprocket track type tractors, wheel loaders and off highway trucks.

Video 3:06

YouTube—Cat Products
Cat Wet Disk Brakes
https://www.youtube.com/watch?v=dvCYBUOtKrk
When you are finished, continue in this section.

Basic Air Brake Components

The air brake components include the air system circuit and valve functions, and the foundation brakes.



Basic schematic of an air brake system

Review the five basic components of an air brake system found here https://www.sgi.sk.ca/air-brake/-/knowledge_base/air-brake/system-components

The following video provides further details on how air brakes work for trucks.

Video 10:59

YouTube—Smart Drive Test
Basic CDL Air Brake Components- Air Brake Smart
https://www.youtube.com/watch?v=dMxilatT0qw
When you are finished, continue in this section.

Engine Brakes or Retarders

In this key point we will look at a generic auxiliary braking system. Please refer to the specifications of the component in your owner's manual.

Retarders are designed to provide auxiliary slowing of the vehicle, such as for controlling the speed on downhill grades without the use of the main braking system.

Many retarders can absorb as much or more horsepower as the engine can develop.

Engine retarders (also known as engine brakes) help to save the main braking system for emergency stopping. The term **engine**

brake can be used to describe retarder devices that use four operating principles:

- Internal engine compression brakes
- External engine exhaust brakes
- Hydraulic driveline retarders
- Electric driveline retarders

Internal Engine Compression Brakes

What is an engine compression brake?

A compression release engine brake, frequently called a Jake Nett brake or Jacobs brake, is an engine braking mechanism installed on some diesel engines.

When activated, it opens exhaust valves in the cylinders after the compression cycle, releasing the compressed air trapped in the cylinders, and slowing the vehicle.

This braking system closes the exhaust path and it stops the gases from being eliminated on the exhaust pipe. As a result, backpressure is built in the manifold and in the cylinders, making the engine work backwards and subsequently slowing down the vehicle.

Some engine brakes can be adjusted to work on some or all cylinders from the cab, this is important in slippery conditions as engine hold back can be adjusted, allowing you to maintain optimum drive wheel traction during engine braking.

External Engine Exhaust Brakes

What is a diesel exhaust brake?

This an older design that may be found on some in-service trucks.

An exhaust brake is a means of slowing a diesel engine by closing off the exhaust path from the engine, causing the exhaust gases to be compressed in the exhaust manifold, and in the cylinder.

The amount of negative torque generated is usually directly proportional to the back pressure of the engine.

Hydraulic Driveline Retarders

How does a hydraulic driveline retarder brake work?

The transmission directs oil into the retarder housing to absorb the vehicle's energy through the drive shaft. The absorbed energy is converted to heat and dissipated through the vehicle's cooling system.

They generate the greatest braking at high drive shaft RPM and work independent of engine speed or gear ratio.

Electric Driveline Retarders

How does an electric driveline retarder brake work?

Driveline retarders are not heavily used in the logging industry in British Columbia.

Electromagnetic retarder function like an electric motor, but in reverse. They have no moving parts and they don't reply on friction and there is never any brake fade. They do get hot because the resistance of the truck is working against the driveline electric motor. The heat is dissipated through the air-cooled rotors.

CAUTION!

Retarders are designed to provide an auxiliary method of slowing the truck on downhill grades, so you can save your brakes which helps save the main braking systems for emergency stops.
Be cautious on slippery roads. When used, engine retarders can lock up your drive wheels, stalling your engine which can result in loss of control.
Make sure you are familiar with manufacturers operating procedures before using your engine retarders.
Engine retarders, like Jake brakes, are noisy and some municipalities don't allow them to be used within their limits.

The following video provides further details on how a compression or Jake Brake works.

Video 4:49

YouTube—Engineering Explained
What is Engine Braking? What is a Jake Brake?
https://www.youtube.com/watch?v=o8Cta2cC2Co
When you are finished, continue in this section.

Braking Systems Theory—Self-Quiz

1. While going down a steep hill, the “descent speed” of a heavy truck or machine equipped with air brakes can be controlled using the exhaust brake only. This leaves the foot controlled foundation brakes cool and for emergency use only.

   - ☐ True
   - ☐ False

2. What type of braking system is found on heavy equipment?

   - ☐ Air brakes
   - ☐ Hydraulic brakes
   - ☐ Hydraulic over air brakes
   - ☐ All of these answers

Now check your answers on the next page.

Braking Systems Theory—Self-Quiz Answers

1. While going down a steep hill, the “descent speed” of a heavy truck or machine equipped with air brakes can be controlled using the exhaust brake only. This leaves the foot controlled foundation brakes cool and for emergency use only.

   Answer: **True**

2. What type of braking system is found on heavy equipment?

   Answer: **All of these answers**

Section 1083-06: Electrical Systems

What you need to know about this section

By the end of this section, you will be able to demonstrate knowledge of the following key points:

6.1 Electrical systems theory including basic parts and function

Key Point 6.1: Electrical Systems Theory Including Basic Parts and Function

In this key point we will look at a generic electrical system. Refer to the specifications of the component in your owner's manual.

The electrical system in heavy equipment machines consists of:

- Battery
- Starter
- Alternator
- Auxiliary equipment

Electrical Systems Overview

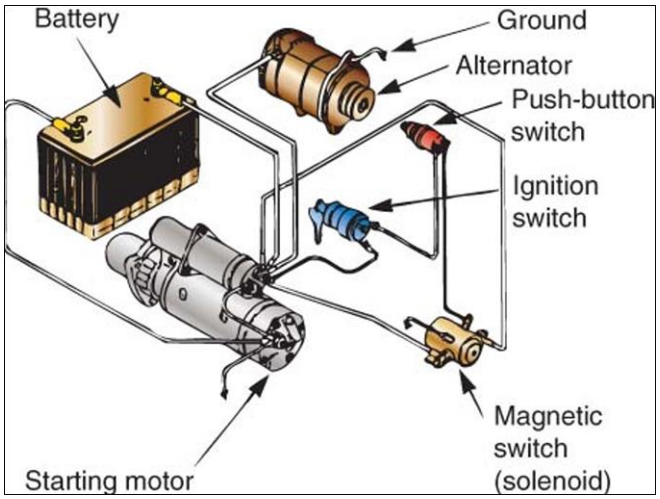
Heavy equipment such as excavators and new heavy equipment used for forestry purposes, run on 24-volt systems due to the cranking power requirements of the diesel engine.

- Batteries - store energy and produce a flow of current for the starter and other electrical devices
- Starters - is an electric motor (powered by batteries) that spins rapidly and produces enough torque to crank the engine.
- Alternators - develop current to charge batteries by principles of electro magnetism. No other electrical system parts can run without the alternator.
- Auxiliary equipment includes:
- Solenoids for some hydraulic control valves
- Lighting circuits
- Warning systems
- Gauges
- Horns
- Buzzers
- Glow plugs (for diesel engines)
- Fans and motors for heaters
- Air conditioning

You will need a working knowledge of what the primary components are and where they are located and to:

- Know how to judge there is a problem
- Recognize safety issues related to each system
- Perform basic troubleshooting, e.g. conduct a visual inspection
- Be able to talk knowledgably to a mechanic

Starting and Charging System



Basic starting system

About batteries

Batteries provide power for the engine cranking and electrical loads when the alternator is not generating power. They also stabilize voltage levels in the electrical system.

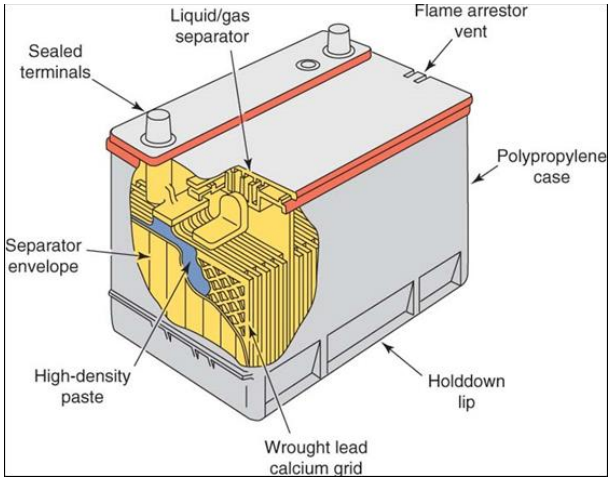


Illustration of a battery

Boosting batteries

CAUTION!

There are many types of voltage systems from 6-24 volt, most trucks use a 12 volt system, some equipment may use a 24 volt system, be sure you are boosting with the same voltage or the electrical system may become damaged and batteries may explode.
Be sure that you also connect the correct polarity to each end of the booster cables
If unsure of procedure, stop and ask for help!

Troubleshooting batteries

CAUTION!

Always wear safety gloves and glasses when disconnecting the batteries during any repair of the charging system. Make sure the vehicle is out of gear, parking brake is set, and the wheels are chocked. Also avoid wearing jewelry and loose-fitting clothing.

Keep battery tops clean and free of dirt and grime. A dirty battery can discharge across the dirt and grime on top of the battery.

Applying a thin layer of grease on the top of the battery posts and cable ends goes a long way to protect your battery and cables from corrosion.

Have a regular battery inspection. Look for any physical signs of damage looking for loose posts, signs that it has overheated.

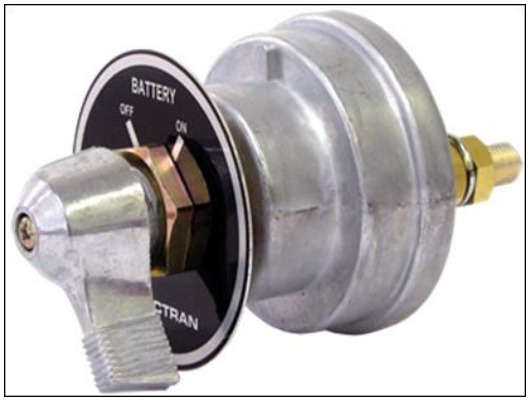
When jump-starting your truck, always jump start to the battery that is closest to the starter. Make sure you are hooked to the batteries in accordance to how they are – in series or in parallel, etc. Refer to the manual or mechanic.

Learning Point

Your truck will not start as you left lights on with the vehicle turned off and killed the batteries. Your co-worker has a set of booster cables and will give you a boost with his processor. This may not be the best idea, why?
The truck and processor have different voltage systems.

Night switch (battery disconnect switch)

Most equipment has a battery disconnect switch. They are helpful in that you can isolate your batteries from the rest of the electrical system. These switches can save draw down on batteries if there is something that could be drawing power like parasitic power loss.



Fuses

Fuses are an electrical component that is designed to protect other components, devices and wiring from any damage that might occur from any excess current flow.

Fuses are generally contained in a fuse box located on or in the cab of the truck.

Refer to your truck's manual for its fuse box location

Troubleshooting fuses

If an electrical circuit or device isn't working check the fuse box and locate the fuse for the circuit that isn't working. If the fuse is blown replace it with the correct sized new fuse. Once replaced the system should function normally. If a fuse continues to blow once replaced, it is an indication of a circuit short. This can be because of a failed electrical component or bare wires touching the trucks body. An incorrect fuse or too low of amperage can be a problem as well.

Relay Switches

Relays in general are used to enable low amperage circuits to switch on or off a higher amperage circuit, for example turning your head lights on or off. If you were to try and directly wire your head lights to the head light switch you would exceed the amperage rating of the switch, melting wires and possibly causing a fire. Relays are also used to switch multiple devices at the same time using only one output. For example. Turning on your radio and the antenna goes up as well.

Trouble shooting relay switches

As a note it's good practice to carry some spare fuses and relay switches as part of a basic spare parts kit.

The signs of a bad relay switch can be, a device such headlights aren't working at all, or not at full power, i.e. your headlights are dim.

Sometimes relay terminals will become impacted with dirt and grime which can reduce proper continuity. So, you may be able unplug the relay and clean up the terminals and the plugins. If that that doesn't work, on some relays you can hear an audible click as the magnetic circuit closes or opens, which means that your relay is probably not the source of the problem.

The best way to check a relay is to use a multi meter. The following video will help illustrate how to use a multi meter to test a relay switch.

Reference

FleetNet America
Electrical Systems in Heavy-duty Vehicles
https://fleetnetamerica.com/blog/post/electrical-systems-in-heavy-duty-vehicles
When you are finished, continue in this section.

CAUTION!

Remember that battery acid is harmful on contact with skin and will damage many other materials as well.

Electrical Systems—Self-Quiz

1. The function of the alternator is to:

   - ☐ Crank the engine for starting
   - ☐ Provide current to charge the battery
   - ☐ Smooth out the idle speed
   - ☐ Alternate the electrical current produced when the engine is running

2. The function of the battery is to: store energy and produce a flow of current to the starter and other electrical devices

   - ☐ True
   - ☐ False

Now check your answers on the next page.

Electrical Systems—Self-Quiz Answers

1. The function of the alternator is to:

   Answer: **Provide current to charge the battery**

2. The function of the battery is to: store energy and produce a flow of current to the starter and other electrical devices

   Answer: **True**

Section 1083-07: Ground Engaging Tool Systems

What you need to know about this section

By the end of this section, you will be able to demonstrate knowledge of the following key points:

7.1 Ground engaging tools and systems and functions

Key Point 7.1: Ground Engaging Tools and Systems and Functions

Ground engaging systems are used on heavy equipment machines such as excavators or graders. There are different attachments for functions such as digging, cutting pavement, and grading.

In forestry, these attachments are used for tasks such as clearing debris during road building and digging out the logging landing areas.

Ground engaging tools and systems include blades and buckets.

Blades

- Cutting edge segments are replaceable
- Edges are reversible allowing for “flipping”
- There are a variety of blades available: U-blades, conventional angle blades, six-way blades, front plough blades, V-blades, wing blades
- Blades are used for cutting the ground surface, leveling loose soil and materials, and clearing snow from the roadway

Ice/snow grader blade. Photo credit: Chris Cole, RPF, P.Eng.

Buckets

Buckets are used for digging, loading, clearing, snow removal, lifting soil, wood chips and light gravel. Also, trenching, “clean out,” and pavement removal.

Some buckets have teeth others are straight cutting edge. Cutting edge segments are replaceable.

Bucket attachment on Excavator (Cambie and Broadway demolition site in Vancouver)

Bucket with teeth recently replaced. Photo by Chris Cole, RPF, P.Eng.

Hard surfacing is adding extra welded material onto attachments like buckets to extend their life. Hard surfacing is shown on the photo above.

Bucket with teeth. Photo by Chris Cole, RPF, P.Eng.

The reference is mostly a preventative maintenance guide, but includes safety tips on page 5, and correct operating techniques on pages 7, 10 and 11.

Wheel loaders correct technique

On page 7 “Maintain bucket positioner in proper alignment, with base edge parallel to floor. Cat buckets are designed for the material to slide over a flat floor. Operation outside the design changes the wear pattern of the bucket and G.E.T. and affects loading.”

Hydraulic excavator operator technique tips

On page 10 “The correct position is square to the face, tips down at 40 degrees, enter the pile, boom up and curl. The tips do the work, minimal bucket contact, better, quicker loading. *More contact equals more wear – minimize non-productive contact!*”

Dozers

On page 11, for dozers, some recommended best practices include:

- Avoid corner loading (digging one corner in too much)
- Avoid excessive speed
- Doze in first gear
- Carry the load in second gear

Reference

Ground Engaging Tools (GET)
Overview of Ground Engaging Tools
http://s7d2.scene7.com/is/content/Caterpillar/CM20180308-56068-63011
When you are finished, continue in this section.

Ground Engaging Systems—Self-Quiz

1. Blade attachments are available in a variety of sizes and shapes.

   ☐ True

   ☐ False

2. Bucket teeth are replaceable and take the wear and abuse of the work completed in order to avoid costly damage to the bucket or ground engaging apparatus.

   ☐ True

   ☐ False

3. Bucket teeth may fall off during operation, so it is important for the operator to check them regularly to make sure they are present and securely connected.

   ☐ True

   ☐ False

4. The part of the grader blade that “cuts” the ground is relatively cheap and easy to replace compared to the grader blade itself.

   ☐ True

   ☐ False

Now check your answers on the next page.

Ground Engaging Systems—Self-Quiz Answers

1. Blade attachments are available in a variety of sizes and shapes.

   Answer: **True**

2. Bucket teeth are replaceable and take the wear and abuse of the work completed in order to avoid costly damage to the bucket or ground engaging apparatus.

   Answer: **True**

3. Bucket teeth may fall off during operation, so it is important for the operator to check them regularly to make sure they are present and securely connected.

   Answer: **True**

4. The part of the grader blade that “cuts” the ground is relatively cheap and easy to replace compared to the grader blade itself.

   Answer: **True**