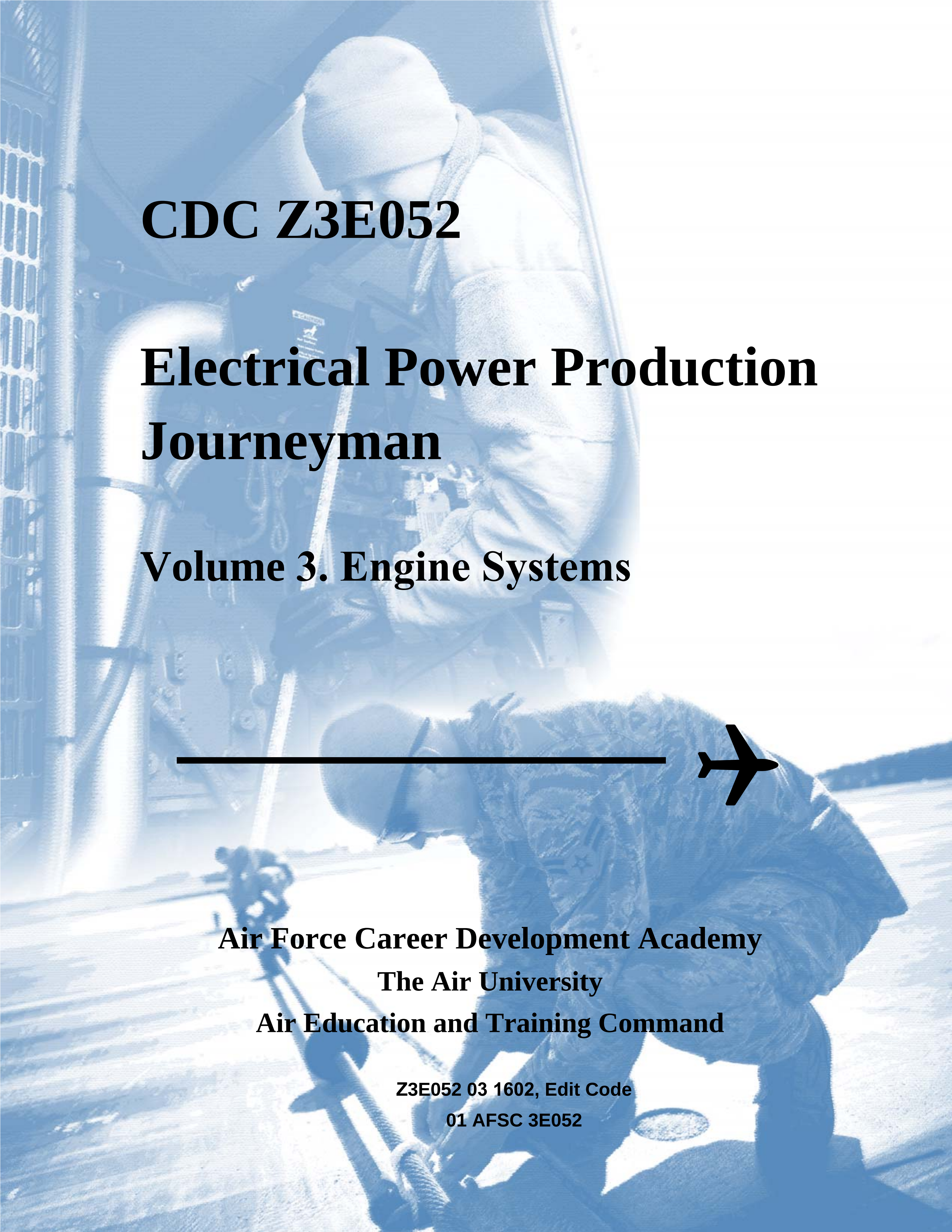

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Electrical Power Production Journeyman

Volume 3. Engine Systems

Air Force Career Development Academy
The Air University
Air Education and Training Command

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Author: MSgt Stewart Herringshaw
366th Training Squadron
(AETC)
366 TRS/TRR
727 Missile Road
Sheppard Air Force Base, Texas 76311-2245
DSN: 736-5854
E-mail address: stewart.herringshaw@us.af.mil

Instructional Systems Specialist: Hozell Odom III

Editor: Sandra F. Glenn

Air Force Career Development Academy (AFCDA)
The Air University (AETC)
Maxwell-Gunter Air Force Base, Alabama 36118-5643

This 5-level career development course (CDC) consists of five volumes of instruction designed to provide students the job knowledge necessary to advance from the 3-skill level to the 5-skill level. Its goal is to introduce you to the various functions of the electrical power production specialty and to provide you the knowledge necessary to become productive members of the career field. This course will not make you an instant expert; however, you can be assured that time and effort devoted to this course will pay off over time. It is your responsibility to allocate on and off-duty time to complete all reading assignments, self-test questions (STQs), and unit review exercises (UREs). Also it is your responsibility to request assistance with your supervisor when having difficulties with any part of the lessons.

Volume 3 provides information designed to reinforce your basic knowledge on engine systems. Unit 1 covers engine systems; unit 2 provides information on fuel systems, unit 3 presents information on lubricating systems, unit 4 covers cooling systems and engine starting aids, and finally, unit 5 covers intake and exhaust systems.

A glossary is included for your use.

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This volume is valued at 12 hours and 4 points.

NOTE:

In this volume, the subject matter is divided into self-contained units. A unit menu begins each unit, identifying the lesson headings, numbers, and page location. After reading the unit menu page and unit introduction, study the section, answer the self-test questions, and compare your answers with those given at the end of the unit. Then complete the unit review exercises.

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MUCH OF THE WORK that you will do as an electrical power production journeyman involves engines. These machines require maintenance to keep them operating at peak efficiency. Well-maintained engines run trouble free for long periods of time. In order to maintain engines, you must understand how the mechanical components work together. In this lesson, we will cover the engine components, theory of operation, and maintenance procedures.

1–1. Theory of Operation

Engines are machines that convert thermal energy into mechanical energy. Understanding the operation of an engine is critical to maintaining power systems and aircraft arresting systems. You must understand the components, terminology, and theory of operation to successfully fulfill the mission requirements.

401. Engine components

Engines contain many components. You need to understand the components and their purposes to be able to perform maintenance to an engine. This lesson discusses the common components used by all engines.

Engine block

The engine block (fig. 1–1) is the foundation of an engine. It houses all of the internal components of the engine. It also contains the cylinders of the engine. These cylinders are generally bored directly into the block, which forms the walls of the combustion chamber. The block construction must hold up to the pressures created by the engine operation. The block also contains drilled passages for coolant and oil to circulate throughout the engine.

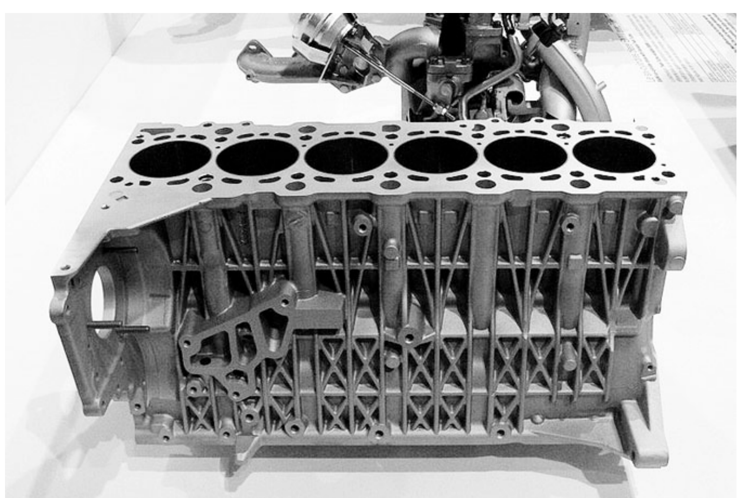


Figure 1–1. Engine block.

Oil pan

The oil pan forms the bottom of the engine. The oil pan and lower portion of the block make up the crankcase. This is where the crankshaft mounts to the engine. The oil pan also provides a storage area for the engine's lubricating oil. We often refer to this storage area as the sump.

Crankshaft

The crankshaft (fig. 1–2) is the major rotating part in the engine. It converts reciprocating motion, up and down, into rotary motion, round and round. This rotary motion is what is used to drive many different components.

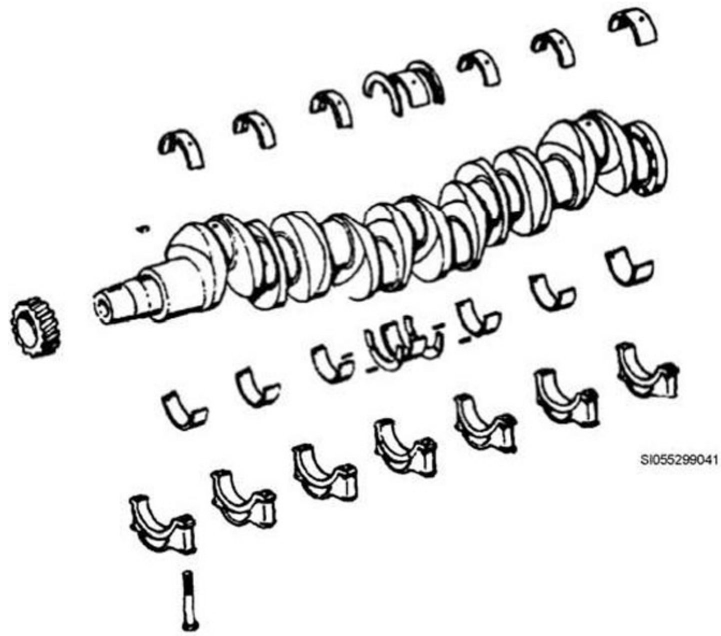


Figure 1–2. Crankshaft.

Main journals

The main journals are the round surfaces on which the crankshaft rotates. You can easily identify them because they are in the centerline with the ends of the shaft. They ride on the cylinder block saddles. They are machined and polished to provide a very smooth finish.

Throws

The throws connect the main journals to the connecting rod journals.

Connecting rod journals

The connecting rod journals are the round surfaces to which the connecting rods connect. They are located at the ends of the throws. You can identify them because they do not align with the main journals.

Counterweights

Counterweights provide balance to the crankshaft when it is spinning. This prevents vibrations that could cause premature failure of engine components. These counterweights extend the opposite way from the connecting rod journals. The size varies based on the design of the engine.

Oil passages

The crankshaft contains drilled oil passages to allow oil to flow to the journals and other components. This provides a thin film of oil that prevents metal-to-metal contact between components.

Bearings

Bearings (fig. 1–3) provide a wearable surface between moving parts. Bearings on the main and connecting rod journals are constructed of a softer material than the journals. This allows the bearing to wear before the journals do. Early detection of bearing failure allows you to only have to change the bearing instead having crankshaft repaired or replaced.

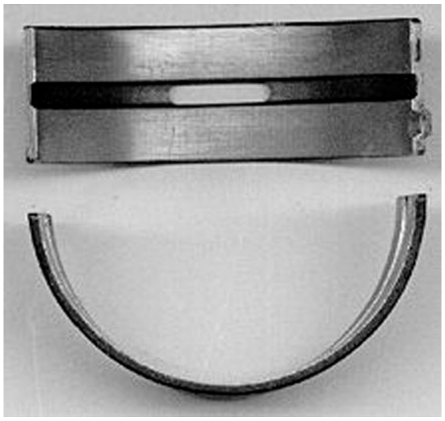


Figure 1–3. Bearings.

Piston

The piston (fig. 1–4) provides the bottom of the combustion chamber. It moves up and down in the cylinder, changing the volume inside the combustion chamber. The piston is used to transfer the energy of expanding gases to the connecting rods.

Figure 1–4. Piston.

Crown

The crown is the top of the piston. It has many designs based on the manufacturer’s specifications. It is the portion of the piston on which the combustion takes place.

Skirt

The skirt is the lower portion of the piston. It provides stability as the piston moves up and down.

Rings

The rings fall into two categories—compression and oil. Compression rings seal the bottom of the combustion chamber between the piston and cylinder. Oil rings control the amount of oil on the cylinder walls. This provides enough oil to prevent friction but limits it to prevent burning of the oil.

Piston grooves

The ring groves are slots in the side of the piston in which the rings ride. These grooves maintain the rings in place to help seal the combustion chamber.

Connecting rod

The connecting rod (fig. 1–5) connects the crankshaft to the piston. This allows it to transfer the power of the piston to the crankshaft. The rods typically use an I-beam construction with a small hole called an eye and a big circle with a split construction. The big end rides on the connecting rod journal and bearing using a rod cap that bolts together with the connecting rod to encircle the crankshaft. The small end connects to the piston using a piston pin. It also commonly has oil passages drilled into it to allow oil to get to the piston and cylinder walls.

Camshaft

The camshaft (fig. 1–6) drives the valve train to operate the valves. It is timed to the engine using a gear, chain, or belt drive. The camshaft also can drive other items such as injectors, fuel pumps, ignition systems, and oil pumps. Camshafts may be located either in the block, using lifters, pushrods to connect to the rocker arms, or above the cylinder head where is makes contact with the valves via only cam followers.

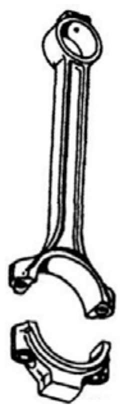


Figure 1–5. Connecting rod.

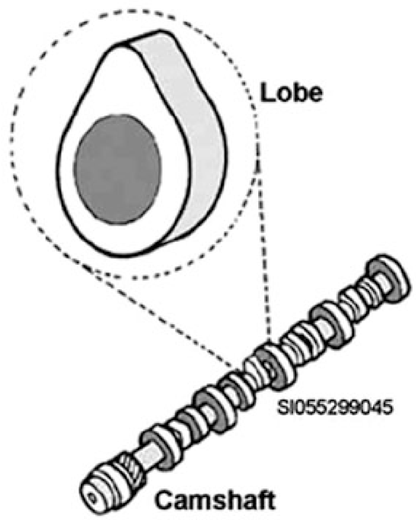


Figure 1–6. Camshaft.

Journals

The journals are rounded surfaces on the camshaft. They provide the surface on which the camshaft rotates. There is a journal at each end of the camshaft and more spread out along the rest of the shaft.

Lobes

The lobes are egg-shaped surfaces along the camshaft. They are the portions of the camshaft that drive the valve train. They are also off set from each other to provide the proper timing to each component.

Valve train

The valve train (fig. 1–7) refers to the group of components that drive the valves. A valve train is also used to operate other items like injectors.

Cam followers

The cam followers ride on a camshaft lobe. You may also hear them referred to as lifters. They raise and lower, following the contour of the lobe.

Push rods

Push rods are long, narrow tubes made from lightweight metal that react to the movement of the cam follower. They connect the cam follower to the rocker arms.

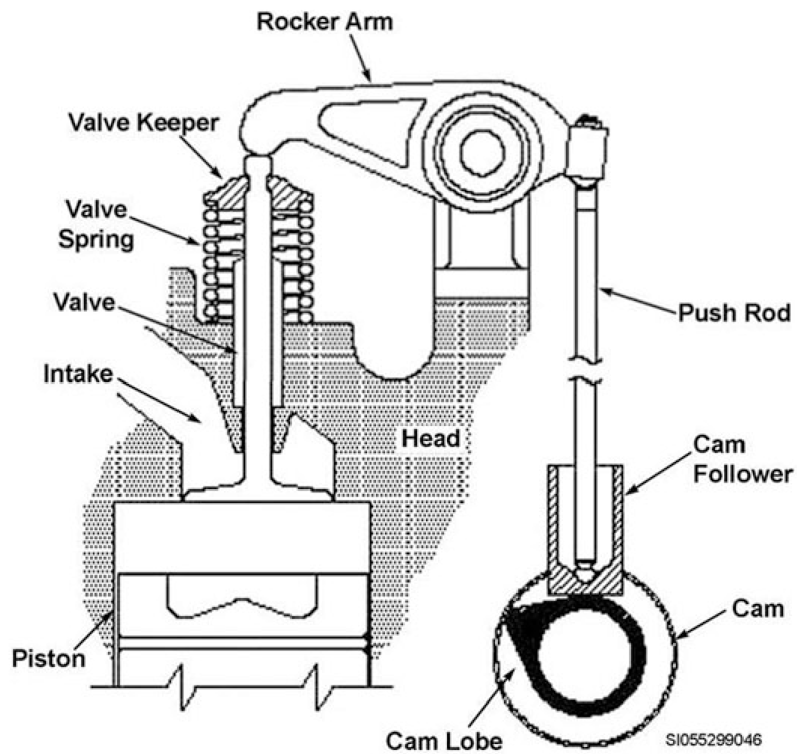


Figure 1–7. Valve train.

Rocker arms

The rocker arms transfer the upward movement of the push rod into a downward movement to the valve. This causes the valves to follow the movement of the camshaft to open and close at the appropriate time.

Valves

The valves (fig. 1–8) open and close to allow fresh air in and burned gases out of the combustion chamber. There are generally two valves, an intake and an exhaust valve, however, many times there are as many as four valves, two intakes and two exhausts.

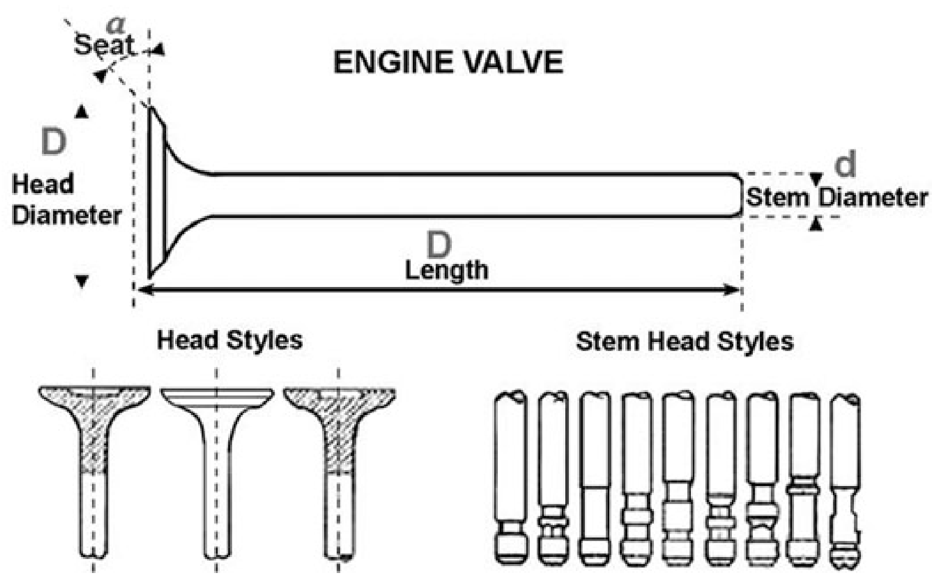


Figure 1–8. Valve.

Valve Characterics	
Head	The head is the portion of the valve that is inside the combustion chamber.
Margin	The margin is the thickness of the valve. This thickness of the valve keeps it from warping and burning.
Face	The face is the surface of the valve that closes the opening in the cylinder head.
Stem	The stem is the long shaft of the valve. This allows the valve to reach the rocker arm.
Spring	The spring pushes the valve into the closed position. The pressure of the spring keeps the valve closed unless the valve train is pushing it open.
Spring washer and keeper (lock)	The spring washer and keeper (lock) hold the valve and valve spring in place.

Cylinder head

The cylinder head (fig.1–9) forms the top of the combustion chamber. It contains coolant passages to help remove heat from the combustion chamber. There are exhaust and intake ports to get fresh air into the combustion chamber and burned gases out. The head also houses many of the items that access the combustion chamber, such as the valves and injectors.

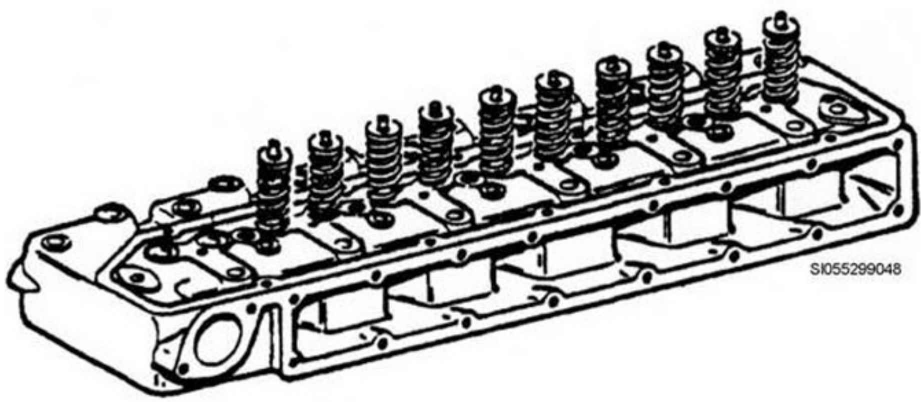


Figure 1–9. Cylinder head.

Flywheel

An action of the piston does not supply an even flow of power to the engine since the amount of power varies as the piston moves. These power surges would create a rough operation of the engine. The flywheel continually stores and releases kinetic energy to smooth the erratic operation of the engine. Flywheels are large, cast disks that have enough weight to compensate for the power surges created by the power strokes of the engine.

Vibration dampener

The vibration dampener mounts to the front of the engine to control torsion vibrations created by the crankshaft. The crankshaft has the counterweights for balance that take care of most of this. When the engine operates in extreme conditions or widely varying loads, the counterweights are not enough. This is where the vibration dampener steps up to relieve any vibrations that could cause the crankshaft to destroy itself.

Many of the components of an engine are the same and do the same job, regardless of the type of engine. Understanding these components and how they work is important to understanding the operation of an engine. Next, we discuss terms related to the operation of an engine.

402. Engine operations

There are several terms you need to know to have a full understanding of the way an engine operates. Knowing these terms discussed in this lesson when performing maintenance allows you to better collaborate with your fellow technicians. You will find that you will often refer to these common terms during a discussion of engines.

Engine terms

The following table inclues terminolgy you will use when collaborating in the operation of an engine. Refer to the manufacturing manual for all other guidance.

Engine Operation Termonlogy	
Stroke	A stroke is the complete movement of a piston. This movement can be in either direction, up or down.
Cycle	A cycle is a complete series of events. The events for an engine are intake, compression, ignition, power, and exhaust. Once the series of events are complete, they begin again.
Top dead center	Top dead center (TDC) refers to the position of the piston when it is at the highest point in its movement.
Bottom dead center	Bottom dead center (BDC) refers to the position of the piston when it is at the lowest point in its movement.
Valve overlap	Valve overlap refers to the amount of time that both the intake and exhaust valves are open at the same time.
Scavenging	Scavenging occurs during the valve overlap. It refers to the fresh air entering the combustion chamber and pushing the burned gases out.
Compression ratio	Compression ratio refers to the comparison in the volume of the combustion with the piston at BDC to the volume of the combustion chamber with the piston at TDC.
Compression ignition	Compression ignition is the use of the high temperature created by the compression of the air in a cylinder to ignite fuel as it is sprayed into the cylinder.

These terms are the key to understanding the operation of an engine. Make sure you can explain these terms without having to think about them. They allow you to understand the basis behind the theory that you are about to read about.

403. Diesel theory of operation

All internal combustion engines must have air, fuel, and ignition. These engines use two basic designs—the two-stroke and the four-stroke. This refers to the number of strokes it takes to complete a cycle. Regardless of the type of engine, the sequence of events remains the same. The events discussed in this lesson are intake of fresh air, compression of the fresh air, ignition, burning of the air fuel mixture to create power, and the exhausting of the burned gases.

Two-stroke diesel engines

As the name of the two-stroke engine implies, a complete cycle of events occurs in two strokes of the piston. These types of engines use a few additional components than you read about in the components section.

The two-stroke engine typically has intake ports located in the bottom of the cylinder wall and exhaust valves in the cylinder head. The intake ports receive air from a cavity called an air box. The engine uses an external blower to pressurize the air in the air box. This allows the air to rush into the cylinder when the port is open.

In the normal sequence of events, the piston is located at BDC and is beginning to move up. The pressurized air rushes into the cylinder. The exhaust valve is also open at this time. Shortly before the piston covers the port, the exhaust valve closes trapping the air in the cylinder. The pressurized air continues to flow into the cylinder until the piston moves up enough to completely cover the port. This is the intake event, shown in figure 1–10.

Once the port is closed, the piston continues to move up compressing the air in the cylinder. This continues until just before the piston reaches TDC. This compression of the air causes the temperature to rise to over 1,000°F. This is the compression event, shown in figure 1–11.

Fuel gets injected into the cylinder just before TDC. Since the combustion chamber has a high temperature created by the compression of the air, the atomized fuel immediately ignites. The combustion of the fuel expands to fill the space between the cylinder head and piston at the same time the piston reaches TDC; this is the ignition event.

The burning fuel continues to expand, pushing the piston down. This push continues until the exhaust valve opens; this is the power event, shown in figure 1–12.

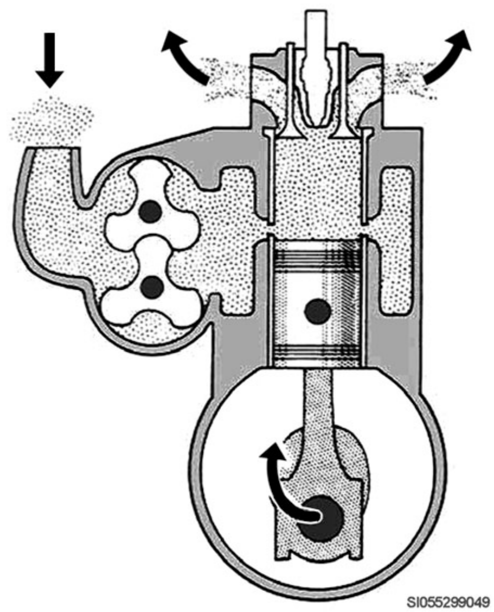


Figure 1–10. Intake stroke of two-stroke engine.

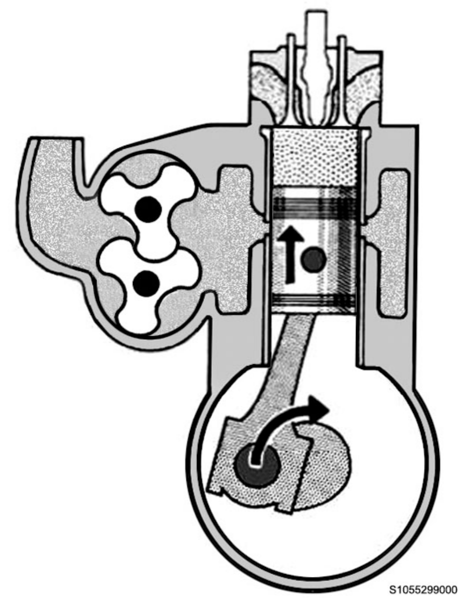


Figure 1–11. Compression stroke of two-stroke engine.

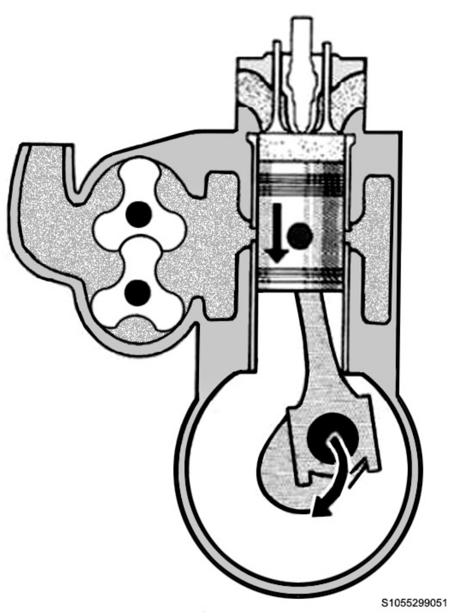


Figure 1–12. Power stroke of two-stroke engine.

Follow the power event, the exhaust valve open allowing the pressurized gases to begin flowing out of the cylinder. The piston then uncovers the intake port and the fresh air begins to flow into the cylinder, pushing the exhaust gases out. This continues as the piston reaches BDC and begins its upward movement. Just before the piston reaches the top of the port, the exhaust valve closes; this is the exhaust event.

Two-stroke engines depend on scavenging to operate. The inrush of fresh air is the only means of removing all of the burned gasses from the cylinder. The use of a blower creates this movement of air. Two-stroke engines will not operate without a blower because there would be nothing to remove the burned gasses from the cylinder.

Four-stroke diesel engines

The four-stroke engine requires four strokes of the piston to complete one cycle of operation. This is different than the operation of the two-stroke that you have just read about. The four-stroke engine also has a few components that are different than the two-stroke.

The four-stroke engine typically uses an intake manifold and ports in the head to direct fresh air into the cylinder. The airflow is controlled by an in intake valve. This means the four-stroke engine has both intake and exhaust valves.

In the normal sequence of events, the piston is located at TDC and is moving down, as shown in figure 1–13. The intake and exhaust valves are both open. As the piston starts its downward movement, the exhaust valve closes leaving only the intake valve opens. The downward movement of the piston creates a vacuum that draws fresh air into the cylinder. This continues until the piston reaches BDC; this is the intake event.

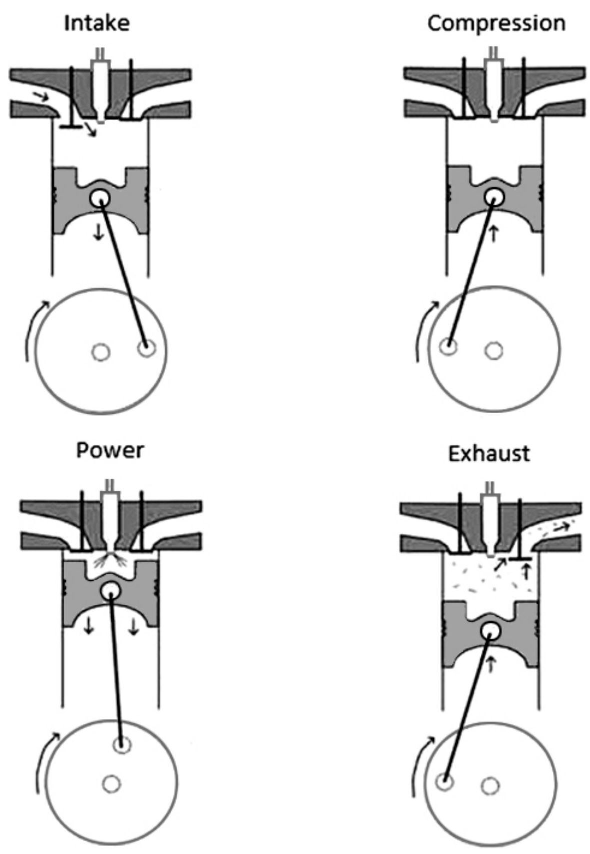


Figure 1–13. Four-stroke principle.

Once the piston reaches BDC, it begins moving upward. The intake valve then closes, sealing the cylinder. The piston continues to move upward, compressing the air. This is the compression event.

Fuel is injected into the cylinder just before TDC. The high temperature created by the compression of the air and the atomized fuel causes ignition. The combustion of the fuel expands to fill the space between the cylinder head and piston at the same time the piston reaches TDC. This is the ignition event.

The expansion of the burning gasses continues to push the piston downward. This energy transfers to the crankshaft through the connecting rod. This continues until the exhaust valve opens just before the piston reaches BDC; this is the power event.

Once the exhaust valve opens, the burned gasses begin to flow out of the cylinder. The piston reaches BDC and begins its upward movement. This movement forces the exhaust gases out of the cylinder. Just before TDC, the intake valve opens and scavenging takes place as the piston reaches TDC; this is the exhaust event.

Four-stroke engines do not require a blower to operate because of the vacuum created by the movement of the piston. This vacuum allows the engine to operate at normal atmospheric pressure. This we refer to as a naturally aspirated engine.

404. Four-stroke gasoline engines

The gasoline four-stroke engine operates on the same principle as the diesel four-stroke engine. The movements of the piston and valves are the same. Although there are a few differences between the two types which are found mainly in the fuel and ignition systems. This lesson discussed the events that occur that completes the engine cycle.

Engine components and operations

The fuel system consists of a carburetor or injectors. The carburetor mixes the intake air and gasoline before they enter the cylinder. Therefore, the cylinder takes in an air and fuel mixture. In some, gasoline engines injectors are used and the fuel is injected into the intake ports or manifold. Additionally many new engines use direct injection like as diesel but the fuel ignited using a spark plug.

The ignition system is also different. The gasoline engine uses an electrical system where the diesel uses compression ignition. The gasoline engine’s ignition system provides an electrical spark at the proper time to ignite the air/fuel mixture.

Ignition system

The ignition system provides an electrical spark in the combustion chamber at the proper time to ignite the air/fuel mixture. Using either a battery or a magneto system accomplishes this. The battery system is by far the more common today, though you still find magneto systems on some equipment. Regardless of the system the engine uses, it must deliver voltage to the spark plug that is high enough to jump the gap and create a spark at the proper time for ignition purposes.

Battery ignition system

This system uses several different components to create the electrical spark in the combustion chamber. These components include the battery, ignition switch, ignition coil, breaker points, condenser, distributor, high-tension wire, and spark plug, as shown in figure 1–14 . The ignition coil contains two coils, the primary and secondary windings.

When the ignition switch is turned on; current flows through the breaker points and ignition coil. This causes a magnetic field to build up around the coil. When the breaker points open, current flow abruptly stops and the magnetic field of the coil collapses. This collapse of the magnetic field causes a massive buildup of up to 250 volts in the primary and secondary coils. The primary coil discharges back toward the condenser, which absorbs the voltage. Without the condenser, the voltage would arc across the breaker points causing them to burn. The condenser holds the voltage momentarily, and then discharges it. The breaker points close as this discharge from the condenser occurs providing a path of current flow back to the battery.

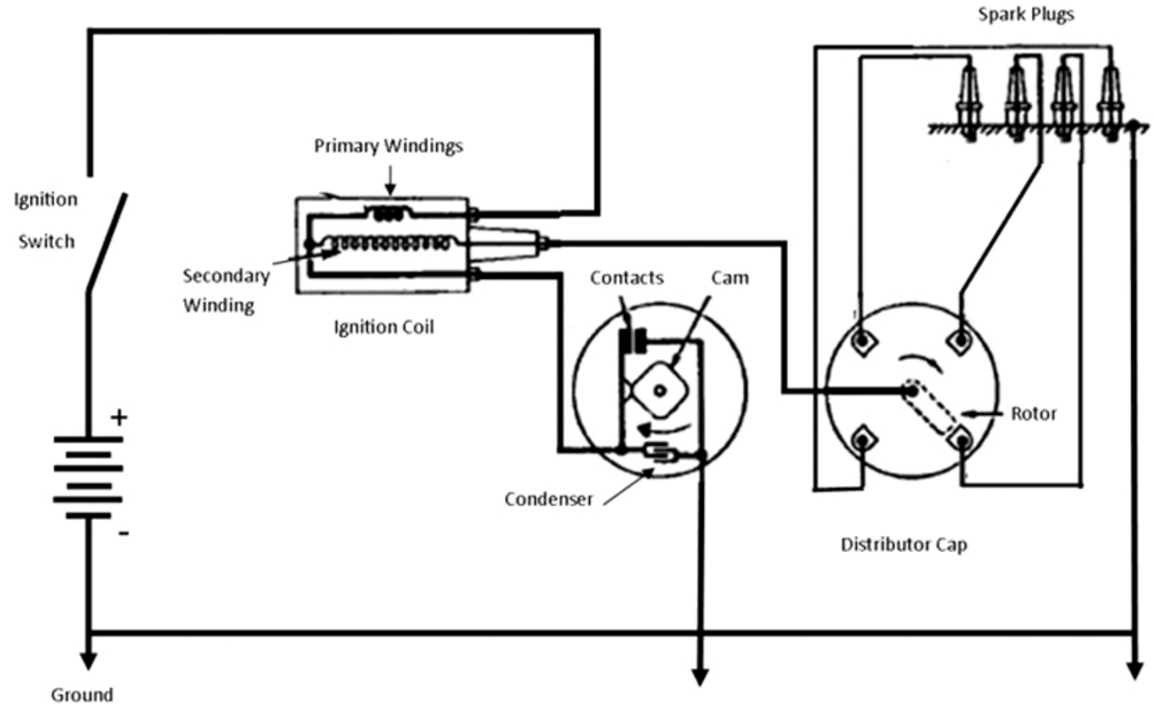


Figure 1–14. Battery ignition system schematic.

The secondary coil is much larger than the primary coil, often containing about 100 times as many turns. This causes the secondary coil to build up much more voltage, up to about 25,000 volts than the primary coil. This voltage discharges through the high-tension wire to the distributor. The distributor connects the coil to the cylinder that is about to fire. The voltage continues through another high-tension wire to the spark plug. The spark plug mounts in the cylinder head with the electrode extending into the combustion chamber. The high voltage created by the secondary winding causes an arc across the gap in the electrode. This arc ignites the air/fuel mixture in the cylinder.

The amount of voltage required to jump a gap on an electrode of a spark plug is about 6,000 to 20,000 volts. The exact amount varies based several variables including the amount of compression, type of spark plug, shape and condition of the electrodes, and spark plug gap.

Electronic ignition system

Many gasoline engines use an electronic ignition system. These systems are a type of battery ignition system since they use a battery for operating voltage. There are different types of electronic systems. One type of electronic system uses a distributor, which has several components that ensure correct spark timing. Hidden under the distributor cap is an ignition signal sensor, which senses a spot on the cam and sends a signal to the ignition module. The ignition module then closes the circuit to ground coming from the ignition coil. When this happens, the coil sends voltage to the distributor cap. Once the voltage gets to the cap, the voltage is transferred to the rotor, which is timed to the correct position on the cap in order to send the voltage to the appropriate cylinder's spark plug. In other words, this electronic ignition replaces a mechanical set of points with a solid-state component to time ignition from the coil. These systems tend to need less maintenance due to the lack of mechanical points, but they still require periodic maintenance that usually involves replacing the cap and rotor.

Another type of electronic ignition is called distributor-less. This system will have either a coil pack, which will send voltage to the correct cylinder via a spark plug wire, or will have a coil for each individual cylinder that receives a signal from the engine control module. In this configuration, the coil is directly attached to the spark plug. Both of these systems require very little maintenance because they do not contain any moving parts and the spark timing is controlled electronically to deliver the spark at the most optimal time no matter the operating conditions.

Magneto ignition system

The magneto ignition system is similar to the battery ignition system. The components that make up the magneto ignition system are a permanent magnet, ignition coil, breaker points, condenser, high-tension wires, and spark plug. The ignition coil contains two coils, a primary and a secondary.

The primary coil typically has about 150 turns of fairly heavy copper. The secondary coil often has about 20,000 turns of fine copper wire. The ignition coil also has an odd shaped core, which is designed to efficiently direct the magnetic lines of force around the coils. This design enables the magneto to produce a voltage that is sufficient to jump the spark plug gap.

The basic operation of the magneto ignition system is the same as the battery system except for the power source. The permanent magnet provides the power. As it passes the core of the coil, lines of force flow to create a magnetic field in the primary coil. This produces current from the coil, through the breaker points, to ground. As the magnet reaches the secondary coil, the breaker points open. This creates a sudden collapse of the magnetic field. The condenser absorbs the current of the primary coil to prevent the burning of the breaker points. This collapse of the magnetic field induces a voltage on the secondary coil. This creates high voltage that moves to the spark plug to create a spark.

Fuel system

The gasoline fuel system supplies fuel to the engine for combustion. The fuel vaporizes and mixes with air before it reaches the cylinder. The normal mixture is 15 parts of air to 1 part of fuel. This ratio varies from start up to acceleration. The main components of a gasoline fuel system are the fuel filter, fuel pump, and carburetor.

Fuel filter

The fuel filter is a unit that removes dirt and foreign particles from the gasoline. Without the filter, these particles would get into other components of the fuel system and clog fuel passages. Many of these filters are sediment-bowls that use a bowl and screen to filter the fuel. In this type of filter, the fuel enters the bowl and passes upward through the filter screen before flowing through the outlet. Any water or solid matter caught by the screen falls to the bottom of the bowl, where you can remove it. Other fuel filters use metal-disc, porous-clay, absorbent-cloth, or paper filter elements. All filters, regardless of their design, remove particles from the fuel.

If there is anything out of the ordinary or the engine has a stained glass bowl and you can’t see through it, remove it. Start by disabling the engine from starting and tag the control panel. Loosen the screw from the bottom of the fuel bowl until you can slide the wire clamp over the side of the glass bowl. Be sure to support the glass bowl as you do this because it will come off at this point. Empty the bowl and clean it. Clean the screen to make sure no particles remain trapped. Replace the bowl and slide the wire clamp over the glass bowl. Tighten the nut finger tight, making sure it is secure. Use the hand primer to fill the bowl with fuel. Start the engine and observe the bowl for leaks and proper operation.

Fuel pump

The fuel pump is a mechanically or electrically operated device that moves fuel from one point to another. The engine camshaft usually drives the mechanical pump, while batteries usually drive the electronic pumps. The fuel pump transfers gasoline from the fuel tank, through the fuel lines, to the carburetor. The pump also keeps the gasoline under a constant pressure.

If the fuel pump requires replacement, be sure that the engine is cool. When working with gasoline; a hot engine could cause a flash fire that could cause severe burns to you and damage to the engine.Disconnect the fuel lines, remove the mounting bolts from the pump and remove the pump.

To reinstall the pump, place it in the opening and bolt it down. If you removed the heat shield, replace it. Connect the fuel lines to the pump and clean up any spills. Start the engine to make sure that everything operates properly. Allow it to run long enough to be sure that the pump is refilling the carburetor bowl.

Carburetor

The carburetor mixes the liquid gasoline with air that is moving on its way to the engine cylinders. To do this, the carburetor uses a venturi. The venturi is a restriction in a passage that causes air to move faster. This increase in velocity causes a decrease in pressure. The greatest speed occurs at the point where the restriction is the greatest. As the restriction reduces, the speed of the air slows.

The fuel nozzle extends into the passage at the point in the venturi where pressure is at its lowest level, as shown in figure 1–15. The decrease in pressure in the passage creates a vacuum, which draws partially vaporized fuel into the passage. The speed of the air in the venturi further vaporizes the fuel. The fuel often does not completely vaporize until it reaches the cylinder and is compressed.

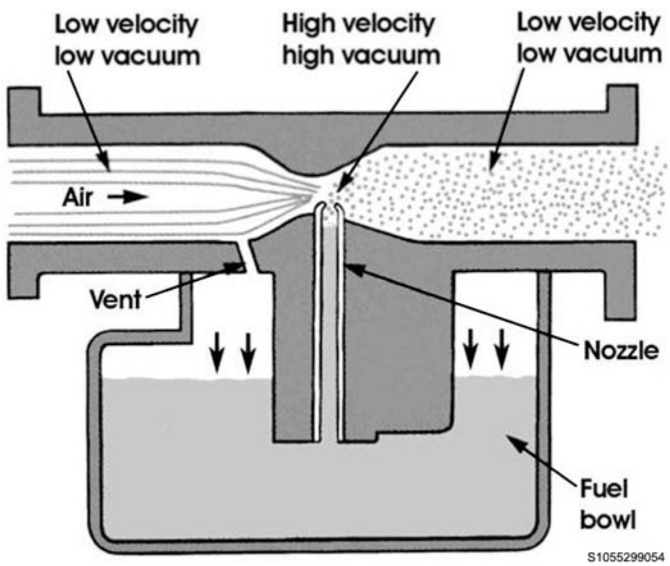


Figure 1–15. Venturi principle.

The carburetor varies the proportions (ratio) of gasoline and air, changing the mixture. A lean mixture is when less fuel (than is required for the given about of air) is present and if a mixture is rich it contains more fuel.The position of the throttle valve controls the amount of air-fuel mixture that enters the cylinders during the intake strokes. Though there are many variations and designs of carburetors, they all perform the same function.

Some of the basic components of the carburetor include: the bowl, float, choke system, venturi, nozzle, throttle valve, load adjustment, and idling circuit. The following list defines each component.

- **Bowl**–The bowl is a small storage area for gasoline in the carburetor.
- **Float**–The float is a small sealed vessel normally made of brass or plastic. The float maintains a constant level of fuel in the bowl. The float rises and falls with the fuel level. As the float lowers with the level of fuel, it unseats a needle valve, which allows fuel to enter the bowl. As the float rises, it seats the needle, thus shutting off the fuel.
- **Choke**–The choke is a round disc, mounted on a shaft that is located at the intake end of the carburetor. When the choke is closed, it provides a rich mixture of air/fuel that is necessary for cold starting.As the engine warms, less choke is required.

- **Venturi**–The venturi is a restriction in the air passage.It causes an increased air velocity as the air reaches the venturi. This change in air speed causes a pressure change. The pressure decreases, creating a vacuum.
- **Nozzle**–The nozzle is a tube that connects the bowl to the air passage.It transfers the fuel from the bowl to the venturi. This is sometimes refered to as a jet.
- **Throttle valve**–The throttle valve is a round disc mounted on a shaft and is located beyond the main fuel nozzle. The throttle valve regulates the amount of air/fuel mixture entering the cylinders by restricting the passage.
- **Load adjustment**–You do load adjustment by use of a fixed jet or orifice, which allows a preset amount of fuel flow for maximum power and economy. Carburetors equipped with a fixed jet are non-adjustable.
- **Idling circuit–**The idling circuit supplies just enough air/fuel mixture to keep the engine running when the engine is idling. The throttle valve closes during idle.

Fuel injection

Automobiles have used fuel injections systems for several years. They are now beginning to make their way into industrial engines. These systems replace the carburetor with fuel injectors. These injectors fall into two categories, port and throttle body. Port injectors inject fuel directly into the intake manifold or cylinder head just before the intake valve. There is an injector for each cylinder the engine has. The throttle body injectors use a device similar to a carburetor with an injector built into it. Either way, the injectors are basically electronic metering valves. This allows the injectors to provide precisely controlled amounts of fuel to the engine based on speed and load.

Older systems used differences in pressures created by an engine driven fuel pump to vary the amount of fuel supplied to the engine. Newer systems use electronically controlled needle valves to adjust the amount of fuel sprayed into the engine. These systems use a solenoid to control the movement of a needle valve. The position of the needle valve controls the amount of fuel supplied to the engine. Fuel injection systems are much more efficient and provide quicker response to speed and load changes.

Understanding the events that occur to complete a cycle is important. Being able to take these events and place them with the movement of engine components is the key to understanding engine operation. If you do not understand the operation of an engine, you will not be able to correct problems. This could cause the failure of the mission.

Answers to Self-Test Questions

401. Engine components

1. What is the purpose of the engine block?

2. What are the main journals?

3. What two categories do rings fall?

4. Why does the cylinder head contain elaborate coolant passages?

402. Engine operations

1. Describe the movement in an engine's stroke.

2. What are the events for an engine?

3. To what does compression ratio refer?

403. Diesel theory of operation

1. What does a two stroke engine use to pressurize the air in the air box?

2. To what temperatures does compression causes the air in the combustion chamber to increase?

3. When is fuel injected into the cylinder?

4. Why do four stroke engines not require an external blower?

404. Four-stroke gasoline engines

1. What components make up the battery ignition system?

2. What does the secondary coil having more coils than the primary coil cause?

3. What does the fuel filters do?

4. What is the venturi?

5. What does the throttle valve do?

1–2. Gasoline troubleshooting and maintenance

Even though the primary type of engines that power production technician work on are diesel, many of the associated equipment and small generators are gasoline. Knowing how to diagnose problems with these engines will help make your job easier.

405. Troubleshooting

Sometimes, in spite of all your efforts in performing inspections and preventive maintenance, malfunctions will occur within a piece of equipment that will make the unit unserviceable. When this happens, you must be able to troubleshoot the system, analyze the malfunction, locate the malfunction, correct the problem and return the system back to service in an expedient manner. This lesson will provide you with useful information that will aid you in troubleshooting the various malfunctions that plague engine systems.

Troubleshooting process

Since troubleshooting is a systematic procedure, the effectiveness depends on how much you know about the equipment and how much you think while working. Use your knowledge and concentration to help you use the process.

As you get started, study the symptoms of the trouble thoroughly and ask yourself these questions:

- What were the warningsigns preceding the trouble?
- What recent repair has been done?
- Has a similar trouble occurred before?

Next, perform a visual inspection of the electrical components. Check wiring harnesses for breaks, and check relays for loose connections, evidence of overheating, cracks, or any signs of damage. Inspecting the electrical components helps you get in the correct area as you make your list of possible troubles. Once you understand what the problem is, consult the proper technical manual for normal engine operation. Consulting the technical manual gives you a clearer understanding of how the engine should be working. You can also use the troubleshooting chart located in the proper technical manual. Make your list and scrub it to develop a plan of attack to find the problem.

Once you have located the problem, a neat and permanent repair is a necessity. After you replace the defective component, do an operational check. This is the most rewarding step in the troubleshooting process. If you do not prove your work, you will not know if you have solved the problem. Remember, one malfunction can produce more than one problem. The following chart shows the cause and remedy of some common engine problems.

Troubleshooting Engine Problems

Trouble	Probable Cause	Remedy
1. Engine fails to turn over.	Battery is low. Short in electric wiring. Wire broken. Faulty starter.	Replace. Check wiring. Find short and wrap exposed wire with insulation tape or replace wire. Find break, replace wire. Repair or replace starter.
2. Engine turns over but fails to start.S	Engine flooded. Battery low. Empty fuel tank. Faulty fuel pump. Water, dirt or gum in gasoline. Faulty carburetor. Spark plug(s) fouled or wet.	Clear flooded engine. Replace. Fill tank. Repair or replace fuel pump. Drain, clear lines and fill tank. Repair or replace carburetor. Clean plugs.

Troubleshooting Engine Problems		
Trouble	**Probable Cause**	**Remedy**
	Spark plug(s) gap incorrect. Ignition cable disconnected or broken. Overheating shutdown switch faulty. Ignition cable wet or oil soaked. Spark timing incorrect. Vapor lock in fuel lines. Fuel solenoid faulty.	Set gap. Connect or repair. Check continuity of wire and switch to ground. If grounded replace switch. Clean and dry. Set timing. Clear vapor lock. Check for 12 volts to solenoid and operation of solenoid.
3. Engine stops.	Empty fuel tank. Faulty fuel pump. Water, dirt or gum in gasoline. Faulty carburetor. Spark plug(s) fouled or wet. Spark plug(s) gap incorrect. Ignition cable disconnected or broken. Ignition cable wet or oil soaked. Vapor lock in fuel lines. Vent hole in fuel tank plugged. Faulty overheat shutdown switch.	Fill tank. Repair or replace fuel pump. Drain, clean lines and fill tank. Repair or replace carburetor. Clean plugs. Set gap. Connect or repair. Clean and dry. Clear vapor lock Clear vent. Replace shutdown switch.
4. Engine misses.	Spark plug(s) gap incorrect. Worn and leaking ignition cables. Weak spark. Loose ignition cable. Water in gasoline. Poor compression.	Set gap. Replace cables. Check distributor. Connect or tighten. Drain and replenish fuel. Restore compression.
5. Engine surges.	Carburetor flooding. Governor spring hooked into wrong hole in lever, or governor rod incorrectly adjusted.	Clear flooding. Adjust governor lever.
6. Engine overheats.	Low grade of gasoline. Engine overloaded. Restricted cooling air circulation. Part of air shroud removed from engine. Dirt between cooling fins on cylinder or head. Carbon in engine. Dirty or incorrect grade of crankcase oil. Restricted exhaust.	Drain and replenish with proper grade. Reduce load. Clear restriction. Replace. Clean fins. Clear carbon. Drain and replenish.
7. Engine knocks.	Poor grade or low octane rating. Engine operating under heavy load at low. speed. Carbon or lead deposits in cylinder head. Spark advanced too far. Loose or burnt out connecting rod bearing.	Drain and replenish with proper grade. Adjust speed and load. Clear carbon. Adjust spark. Repair.

Troubleshooting Engine Problems		
Trouble	**Probable Cause**	**Remedy**
	Engine overheated. Worn or loose piston pin.	
8. Engine backfires through carburetor.	Water or dirt in gasoline. Engine cold. Poor grade of gasoline. Sticky inlet valves. Overheated valves. Spark plugs too hot. Hot carbon particles in engine. Ignition firing order incorrect . Ignition timing incorrect.	Clear lines and tank. Warm up. Drain and replenish. Depot level repair. Allow engine to cool. Allow engine to cool. Clear carbon. Reorder igniton cables. Perform engine timing.

Once you have an understanding of how an engine operates, you must maintain it in top operating condition. This includes periodically changing fluids and making adjustments to prevent breakdowns. You must also fix problems as they occur. The next lesson discusses some of the common engine maintenance you do. We start with gasoline engine tune-ups, and then cover component maintenance, and finally we discuss corrosion control.

406. Gasoline engine tune-up

Because gasoline engines use an electronic ignition system and a fuel system that mixes the fuel vapor with the air, you must adjust these systems periodically to keep them operating at peak efficiency. We refer to this as a tune-up. This lesson starts by describing all of the components in the ignition and fuel system. Once you have an understanding of how each of these items work, you can read about the procedures for performing a tune-up.

Engine tune-up process

The tune-up of a gasoline engine keeps it in top operating condition. Always use the manufacturer's manual to ensure you meet specifications. Tune-ups commonly include carburetor adjustments, adjusting the valve tappet, timing the engine, checking the cylinder compression, inspecting the spark plugs, inspecting and adjusting the breaker points, inspecting the cooling system, and adjusting the governor. Your engine may or may not require all of these actions.

Carburetor adjustments

You will see different carburetors throughout your career. Some of them require adjustments to the idle speed and fuel mixture. While others are considered non-adjustable; these only require fine-tuning to the idle speed. There are several ways to adjust a carburetor, as shown in figure 1–16. The next few paragraphs describe the common way to make the adjustments. Consult the appropriate manufacturer's manual for your specific engine.

The only adjustment to non-adjustable carburetors is the idle speed. You adjust this by turning the idle speed adjusting screw to achieve the desired idle speed.

Adjustable carburetors have adjustments for idle speed, low-speed air/fuel mixture, and high-speed air/fuel mixture. The idle speed adjustment is the same as a non-adjustable carburetor. To adjust the low-speed air/fuel mixture, make an initial adjustment according the manufacturers specifications. Once you have the initial adjustment, start the engine and let it reach operating temperature. Now slowly turn the needle valve out until the engine begins to run erratic. Now slowly turn the needle valve in. Count the number of turns it takes to make the engine begin to run erratic. Now back the needle valve off to a position half way between the points that created erratic operation. Once you complete the setting, you may find it necessary to readjust the idle speed.

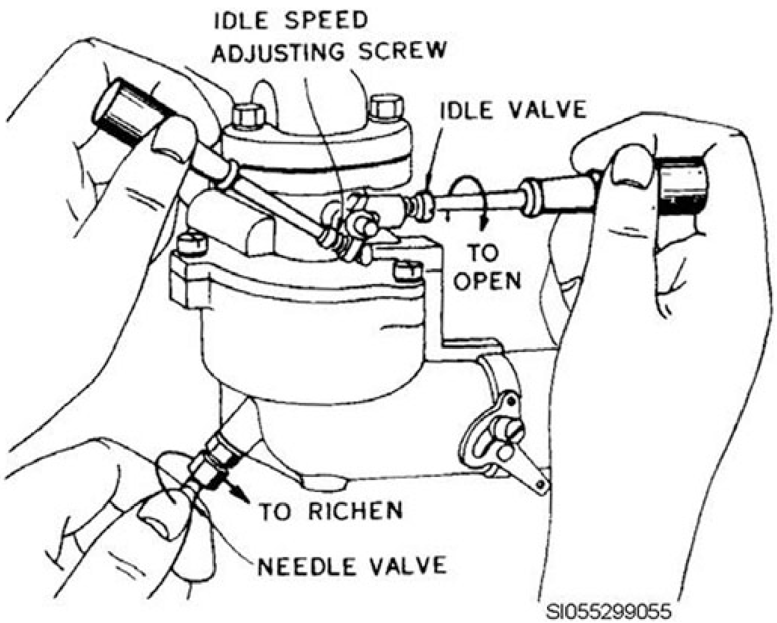


Figure 1–16. Typical carburetor adjustments.

You make the high-speed air/fuel mixture adjustment with the engine at a higher revolution per minute (RPM). The RPM can be quite different between different manufacturers, but generally falls in the 1,500 to 2,000 RPM range. Make this adjustment the same way you made the low-speed air/fuel mixture, except you use the high-speed needle valve.

You can get better adjustments by using a vacuum gauge to set the air/fuel mixtures. Attach the vacuum gauge to the intake manifold. Make the initial adjustments and start the engine. Once the engine reaches operating temperature, adjust the low-speed needle valve so the vacuum is the greatest without changing the idle speed. Now increase the engine RPM and adjust the high-speed needle valve until the engine reaches its highest vacuum.

Valve tappet adjustments

Valve clearance—or valve lash, as it is sometimes called—is the clearance necessary to allow the valve stem to expand while the engine is operating. Both diesel and gasoline engines have valve adjustments that can be made. On some diesel engines there are adjustments for mechanical actuated injectors. The proper clearance is determined by the engine builder and given in the technical order or manufacturer's manual.

Usually clearance is measured by inserting a thickness gage between the valve and the rocker arm. Valve actuating gear consists of the camshaft, cam follower, push rod, rocker arm, and valve.

It is important to maintain the specified clearance. Too much clearance results in noisy operation, excessive wear, and improper valve timing, since the valve opens later and closes earlier than it does with proper clearance. Too little clearance is even more serious, as it may prevent the valve from seating properly. This may prevent combustion through the loss of compression.

You can set the valve clearance with the engine cold, but you make the final adjustment after the engine reaches normal operating temperature. This "hot" valve clearance adjustment makes sure that the valves have the same stem clearance when all parts expand to normal operating range. This clearance is also essential to proper valve timing. When adjusting the clearance, be sure to position the engine properly. Place the piston on the cylinder you are adjusting at TDC on the compression stroke. In this position, the intake and the exhaust valve or valves are closed and the cam followers for this cylinder are on the base circle of the cam.

All engines provide a means for adjusting the clearance in the valve gear somewhere between the cam follower and the valve stem. In most engines, this adjustment consists of an adjustable screw and locknut located at one end of the rocker arm.

To obtain maximum efficiency, a gasoline or diesel engine must be serviced and maintained according to applicable directives and current technical orders. Proper timing of the fuel injectors and correct valve clearance are of the utmost importance for efficient operation of the engine. Improper valve clearance causes loss of power and may result in burning of the valve and valve seat. Burning causes additional maintenance that could have been prevented by maintaining the proper valve clearance.

Spark plug inspection

Remove the spark plug and look at the electrode. A normal operating spark plug is dry with the electrode being a grayish tan color. There should be no carbon buildup between the ceramic and electrode. You generally replace the spark plug if you determine that it is bad. You can clean a spark plug if you have a spark plug cleaner.

Breaker point adjustments

To adjust the breaker points rotate the engine to the high point of the breaker point cam. This opens the breaker points. Use a thickness gauge to check the gap to make sure it is at the specified distance. If you need to make an adjustment, loosen the set screw and move the stationary contact to the desired position. Tighten the set screw and recheck the gap.

You must be able to maintain gasoline engines to achieve mission success. Performing a tune-up is the basis of a good operating engine and keeps the engine operating at peak efficiency. This allows you to concentrate on other important items. Next, we discuss how to maintain other engine systems.

407. Engine maintenance

Engines break down, regardless of how well maintained they are. When something goes wrong, you need to take the correct actions to fix it. The most important aspect of doing engine maintenance is to use the appropriate technical order or manufacturer’s manual. This makes sure that you do the maintenance that is required without missing an important step and more importantly, do these steps safely. This lesson covers the basic information that you need to understand to perform maintenance to the engine without getting specific to any particular engine.

Gaskets and seals

Gaskets fit into irregularities that exist on surfaces as two components are connected. This prevents leakage through the mated surfaces. If you do not install gaskets properly, they will not fill these irregularities and leaks may occur. Gaskets may be made of several types of material to include, fiber, cork, rubber synthetic rubber, copper, and other soft metals. The component that you are trying to seal determines what type of gasket material you use. Exhaust gaskets must be able to with stand extremely high temperatures, while cylinder heads must be able to with stand extremely high pressures. It makes sense that they would use different gasket materials.

To install gaskets properly, you must follow a few sensible rules; clean old gasket off. Make sure that the material is the right type for the components on which you install it. One of the main things that you must make sure of is that you use the right gasket. Torque the components to the proper torque, and tighten them in the correct order. You can find this information in the TO or manufacturer’s manual. Never reuse a gasket that has been compressed because it will often leak. Be sure not to bend, tear, or break the gasket material.

Engine block

The first thing to look for in an inspection of an engine block is leaks. You could find oil or coolant leaks since the block contains oil and coolant passages. Also look for cracks. This is often difficult because of the buildup of grime on the engine. This is why it is important that you keep the engine clean. It makes it much easier to find problems with the block as they occur.

One other thing to look at is freeze plugs. Freeze plugs seal coolant passages and provide protection against the block cracking if the engine coolant freezes. They dislodge from the engine if the pressure becomes too great. Inspect the freeze plugs for general condition and security.

Vibration dampener

When inspecting a vibration dampener ensure that it is secure. Also check for any cracks or chips, thses can cause it to become unbalance.

Cylinder head

After removing the cylinder head inspect cylinder head gasket for possible oil, coolant, or combustion chamber leaks. Generally these can be found by looking for discoloration and or rust around the combustion chamber.

Timing gears

Inspect camshaft gear for chipped, broken, or missing teeth. If camshaft gear has chipped, broken, or missing teeth, the camshaft must be removed and the camshaft gear replaced.

Being able to maintain the engine systems of your equipment is essential to the success of the mission. You must replace components as necessary to keep the engine operating. Don't forget to consult the appropriate TO when you do maintenance to an engine.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

405. Troubleshooting

1. What do improper adjustments to a carburetor cause?

2. What are the causes of a gasoline engine to crank but not start?

3. What are possible cuases that would cause an engine to surge?

406. Gasoline engine tune-up

1. What is the initial adjustment you make to the low-speed air/fuel mixture?

2. What method of air/fuel ratio adjustments gives you the best results?

3. When do you make final valve adjustments?

4. What do you adjust on the breaker points to correct the gap?

407. Engine maintenance

1. Of what materials are gaskets made?

2. What conditions are inspected on vibration dampeners?

3. What are signs of a combustion chamber leak when inspecting cylinder heads?

Answers to Self-Test Questions

401

1. It houses all of the internal components of the engine.
2. The round surfaces on which the crankshaft rotates.
3. (1) Compression.
   (2) Oil.
4. To help remove heat from the combustion chamber.

402

1. It can be in either direction, up or down.
2. Intake, compression, ignition, power, and exhaust.
3. The comparison in the volume of the combustion with the piston at BDC to the volume of the combustion chamber with the piston at TDC.

403

1. External blower.
2. Just before TDC.
3. Above 1,000ºF
4. A four stroke generated vacuum with the downward movement of the piston.

404

1. (1) Battery.
   (2) Ignition switch.
   (3) Ignition coil.
   (4) Breaker points.
   (5) Condenser.
   (6) Distributor.
   (7) High-tension wire.
   (8) Spark plug.
2. The secondary coil to build up much more voltage, up to about 25,000 volts, than the primary coil.
3. Removes dirt and foreign particles from the gasoline.
4. The venturi is a restriction in the air passage.
5. Regulates the amount of air/fuel mixture entering the cylinders by restricting the passage

405

1. (1) Engine backfires through carburetor
   (2) Engine overheats
   (3) Engine surges
   (4) Engine misses
   (5) Engine stops
   (6) Engine turns over but fails to start
2. (1) Engine flooded.
   (2) Battery low.
   (3) Empty fuel tank.
   (4) Faulty fuel pump.
   (5) Water, dirt or gum in gasoline.
   (6) Faulty carburetor.
   (7) Spark plug(s) fouled or wet.
   (8) Spark plug(s) gap incorrect.
   (9) Ignition cable disconnected or broken.
   (10) Overheating shutdown switch faulty.
   (11) Ignition cable wet or oil soaked.
   (12) Spark timing incorrect.
   (13) Vapor lock in fuel lines.
   (15) Fuel solenoid faulty
3. (1) Carburetor flooding.
   (2) Governor spring hooked into wrong hole in lever, or governor rod incorrectly

406

1. Manufacturers reccomendation
2. Vacuum guage method.
3. Stationary contact
4. After the engine reaches normal operating temperature

407

1. (1) Fiber cork.
   (2) Synthetic rubber.
   (3) Copper.
   (4) Other soft metals.
2. Chips and cracks
3. Discoloration and or rust around the combustion chamber Burned or warped valves, worn piston rings, and cylinder liners are some of the defects that cause a loss of compression.

Complete the unit review exercises before going to the next unit.

Unit Review Exercises

Note to Student: Consider all choices carefully, select the *best* answer to each question, and *circle* the corresponding letter. When you have completed all unit review exercises, transfer your answers to the Field-Scoring Answer Sheet.

Do not return your answer sheet to the Air Force Career Development Academy (AFCDA).

1. (401) Which engine component houses *all* of the internal components of the engine?
   a. Head.
   b. Block.
   c. Oil pan.
   d. Crankshaft.

2. (401) Which engine component converts reciprocating motion, up and down, into rotary motion, round and round?
   a. Bearings.
   b. Camshaft.
   c. Crankshaft.
   d. Rocker arms.

3. (401) Which engine component transfers the power of the piston to the crankshaft?
   a. Flywheel.
   b. Camshaft.
   c. Valve train.
   d. Connecting rod.

4. (401) The engine component that forms the top of the combustion chamber is the
   a. liner.
   b. block.
   c. piston.
   d. cylinder head.

5. (401) The type of energy that the flywheel continually stores and releases to smooth the erratic operation of the engine is called
   a. heat.
   b. kinetic.
   c. hydraulic.
   d. pneumatic.

6. (402) Which term describes a complete series of events?
   a. Cycle.
   b. Stroke.
   c. Scavenging.
   d. Compression ratio.

7. (402) The position of the piston when it is at the *highest* point in its movement is *best* described by which term?
   a. Scavenging.
   b. Valve overlap.
   c. Top dead center (TDC).
   d. Bottom dead center (BDC).

8. (402) Which term describes the position of the piston when it is at the *lowest* point in its movement?
   a. Scavenging.
   b. Valve overlap.
   c. Top dead center (TDC).
   d. Bottom dead center (BDC).

9. (402) Which term describes the amount of time that both the intake and exhaust valves are *open* at the same time?
   a. Cycle.
   b. Scavenging.
   c. Valve overlap.
   d. Compression ignition.

10. (403) In a diesel engine, how *high* does the compression of the air causes the temperature to rise?
    a. 120ºF.
    b. 212ºF.
    c. 500ºF.
    d. over 1,000ºF.

11. (403) On a two stroke engine, what creates the movement of intake air?
    a. Blower.
    b. Vacuum.
    c. Centrifugal force.
    d. Atmospheric pressure.

12. (403) On a four stroke engine, what is the position of the valves and how is the piston moving during the exhaust event?
    a. Both valves closed and the piston moving upward.
    b. Both valves open and the piston moving downward.
    c. Intake valve closed, exhaust valve open, and the piston moving upward.
    d. Intake valve open, exhaust valve closed, and the piston moving downward.

13. (404) Identify the component that provides an electrical spark in the combustion chamber at the proper time to ignite the air/fuel mixture.
    a. Carburetor.
    b. Spark plug.
    c. Distributor cap.
    d. Ignition system.

14. (404) Which component prevents the voltage in an ignition system from arcing across the breaker points, causing them to burn?
    a. Coil.
    b. Magnetic.
    c. Condenser.
    d. Distributor.

15. (404) Identify a *restriction* in the passage of a carburetor that causes air to move faster.
    a. Jets.
    b. Nozzle.
    c. Venturi.
    d. Throttle.

16. (404) What causes a four stroke gasoline engine to operate in a lean condition?
    a. An excess of fuel.
    b. An excess of oil.
    c. An excess of air.
    d. Not have enough oil.

17. (405) Which troubleshooting choice is *not* a probable cause that a gasoline engine will *not* crank?
    a. Short in electrical wiring.
    b. Engine flooded.
    c. Battery is low.
    d. Faulty starter.

18. (405) Identify the type of malfunction that occurs if a gasoline engine's ignition firing order is incorrect.
    a. Engine backfires through the carburetor.
    b. Engine will not crank.
    c. Engine overheating.
    d. Engine knock.

19. (406) What do you use to check the gap of breaker points to make sure it is at the specified distance?
    a. Ruler.
    b. Caliper.
    c. Thickness gauge.
    d. Inside micrometer.

20. (407) Which item fits into irregularities that exist on surfaces as you connect two engine components during engine maintenance?
    a. Gaskets.
    b. Wedges.
    c. Lock tight.
    d. Sealing compound.

21. (407) Identify the reason you inspect a vibration dampener during engine maintenance.
    a. Security only.
    b. Cracks and chips only.
    c. Security, cracks, and chips.
    d. Security, paint, cracks, and chips.

Please read the unit menu for unit 2 and continue ➔

Unit 2. Fuel Systems

2–1. Diesel Fuel Systems **2–1**
408. Common system components 2–1
409. Fuel injection systems 2–6
2–2. Maintenance **2–11**
410. Inspection and repair 2–11
411. Troubleshooting diesel fuel systems 2–14
2–3. Electronic Governors **2–16**
412. Components and theory of operation 2–16
413. Governor maintenance 2–19

THE FUEL SYSTEM PROVIDES the life blood for an engine. Without fuel, an engine becomes a rather large paper weight because it will not operate. Remember, an engine requires air, fuel, and an ignition source to operate. The fuel system provides the sufficient amount of clean fuel to burn. Your ability to understand and maintain fuel systems is one of the key factors in the successful operation of your generator sets.

2–1. Diesel Fuel Systems

The engine you primarily work with in the power production field is the diesel engine. Most of your generator sets use varying sizes of diesel engines. Each of these engines has a fuel system, which is one of the more important systems on an engine. You must have a good understanding of how that fuel system works to keep the engine operating at peak efficiency. There are four basic types of fuel systems with which you work. This section describes the system components, operating principles, and maintenance that you need to maintain these fuel systems.

408. Common system components

Though there are four different fuel systems, they all have many common components. These components are just as important as the system specific components discussed. You must remember to maintain these common components because they can lead to the failure of your engine system. In this lesson, we describe these components and explain how they fit into the system.

Storage tank

The storage tank is a large fuel tank that stores fuel for the operation of your generator. This tank may be inside or outside the facility. It should hold enough fuel to last for at least 72 hours of operation at full load.

Day tank

The day tank is a small fuel tank from which a generator operates. It is located inside the facility in close proximity to the generator.

Fuel strainer

The fuel strainer removes large debris from the fuel. The strainer is often a screen mesh but can also be made of other material. You normally find the strainer on the input or suction side of the fuel transfer pump so large particles do not damage the pump.

Fuel filter

The fuel filter removes small contaminates from the fuel. Most filters use paper as the filter material. These filters remove most contaminates from the fuel. You normally find the filter on the pressure side of the transfer pump before the fuel manifold.

Transfer pump

The fuel transfer pump moves fuel from one place to another. Systems that use a storage tank and day tank use a transfer pump to replenish the day tank. These pumps use float valves to maintain the day tanks at the correct level without overflowing them. You may also find transfer pumps between the day tank and the engine. This provides fuel at low pressure to the fuel injector pump.

Injectors

Fuel injectors spray fuel under high pressure into the combustion chamber at the appropriate time for combustion. These injectors also distribute the fuel into the combustion chamber in such a way as to maximize combustion based on the position of the injector, the shape of the crown of the piston, and movement of the air in the combustion chamber. The injector also atomizes the fuel, allowing better burning. Injectors fall into three categories, mechanical, electronic and hydraulic.

Mechanical

Mechanical injectors fall into two designs, flanged and cylindrical. The difference of these two designs primarily falls into the housing and how fuel reaches the injector. The flanged injector (fig. 2–1) mounts into the top of the head with only the tip entering the cylinder head. The fuel lines connect directly to the injector body. The cylindrical injector (fig. 2–2) mounts almost completely into the cylinder head. The fuel lines connect to the head and reach the injector through passages. The operation of these two designs is the same once fuel reaches the injector.

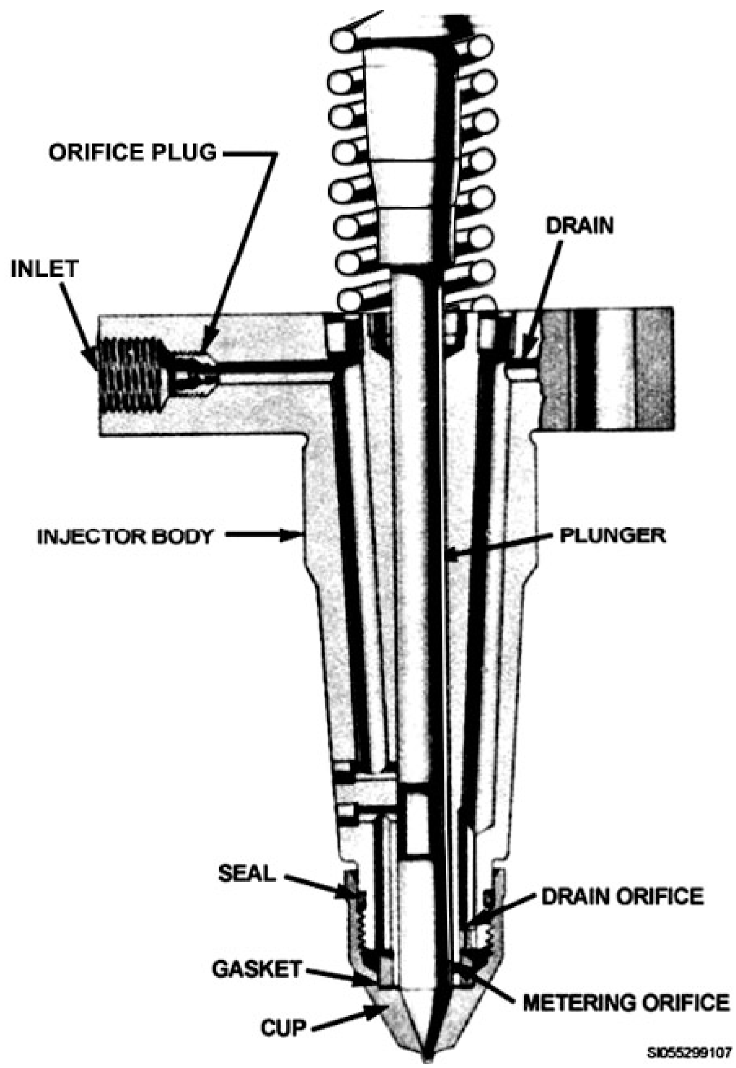


Figure 2–1. Flanged fuel injector.

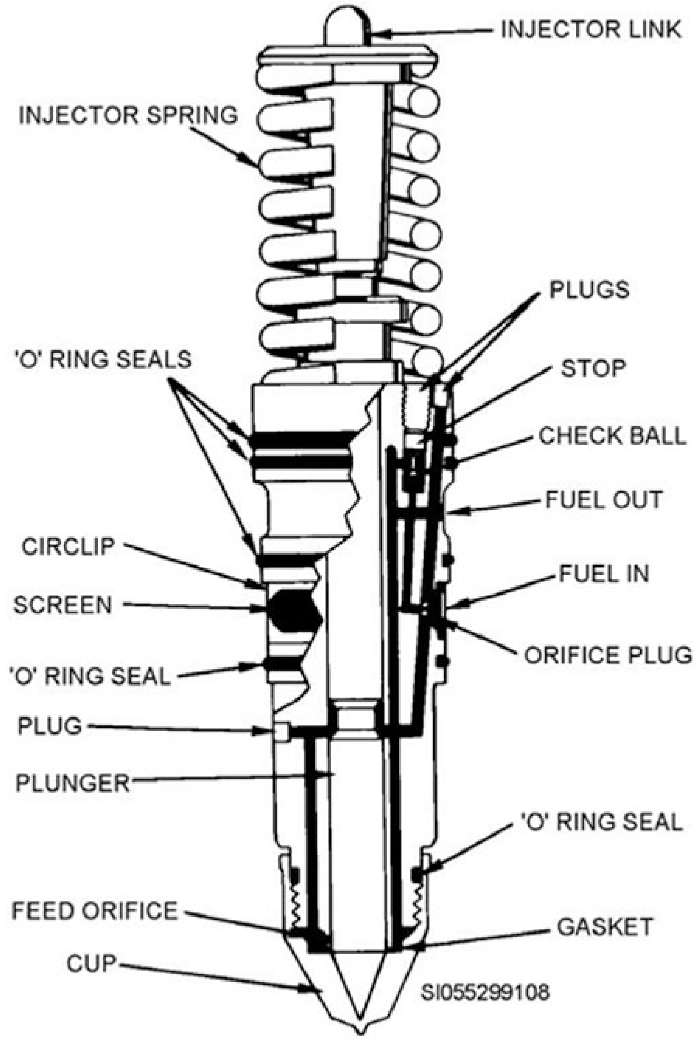


Figure 2–2. Cylindrical fuel injector.

The mechanical injector begins its operation as fuel enters the inlet port (fig. 2–3). Fuel then moves through a passage and passes a check ball. The fuel then moves through another passage to the metering orifice. The fuel continues to circulate through the injector as long as the plunger remains seated. The fuel moves through the drain passage and out of the injector. This movement of fuel cools, cleans, and lubricates the injectors' internal components.

Once the plunger begins to move up, the drain passage closes, trapping fuel in the metering orifice. The plunger continues to move up, opening the metering orifice which allows fuel to flow into the cup. The amount of fuel reaching the cup depends on the length of time the metering orifice is open and the pressure of the fuel.

Once the plunger begins to move down, the check ball prevents fuel from flowing out of the injector through the intake port. The metering valve closes, trapping fuel in the cup. The plunger continues its downward movement, increasing the pressure of the fuel in the cup. This increase of pressure becomes greater than the pressure in the combustion chamber. Once this occurs, the fuel injects into the combustion chamber causing ignition. The plunger completes its downward movement by seating against the cup until its time for the next injection cycle.

Shortly after the metering valve closes, the drain valve opens allowing the fuel inside the injector to continue to circulate. This allows fuel to flow back to the metering orifice while removing any heat and any foreign object from the injector.

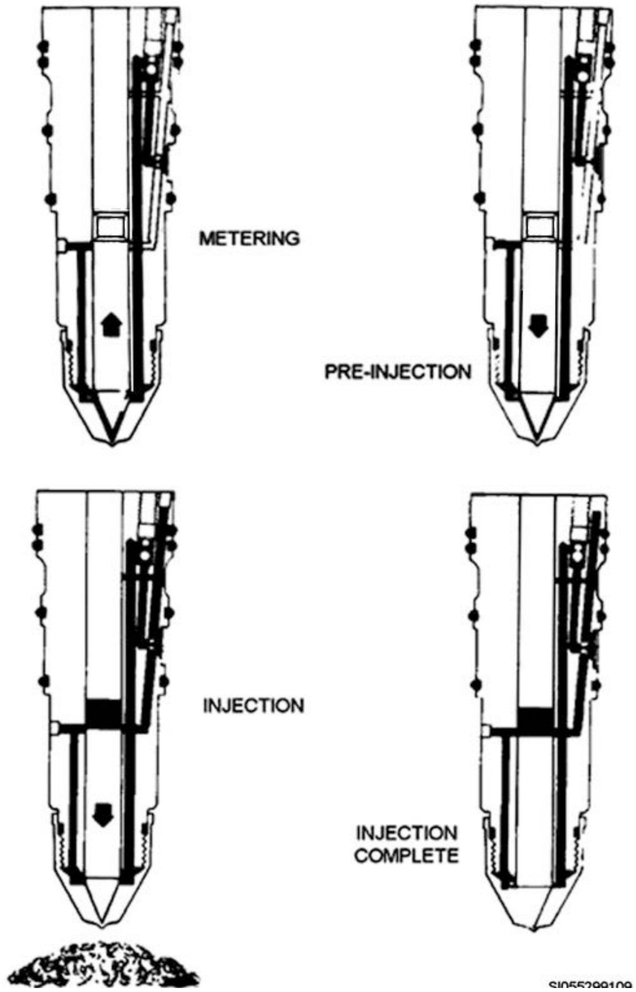


Figure 2–3. Injection cycle.

Hydraulic

Hydraulic injectors (fig. 2–4) use pressurized fuel to operate. The injection pump pressurizes fuel that is directed to the fuel injectors. This pressure can be as high as 5,000 pounds per square inch (psi) depending on the engine design. The pressure used depends on the amount of pressure developed inside the cylinder during compression. Typically you see injectors that operate around 2,500 to 3,000 psi.

The high pressure fuel enters the injector through the fuel duct. This duct directs fuel to the pressure chamber in the injector nozzle (fig. 2–5). Fuel pushes against the nozzle needle and a pressure spring holds the nozzle needle in place (fig. 2–4). The nozzle needle moves upward when the pressure of the fuel overcomes the pressure of the spring. This opens the orifice allowing the pressurized fuel to enter the cylinder. The fuel continues to flow into the cylinder until the pressure of the spring becomes greater than the pressure of the fuel. The spring forces the nozzle needle down closing the orifice. This stops the flow of fuel into the cylinder.

The hydraulic injector uses several different types of nozzles depending on the distribution requirements of the combustion chamber. Manufacturers determine which type of nozzle to use based on the shape of the combustion chamber. The two most common nozzles are the pintle and the hole type. The pintle nozzle, shown on the left of figure 2–5, only has one hole and creates a cone shaped spray pattern. You commonly find them on engines with pre-combustion chambers or when the injector enters the cylinder from the side. The hole type nozzle, shown on the right of figure 2–5, uses multiple orifices set at an angle. There can be as many as 18 orifices from which fuel sprays. The number and arrangement of the orifices determine the spray pattern. The hydraulic injector is adjustable to vary its operating pressure. You can make these adjustments using the pressure adjusting screw at the top of the injector or shims between the housing and pressure spring.

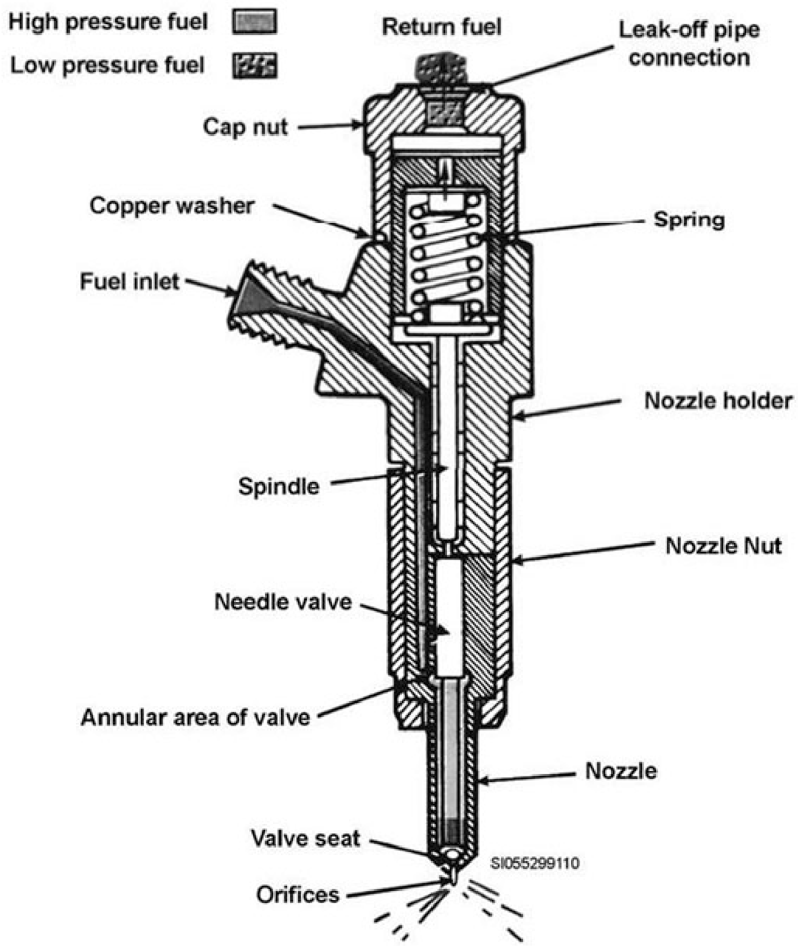


Figure 2–4. Hydraulic fuel injector.

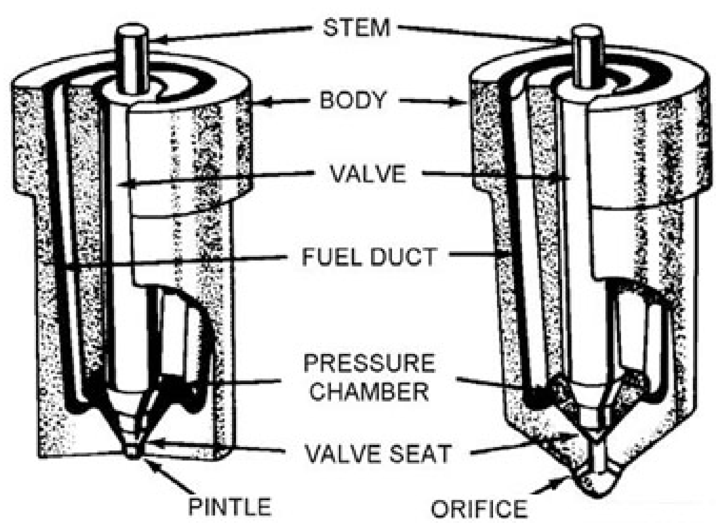


Figure 2–5. Injection nozzles.

Electronic

An electronic injector is controlled by an engine control module (ECM). A fuel pump provides high pressure fuel to the electronic injector. Dependent on injector timing, the ECM provides an electrical signal to the injector. The injector opens and injects the high pressure fuel into the cylinder.

These common components work together with the specific systems we discuss next. Much of the maintenance you do to the fuel system deals with these common components. You should now have a basic understanding of what each component does and how they fit into the entire system. In the next lesson, we discuss the individual cylinder fuel injection system.

409. Fuel injection systems

Diesel engines require high pressure fuel systems to be able to inject fuel into the combustion chamber due to the high compression pressures in the cylinder. Manufacturers have developed several different ways of doing this. Though there are major differences in each system, they all provide the correct amount of fuel based on speed and load at the proper time under the correct pressure. The most common fuel injection systems you see are the port and helix, Cummins pressure-time (PT), distributor, and electronic**.** In this lesson, we discuss the components of a fuel injection system.

Port and helix injection pump

The port and helix injection pump (fig. 2–6) consists of a housing that supports multiple injection pumps. There is a pump for each cylinder of the engine and each pump operates by moving on an internal camshaft that the engine camshaft drives through a series of gears. Each pump uses a cam follower that rides on the camshaft lobe, the plunger spring holds the cam follower against the lobe throughout the rotation, and the housing contains an oil pump to provide lubrication between the cam lobes and cam followers.

Each pump consists of a plunger and barrel assembly. These are mated assemblies, meaning they are built at the same time to provide the tight tolerances required to provide a seal. The plungers contain a helix cut into them. This helix is a groove cut into the plunger at an angle. During operation, fuel fills the cavity between the helix and barrel assembly. The fuel enters the cavity through the input port that is submerged in fuel, then the fuel exits the port at the top of the barrel assembly as the plunger moves on the cam lobe.

Each pump contains a control rack made up of a toothed shaft that moves horizontally. The movement of the control rack shaft rotates the plunger in each of the pumps. The rotation of the plunger allows more or less fuel to be pumped into the cylinder by adjusting the position of the helix in relation to the port. This rotation of the plungers changes the amount of fuel injected into the cylinders.

Cummins pressure-time fuel system

We commonly refer to this system as the PT system with the *P* standing for pressure and the *T* for time. The system pressure and the amount of time the injector opens determines the amount of fuel supplied to the engine for combustion. Cummins has used this system for many years and made several design changes to both the pump and injectors.

Construction features

The PT fuel system (fig. 2–7) consists of the fuel pump, governor, fuel supply and drain lines, and the injectors. The fuel pump is not an injection pump because it does not produce the high pressure fuel necessary for injection, meter a specific amount, or determine when to inject the fuel into each cylinder. Instead it is a positive displacement pump that provides moderate pressure, about 250 psi, to the injector. The mechanical injectors, which you have read about, control much of the aspects necessary for injection of fuel into the cylinder.

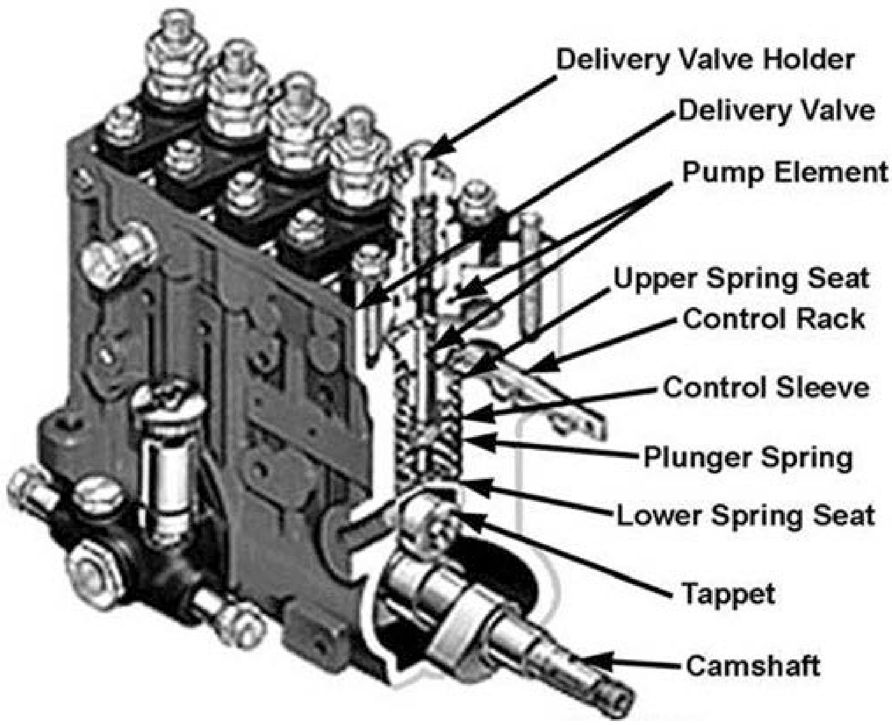


Figure 2–6. Multiple plunger port and helix injection pump.

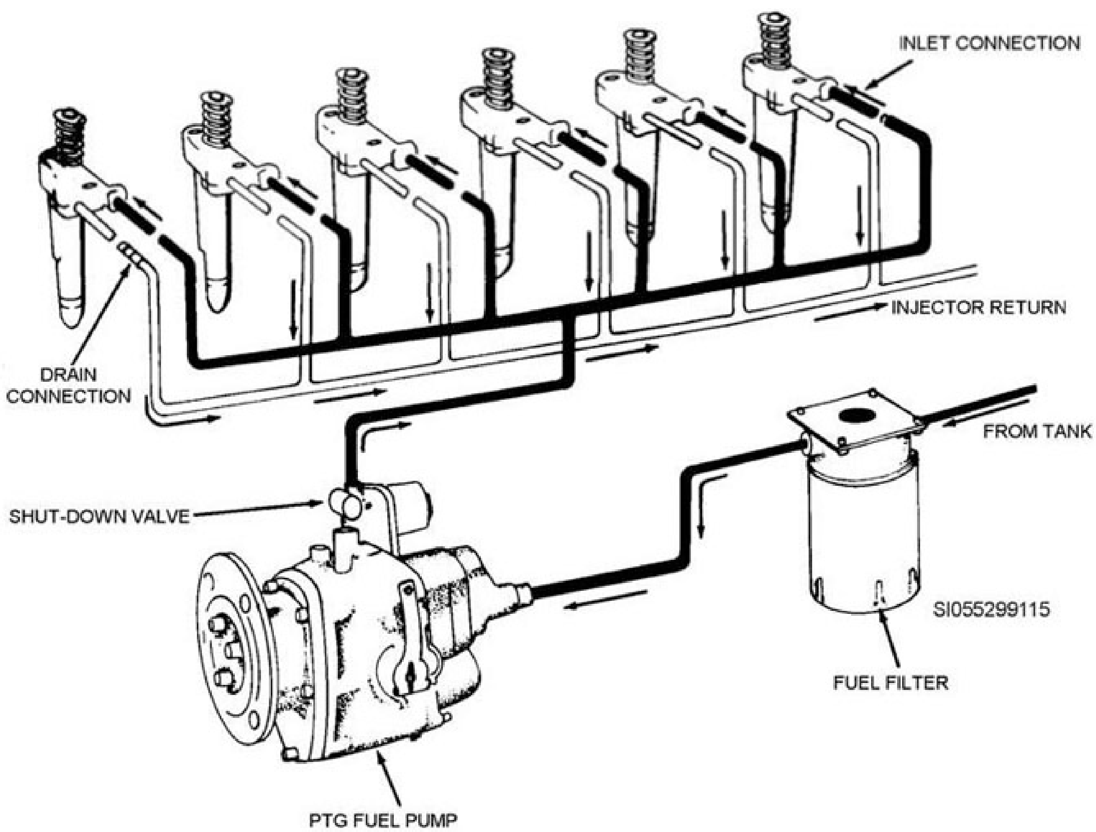


Figure 2–7. Pressure-time fuel system.

Pressure-time system operating principles

Fuel transfer pumps supply the Cummins PT pump with low pressure fuel. The positive displacement pump pressurizes this fuel as it moves it through the pump housing. The fuel then moves past the governor plunger. Under normal operation, the governor plunger has no effect on the fuel flow. If the engine goes into an overspeed condition, the plunger covers the port, limiting how much fuel passes to the output of the pump and how much is returned to the fuel tank through the bypass. The fuel then moves to the air-fuel control valve, if so equipped, and then out of the pump. This allows more fuel to flow to the engine when the air flow increases and less fuel to flow when the air flow decreases.

As the engine speed increases, the positive displacement pump increases the amount of fuel moved through the pump. This increase in fuel pressure allows more fuel to move through the pump into the air-fuel control valve, if so equipped. The increase in engine speed also means more air flow, so the air-fuel control valve opens to allow more fuel to pass to the fuels lines. This increase in pressure and fuel and the shorter amount of time the injector opens determines how much fuel reaches the combustion chamber.

As the engine speed decreases, the positive displacement pump decreases the amount of fuel moved through the pump. This lowers the pressure and amount of the fuel reaching the air-fuel control valve, if so equipped. This decrease in speed means less air flow and less fuel flowing through the air-fuel control valve to the fuel lines. The lower fuel pressure and longer time the injector is open determines the amount of fuel that reaches the combustion chamber.

The one factor that we have not looked at so far is the throttle. The generators you operate use a governor to maintain the correct amount of fuel to the engine based on the operating speed and the amount of load on the generator. This governor controls the throttle valve of the Cummins PT fuel pump. The throttle valve moves to open and close a port inside the PT pump. This controls the amount of fuel passing through the fuel lines, thus controlling the amount of fuel getting to the combustion chamber. This allows the engine to maintain the speed necessary for the correct frequency and voltage output while providing the customer with current load demands.

Distributor-type fuel system

Many small power production generators use this type of fuel system. Although there are several manufacturers of distributor-type fuel systems, this lesson discusses only one popular type.

Construction features

The Roosa Master injection pump (fig. 2–8) is the single-cylinder, opposed-plunger distributor type. It contains three main rotating components, the drive shaft, distributor rotor, and transfer pump. The pump also contains a hydraulic head, fuel meter valve, and governor.

Drive shaft

The drive shaft (fig. 2–9) has a gear attached to one end that engages the engine camshaft. This is what causes the rotating components, the distributive rotor and transfer pump, of the injector pump to move.

Distributor rotor

The distributor rotor (fig. 2–9) contains the cylinder with the plungers. Some pumps have one cylinder while others have two cylinders. The cylinders contain two plungers, one at each end of the cylinder. We refer to this as opposing plungers. These plungers rest against rollers that ride on a cam ring. The cam ring moves the plungers to pressurize the fuel. The distributor rotor also contains inlet and outlet ports, as well as a delivery valve. These allow fuel to move into the chamber and direct pressurized fuel to the cylinder.

Transfer pump

The transfer pump (fig. 2–9) is located at the end of the distributor rotor. It is a positive-displacement, vane type pump covered by the end plate. The transfer pump moves fuel from the inlet to the pump cylinder.

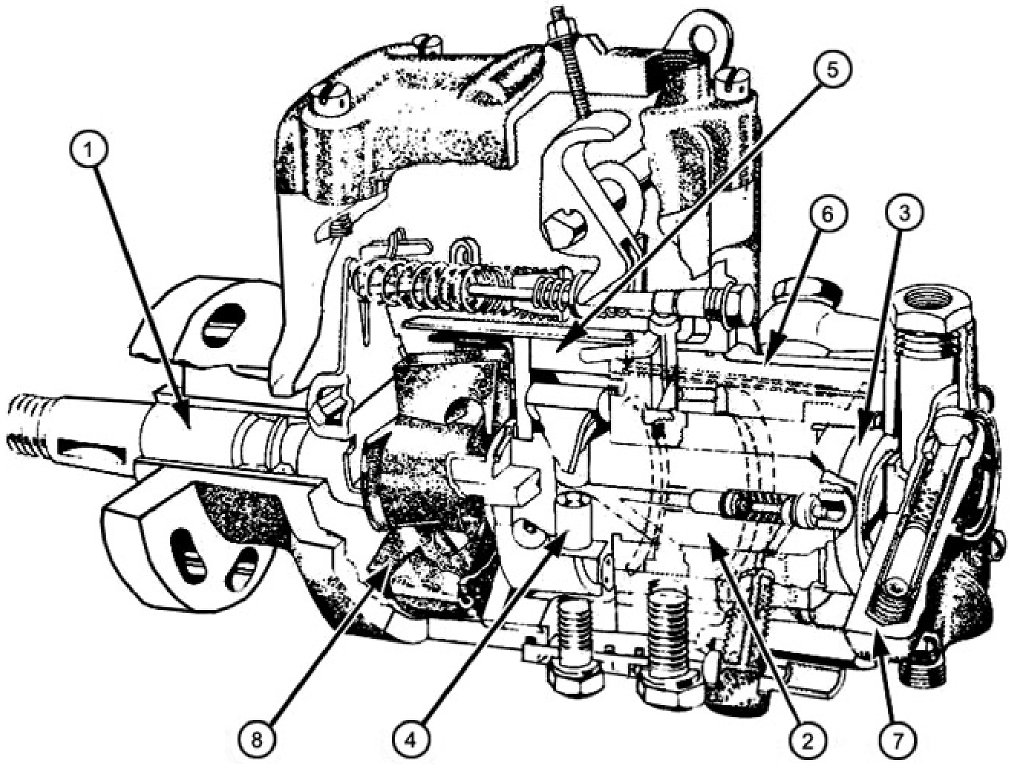


Figure 2–8. Distributor-type fuel pump.

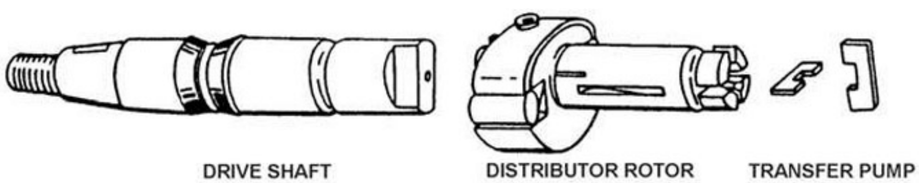


Figure 2–9. Main rotating parts.

Hydraulic head

The hydraulic head fits tightly around the distributor rotor. It contains inlet passages that allow fuel to get into the pump cylinders. The hydraulic head also houses the metering valve as well as contain outlet passages connected to the injectors. This directs the pressurized fuel to the correct injector based on the position outlet port of the distributor rotor and the port in the hydraulic head with which it aligns.

Fuel metering valve

The fuel metering valve controls the amount of fuel entering the pump cylinder. This controls the amount of fuel that reaches the combustion chamber to control the speed of the engine based on the load on the engine. The metering valve contains a helix cut at an angle that covers different amounts of the intake passage to change the amount of fuel reaching the pump cylinder. The position of the metering valve helix in relation to the inlet passage determines the amount of fuel supplied to the engine.

The delivery valve uses a spring to hold it closed. This keeps fuel pressurized in the lines to keep them ready for the next injection cycle. The valve opens once the fuel pressure in the cylinder becomes greater than the spring tension. Once the fuel begins to flow, it passes through the delivery valve into the outlet passage. Some pumps use a single delivery valve at the top of the cylinder while others use a delivery valve for each fuel line.

Governor

The governor controls the position of the metering valve. The engine throttle controls the speed of the engine through the use of the governor. The mechanical governor uses flyweights and spring tension to regulate the engine speed within close tolerances. We discuss more about governors and how they work later.

Operating principles

The fuel transfer pump moves fuel into the pump housing and pressurizes it. The low pressure fuel leaves the transfer pump and inlet passage in the hydraulic head. From there, it passes the metering valve that allows the correct amount of fuel to pass based on the speed of the engine and the amount of load on it. It then enters the charging passage and waits on the rotor to open it. As the rotor rotates into the position that the inlet passage opens, fuel flows into the cylinder. The pressure of the fuel pushes the pistons out, following the cam ring to a low point, as the cylinder fills. The rotor continues to rotate, closing the inlet passage, trapping the fuel in the cylinder. The pistons begin to move in following the cam ring to the highpoint. This inward movement of the pistons pressurizes the fuel and pushes it toward the delivery valve. Once the pressure in the cylinder becomes greater than the spring tension of the delivery valve, the valve opens allowing fuel to flow into the outlet passage. The rotor has rotated to the position where one of the injector lines is open. The pressurized fuel surges into the line, increasing the pressure, causing the injector to open and inject fuel into the cylinder. As the rotor continues to rotate, the pistons reach the highpoint of the cam ring and pressure peaks. As the fuel flows through the delivery valve, pressure in the cylinder decreases. Once the spring tension overcomes the pressure of the fuel in the cylinder, the valve slams shut. This prevents back flow of fuel from the outlet passage while shutting down the flow of fuel to the combustion chamber without dribbling. The rotor continues to rotate, opening the inlet passage to allow fuel to flow into the cylinder as the cycle repeats itself. Pressurized fuel flows to each of the injectors in firing order to keep the engine operating.

Electronic fuel injection

Most new generators are using some form of electronic fuel injection. To have fuel delivery controlled electronically, manufacturers have been able to increase engine output while at the same time increasing efficiency.

Operating principles

Electronic fuel injection systems generally use a pump, a common rail, electronic injectors and an electronic control module or ECM. The fuel pump pressurizes the common rail at the precise moment neede the ECM send a signal to the injector to inject fuel into the cylinder. The timing and pressure of the injection is controlled by the ECM. When dealing with electronic systems, it is important to know how to use the diagnostic software that corresponds with the generator you are working with.

Remember the fuel system is the life blood for the engine. Understanding the operation of these systems allows you to maintain it in top operating condition. Now that you have this understanding, let’s talk about the maintenance required to keep your engine running good covered in the next section.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

408. Common system components

1. What are the two designs of mechanical injectors?

2. Name what the amount of pressure required by a hydraulic injector depend?

3. What determines the spray pattern in a hole type nozzle?

4. What is used to send a signal to fire an electronic fuel injector?

409. Fuel injection systems

1. What are the common types of fuel injection systems?

2. How much pressure does a Cummins PT fuel pump supply to the injectors?

3. What determines the amount of fuel that reaches the combustion chamber as engine speed decreases?

4. What are the three main rotating components in a Roosa Master distributive-type injector pump?

5. What are the major components of an electronic fuel injection system?

2–2. Maintenance

Maintaining the fuel system is the key to the efficient operation of an engine. You need to not only understand the basic steps of the maintenance, but also the when and why we do this maintenance. Remember always use the appropriate technical order or manufacturer’s manual to accomplish any maintenance. The items we cover in this section are general procedures and not for any specific engine system.

410. Inspection and repair

Proper inspections allow the power production technician to identify problems before they result in catastrophic failures. Once identified, it is important to know how to repair or replace the broken component. In this lesson, we discuss the steps of proper maintenance and the when and why the maintenace is necessary.

Priming and bleeding fuel system

Once you replace a fuel system component, you must bleed the fuel system to remove air from the fuel system. Most systems are equipped with a hand primer whil some units are equipped with a bleed valve. Open the bleed valve, if the system is equipped with one or the fuel line at the highest point in the system. It helps to make sure the strainer and filter are full of fuel before you begin this. Begin pumping with the hand primer. Observe the fuel coming out of the drain tube or fuel line. When fuel is air-free and the fuel is flowing, close the bleed valve or fuel line.

Fuel transfer pumps

Fuel transfer pumps supply the engine with the fuel necessary for combustion. You need to inspect these pumps regularly to make sure they provide the required amount of fuel. The inspection of the fuel transfer pumps consists mainly of checking for fuel leaks and making sure that the pumps operate properly. If the pump fails to properly operate, the fuel will not reach the engine. This will cause the engine to shut down. Specific intervals for these inspections vary depending on the type of pump. Many electric fuel transfer pumps have a filter and magnet that you need to inspect at regular intervals. This is due to the fact that they are the first component to filter the fuel and they pick up all of the garbage for the day tank.

Fuel injection pumps

It is essential that the injector pump operates at peak efficiency or the engine performance will suffer. You read about the operation of several injection pumps earlier in this unit. The steps we discuss in the next few paragraphs cover some general maintenance requirements. Consult the technical order or manufacturer’s manual for specific procedures. However when doing a visual inspection, check for security of all lines and mounting bolts. Check linkage (if any is present) for any leaks.

Filters and strainers

Engines normally use fuel strainers between the fuel transfer pump and the high-pressure pumps to make sure that only clean fuel reaches the engine. The fuel strainers used with diesel engines are typically metal-edged or wire mesh types designed to remove any coarse particles from the fuel. Fuel strainers may have blade mechanisms for scraping dirt from the elements without disassembling the strainer. You must inspect strainers at regular intervals to make sure they are clean and properly torqued. Replace strainers when you find them damaged beyond repair. Fuel filters are installed after the strainers and are designed to remove any small particles of dirt or any moisture that passes the strainers. Fuel filters are usually replaceable paper cartridges. On most small power units, you find the strainer on the suction side of the transfer pump and the fuel filter installed on the output side of the fuel pump. Replace fuel filters at regular intervals to prevent them from clogging or becoming damaged. This preventive maintenance keeps your engine operating at peak efficiency.

You must observe several safety precautions when you are working with fuel systems. Avoid prolonged skin contact with fuel because it is a carcinogen and could cause cancer. Avoid breathing fuel fumes and wipe up fuel spills immediately to prevent someone from slipping on it and to decrease the possibility of fire.

There are two types of filters that you commonly see on a generator: the element type and spin on type. You may encounter the element type on older units, but the majority of generators come with spin on type. To replace spin on filters, turn the shut off valve to disable the fuel flow and simply spin off.

Inspecting and cleaning strainers

Clean the strainer element thoroughly with diesel fuel and dry all the components thoroughly. Use low-pressure compressed air to dry out the fuel strainer housing and to free any suspected restrictions in the fuel lines. There is nothing to wear out on the ordinary strainer except the seals and gaskets.

Take a good look at the strainer element to determine whether there is any damage. If anything looks out of the ordinary, replace the strainer element. Wash the strainer and filter bowls with cleaning solvent and dry them thoroughly with rags, look at the bowls for damage. The most common problem that occurs in the bowls is an out-of-round condition. This condition makes it very difficult to get a proper seal as you reinstall them. Clean the head and inspect it for damage.

Reinstalling fuel filters

For the spin-on filter, fill it with fuel and wet the gasket. Spin the filter onto the shaft and snug it. Only tighten it one-fourth turn after it makes contact with the head. Many technicians use a strap wrench to install filters. This is a poor practice because it over compresses the gasket and shortens its life, which could cause leaks. It also makes it nearly impossible to remove the filter the next time it is due service.

Replacing fuel system protective devices

The fuel system has protective devices that are different than the ones you find in other engine systems. You think of protective devices as preventing damage to the engine. The fuel system protective devices don’t protect the engine as much as they protect you. The fuel level sending unit allows you to make sure the engine does not run out of fuel. If for some reason the engine runs out of fuel, the low fuel level switch shuts the engine down just before the fuel is gone. This prevents getting air into the fuel system so you do not need to bleed the system.

Fuel level sending unit

The fuel level sending unit provides the fuel level gage with an electrical signal to allow you to read the fuel level in the storage tank. If the fuel level gage is not reading properly, you may need to replace the sending unit. To do this, do the following actions:

- Disconnect the negative side of the battery to prevent the generator from starting.
- Disconnect the sending unit’s electrical lead.
- Remove the sending unit from the fuel tank.

You may need to remove other engine components to gain access to the sending unit. Be sure to tag the wires on sending units equipped with two or more wires; then you can reinstall them correctly.

To install a new sending unit, screw it into the fuel tank and connect the electrical lead to the sending unit. Connect the negative side battery and start the generator to make sure that the fuel level gage reads correctly and that there are no leaks around the sending unit.

Low fuel level switch

The low fuel level switch is designed to prevent the engine from operating if there is no fuel. It is better to shut the engine down with a small amount of fuel left instead of letting it run completely out of fuel. If it runs completely out, you have to bleed the fuel system and it takes much longer to get the generator back in service. You typically find this switch located in the day tank. To replace it, disconnect the negative side of the battery to prevent the generator from starting. Disconnect the low fuel level switch electrical lead and unscrew it from the tank.

To install a new switch, screw it into the tank and connect the electrical lead to it. Connect the negative side of the battery and start the generator to make sure that there are no leaks around the pressure switch.

Testing fuel for water

Water can get into your fuel system in several ways. The most obvious is to put it in with contaminated fuel as you fill the tank. Water could also get in because of rain or snow or because of a tank that is not properly sealed. The most common way water gets into your fuel tank is through condensation. This takes place because of temperature differences between the inside and outside of the tank. It is more likely to happen in humid places and in the winter. The easiest way to alleviate this is to keep your tank full of fuel. This prevents condensation from building up. Regardless of how much care that you take, test the fuel regularly for water content. This test is the same for gasoline and diesel fuel systems.

The easiest way to test fuel for water is to use water-finding paste. Since water is heavier than fuel, it settles on the bottom of the tank. Put the water finding paste on about the lower two inches of a dipstick. Place the dipstick in the fuel tank until it reaches the bottom of the tank. Hold the stick in the fuel tank for a short period of time, usually around 30 seconds depending on the manufacturer's recommendations. This is to allow the water to react with the paste. The amount of time varies depending on the manufacturer of the paste. Pull the stick out of the tank and observe the paste on the bottom of the dipstick. If the paste shows a change in color, water is present.

If your tank has water in it, take the appropriate action to remove it. Two of the more common ways are to drain it from the bottom of the tank or to use a pump to remove it. Regardless of the way you remove it, make sure you see a solid stream of fuel flowing before you stop. Discard the contaminated fuel according to local policies.

Now you can see how maintaining the fuel system is the key to the efficient operation of an engine. Make sure that you not only understand the basic steps of the maintenance, but also the when and why you do this maintenance. Remember always use the appropriate technical order or manufacturer's manual to accomplish any maintenance. Take the time to do any maintenance necessary because the fuel system is the life blood of an engine.

411. Troubleshooting diesel fuel systems

Troubleshooting diesel fuel systems is the same for each type of fuel system. The most common troubles caused by the fuel system is the engine running erratically or misfiring; the engine cranking but not starting; and the engine exhaust color being black, white, or blue because of something in the fuel system. Within this lesson, we will cover malfunctions, causes, and corrective actions within troubleshooting diesel fuel systems.

Probable causes and corrective actions

The following table lists some of the probable causes and corrective actions of the engine fuel systems. Review the information in the table to help you become better prepared to perform your duties as a technician.

Troubleshooting Diesel Fuel Systems

Malfunction	Probable Cause	Corrective Action
Engine cranks but will not start.	1. Fuel supply exhausted. 2. Air in the fuel system. 3. Restricted fuel supply line. 4. Defective day-tank float switch. 5. Defective fuel solenoid. 6. Clogged fuel filter and/or strainer elements. 7. Defective nozzle-holder assembly. 8. Contaminated or improper grade of fuel.	1. Fill fuel tank or use an auxiliary supply. 2. Bleed the fuel system. 3. Clean restriction or replace the line. 4. Replace the float switch. 5. Replace the fuel solenoid valve. 6. Service the filter and/or strainer. 7. Replace the nozzle-holder assembly. 8. Drain fuel supply and fill with proper grade of fuel.

Troubleshooting Diesel Fuel Systems		
Malfunction	**Probable Cause**	**Corrective Action**
Engine runs erratically or misfires.	1. Contaminated or improper fuel. 2. Air in the fuel system. 3. Restricted fuel lines. 4. Defective nozzle-holder assembly. 5. Dirty air cleaner. 6. Defective turbocharger.	1. Drain fuel system and fill with proper fuel. 2. Bleed the fuel lines. 3. Clean fuel lines. 4. Replace the nozzle-holder assembly. 5. Service the air filters. 6. Replace the turbocharger.
Engine exhaust is excessively black.	1. Improper fuel. 2. Defective injector.	1. Drain the fuel system and fill with the proper fuel. 2. Replace the injector.
Engine generator set shuts down and NO FUEL indicator illuminates, but sufficient fuel remains in the main tank for operation.	1. Defective day-tank float switch. 2. Defective fuel solenoid valve. 3. Clogged fuel filter or strainer. 4. Clogged fuel transfer pump screens. 5. Defective fuel transfer pumps.	1. Replace the float switch. 2. Replace the solenoid valve. 3. Service the filter and strainer. 4. Service fuel transfer pumps. 5. Replace pumps.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

410. Inspection and repair

1. When you are bleeding a fuel system, when do you close the bleed valve or fuel line?

2. What happens if you do not tighten the fuel strainer to the correct tightness?

3. Where do you put the water finding paste on the tip of a dipstick?

411. Troubleshooting diesel fuel systems

1. What are the possible causes for excessive black exhaust?

2. If an engine is running erratically and air is discovered in the fuel system, what corrective measures should be taken?

3. If a generator has contaminated or improper fuel type, what corrective measures should be taken?

2–3. Electronic Governors

Electronic governors are the design of choice by generator manufactures today because of the quick response to load changes. This allows the manufacturer to design generators to meet very tight requirements of frequency control. This is essential in today's world because of all of the high-end electronic components used on equipment. Our generators must maintain the proper voltage and frequency, the electronic governor allows them to do that. Within this section, we will go over design features, operation, and maintenance of electronic governors.

412. Components and theory of operation

Generators we use must have the capability to maintain constant speed and frequency to supply our customer with the proper levels of power. The most common governor you will see is the electronic governor constant speed type. This lesson discusses the components and operations of this type of governor.

Components

The first thing you need to know about a governor is the components that make up the system. These components vary slightly from manufacturer to manufacturer, but the basic concept remains the same. The most common components you will see are the magnetic pickup, electronic control unit, and actuator.

Magnetic pickup

A magnetic pickup (MPU), often called a mag pickup, is a self-contained device that requires no external power. It consists of a one piece shell housing a permanent magnet with a coil wound around it (fig. 2–10). One end of the mag pickup has a pole piece protruding with the other end having the electrical connections. The mag pickup mounts into the engine's bell housing with the pole piece positioned in close proximity to the engine flywheel.

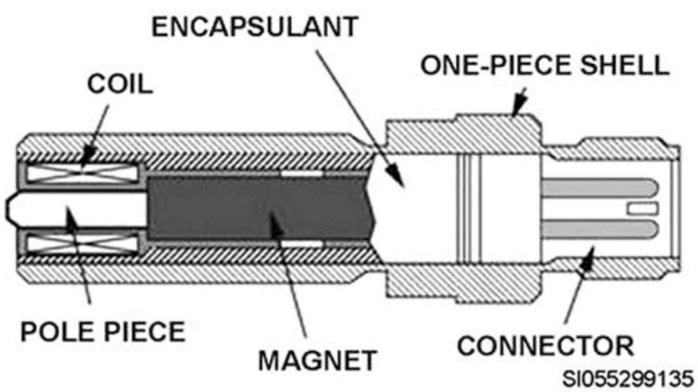


Figure 2–10. Magnetic pickup.

As the engine rotates, the flywheel turns and the teeth on the flywheel cut through the magnetic field created by the mag pickup's permanent magnet. The teeth on the flywheel are made of ferromagnetic material. As one of these teeth move through the magnetic field, the lines of flux move. As a flywheel tooth gets to the mag pickup pole piece, the magnetic field moves from around the magnet, down the pole piece and through the flywheel tooth. This movement causes the lines of flux to cross the conductor inducing a voltage. As the tooth moves away from the pole piece, the magnetic field returns to its original position around the magnet. This movement induces a voltage in the other direction.

This back and forth movement induces alternating current (AC) voltage in the coil of the mag pickup. Each time a tooth crosses the magnetic field, an AC cycle takes place. The speed at which the flywheel teeth cross the pole piece determines the number of AC cycles, or frequency, the mag pickup produces. This AC voltage moves to the electronic control unit.

Electronic control unit

The electronic control unit (ECU) is the brain of the electronic governor. It takes the AC signal from the mag pickup, changes it to direct current (DC) and compares it to a reference voltage. It, then, decides if the engine is operating too fast, too slow, or at the right speed. It, then, provides an output to the actuator that makes any adjustments necessary to the engine speed.

Input circuit

The input circuit receives the AC voltage from the mag pickup. It uses a rectifier to change the AC into DC. The circuit, then, filters the DC voltage smooth. This smooth DC voltage is ready to compare to the reference voltage.

Reference circuit

The reference circuit looks at the reference voltage and input voltage and decides what action to take. This reference voltage normally comes from the engine batteries. If the battery voltage is much too high, so the governor lowers the reference voltage to the appropriate values. The reference circuit takes this adjusted voltage and compares the predetermined reference voltage to the varying input voltage. If they are the same, nothing changes. If the input voltage from the mag pickup is different, the reference circuit signals the amplifier to make the appropriate changes. You can change the reference voltage slightly using a frequency adjusting rheostat. This allows you to vary the engine speed to make adjustments to the desired levels.

The output signal to the amplifier is inversely proportional to the input signal from the mag pickup and directly proportional to the reference circuit. If the reference circuit voltage is increased, the output of the amiplfier is also increased. If the input voltage is lower than the reference voltage, the output signals to the amplifier increases. If the input voltage is higher than the reference voltage, the output signal to the amplifier decreases.

Amplifier circuit

The electronic components of the reference circuit cannot create a signal strong enough to cause the actuator to function. Therefore, the amplifier circuit receives a signal from the reference circuit and strengthens it to provide the necessary output values to the actuator. The output of the amplifier is directly proportional to the output of the reference circuit.

Ramp generator circuit

The ramp generator circuit allows the engine to operate at idle speed to allow the engine to warm up before accelerating to the rated speed. This is an optional feature that you do not find on all governors. The ramp generator circuit establishes the speed of the engine by determining the reference voltage used by the reference circuit. The circuit uses two different reference voltages, one for idle and one for rated speed; each voltage is controlled by a switch. The ramp generator switch may close either manually, by oil pressure, a timed sequence, or a crank terminator. When it is in the idle speed position, the ECU uses the idle speed reference voltage. Once the switch changes, the ECU uses the rated speed reference voltage.

Actuator

The actuator receives a signal from the ECU and positions the fuel rack based on this signal. This position of the fuel rack supplies the engine with the correct amount of fuel based on speed and load. Generally an actuator consists of a coil, swing arm, and spring. The ECU provides a signal to the actuator. This voltage input creates a magnetic field in the coil. This magnetic field attracts the swing arm, pulling it towards the coil. The spring opposes this movement forcing the swing arm away from the coil. The greater the magnetic field, the more the swing arm moves to overcome the spring tension. This movement causes the fuel rack to move increasing the amount of fuel supplied to the engine. The smaller the magnetic field, the more the spring tension moves the swing arm away from the coil thus overcoming the magnetic force. This movement causes the fuel rack to move while decreasing the amount of fuel supplied to the engine.

Operations

The operation of the electronic governor can seem rather complicated because you cannot see how the electrons move throughout the components. Their operation is really not as complex as many make them out to be. The key is to understand what each of the components do and how they fit into the overall operation.

Start up fuel control

Notice that the amount of fuel is proportional to output voltage of the governor control unit. The operating sequence begins before the engine starts, as shown in figure 2–11. The following list provides the steps to the sequence of operation. Each step is represented in figure 2–11.

- There is no voltage applied to the actuator until the engine is started.
- When the engine rotates during the starting process, the MPU generates voltage and the ECU determines the need to increase engine speed.
- The amplifier output voltage rises to maximum voltage.
- As the engine starts, it accelerates until it reaches idle speed.
- The ECU senses the correct engine speed and reduces its output to reduce fuel to maintain idle.
- The ramp generator provides for a controlled acceleration from idle speed to rated speed.
- When the ramp switch closes, the reference voltage increases to the rated speed setting.
- The ECU then senses the engine speed needs to increase and increases the amplifier output. This increases the amount of fuel increasing the engine speed toward the rated speed.
- The governor controls fuel as required to maintain a steady increase in speed determined by the ramp. When the ramp to rated speed ends, the engine is ready for load applications. The ramp now has no further function until the next time you start the engine.
- When the load on an engine increases, the speed decreases. The governor control unit increases its output voltage to the actuator, in turn increasing fuel to the engine. The result is the engine returns to its rated speed.
- When the load on an engine decreases, the speed increases. The governor control unit decreases its output voltage to the actuator, in turn decreasing fuel to the engine. The result is the engine returns to its rated speed.

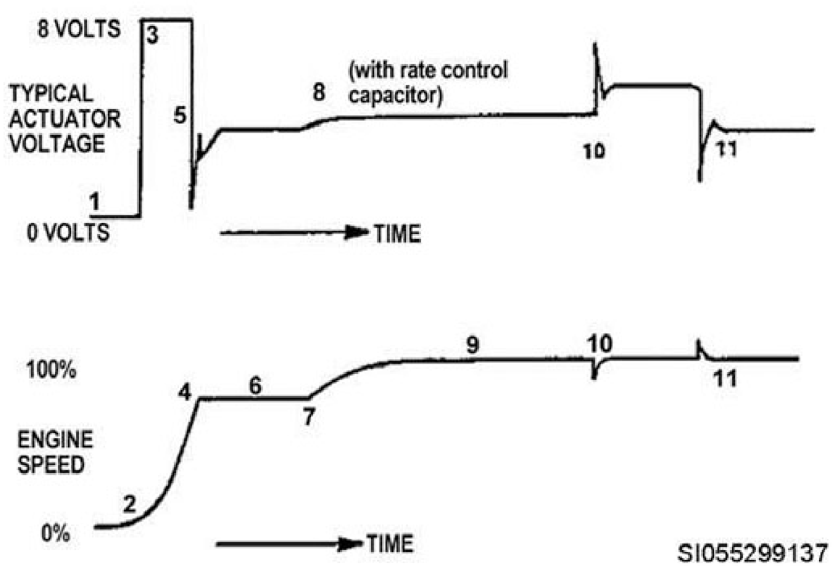


Figure 2–11. Operating sequence.

Speed decrease

The mag pickup senses this decrease in speed because the number of cycles of AC decreases. This decrease in frequency moves into the ECU, where the input changes it into DC and smoothes it out with a filter. The input voltage has decreased since the load change. The reference circuit compares the mag pickup signal with the reference voltage and determines the speed is low. The reference circuit then sends a signal to the amplifier that is higher than the signal before the load change. Since the signal to the actuator is higher, the magnetic field overcomes the spring tension causing the actuator to move the fuel in the increased fuel direction. The engine receives more fuel, therefore, increasing the engine speed.

As the engine speed returns to the preset level, the mag pickup senses the speed change. The ECU sees this change and makes minor adjustments to the amplifier output to maintain the engine speed at the correct level.

Speed increase

When load to an engine decreases, the speed increases. The mag pickup senses this increase in speed due to the increase in the frequency of the AC cycles. This mag pickup signal enters the ECU and is changed to DC and filtered smooth. The reference circuit sees this increase in the DC from the input circuit because it becomes higher than the reference voltage. The reference circuit then decreases the signal to the amplifier. This decreases the output of the amplifier signal to the actuator. This decreased signal reaches the actuator decreasing the magnetic field of the coil, causing the engine to receive less fuel.

Changing the engine speed

As you know, the reference voltage is adjustable by turning the frequency-adjusting rheostat. As you turn the rheostat, notice the engine speed changes. Since the speed of the engine determines the frequency of a generator, you also see the frequency of the generator change. What you are really changing is the intensity of the reference voltage. Since the ECU compares the MPU output to this reference voltage, a difference between them creates a change in the output to the governor actuator. The actuator controls the fuel rack of the injector pump, thus controlling the amount of fuel applied to the engine.

Electronic governors are not as complicated as they seem. You need to understand each of the components and how they fit into the operation. This allows you to see problems before they become major issues. Now that you have this understanding, let’s look at the maintenance that you must do on an electronic governor.

413. Governor maintenance

As you know, an electric governor allows an engine to remain at a constant speed regardless of load changes. You have just finished reading about that operation now let’s look at the maintenance required to keep them in top operating condition. This lesson discusses the required maintenance to include inspecting, replacing, and adjusting electronic governors, to include replacing speed switches.

Inspecting governor components

You do preventive maintenance checks and services to make sure that the generator is ready for operation at all times. You must inspect it to identify and correct defects before they result in serious damage or failure. The inspection of an electronic governor consists of visually inspecting the governor control unit, actuator, and inspection of the governor control unit wires for any signs of deterioration, cracking, or overheating. Make sure the hold-down screws on the governor terminal block are tight, with the wire connections having no play under the screws. If you cannot tighten a loose screw, look for stripped or damaged threads in the housing. Check the housing for security, corrosion, or any other visual damage that the casing may have.

Check the actuator for loose connections, security of mounting, and other damage. Look for any signs of overheating to the wires and actuator. Inspect the throttle linkage to make sure there is no binding or no leaks on electro-hydraulic actuators.

Also check the MPU for loose connections, security of mounting, and other damage. Lastly you have to make sure that the locking bolt is secure to prevent the MPU from vibrating loose.

Replacing governor components

Any time you find damaged governor components, replace them. This holds true for the ECU, actuator, and mag pickup. Failure to replace faulty components can lead to incorrect engine responses to load changes, hunting and surging, or total system shut down.

To replace the electronic control unit, disconnect the negative side of the battery. Some control units have their connections made through quick-disconnect plugs and some have wires that are connected using terminal boards. If you are removing a quick-disconnect type, unscrew the plug and remove it. If you are removing the terminal board type, tag all of the wires and loosen the screws that hold the wires in place. Remove the governor control unit's mounting bolts and remove the control unit. Install a new control unit by mounting it securely and install the wires that you removed. Make any initial adjustments that are called for by the technical order or manufacturer's manual and reconnect the battery.

To replace the governor actuator (fig. 2–12) disconnect the negative side of the battery. Remove any components that may obstruct access to the actuator and tag and disconnect the electrical leads from the actuator. Disconnect the linkage to the fuel injector pump. Be sure to count the number of turns as you disassemble the linkage and write it down to reference back to when you reassemble the linkage. Remove the hold-down bolts, and remove the actuator from the housing. To install a new actuator, mount it to the frame then connect the fuel injector linkage. Refer to the note that you made when you were disassembling the linkage. This will give you the initial adjustment for the linkage. Connect the wiring that you removed, and replace any other components that you removed. Connect the battery and start the engine. Lastly, make any adjustments that are required to make sure of a full range of movement of the fuel rack.

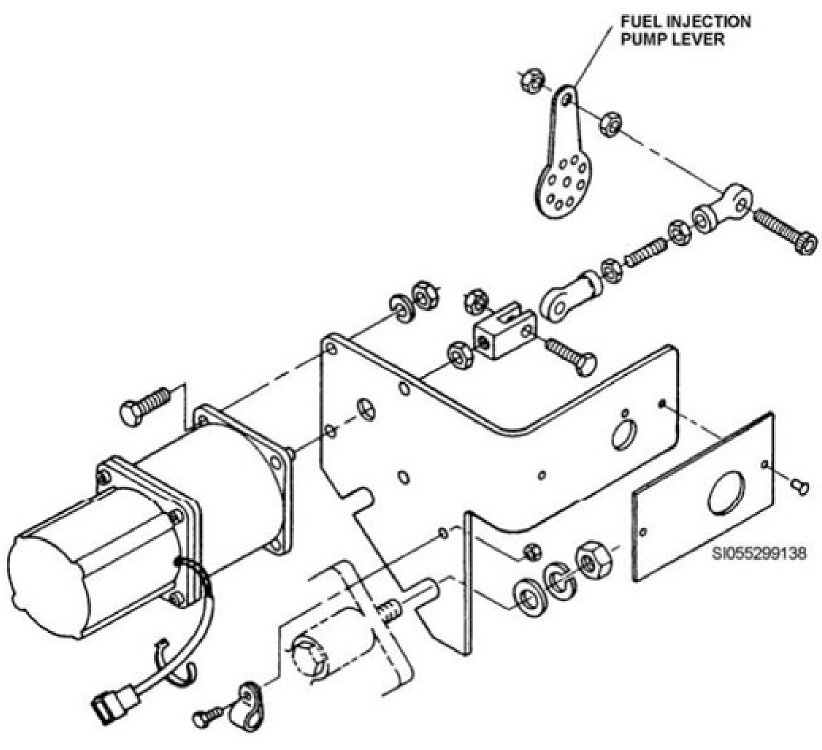


Figure 2–12. Governor actuator.

To replace the MPU, disconnect the negative side of the battery and tag and disconnect the MPU's electrical leads. Loosen the lock nut and remove the MPU from the flywheel housing. Use a flashlight to look into the hole for the magnetic pickup to make sure the flywheel has a tooth positioned on the high spot for the MPU to seat properly. If it is out of alignment, rotate the engine until it reaches the correct position. To install a new MPU, screw the MPU into the flywheel housing until it makes contact with the top surface of the gear tooth on the flywheel. Back the MPU out one complete revolution and tighten the locking nut. Connect the electrical leads and remove the tags then connect the negative battery cable. Make any necessary adjustments before starting the engine. The adjustments will vary from engine to engine, but they usually involve taking meter readings of the output of the MPU. Do not turn the MPU inward more than one-eighth turn at a time as you make these adjustments, this prevents damage to the MPU. Once you make the adjustment, tighten the locking nut and start the engine to make sure that it operates normally.

Governor control module adjustments

There are four adjustments you may make to the governor control module they are: gain, running speed, idle speed, and droop. You need to understand what each of these adjustments do for the operation of the engine (fig. 2–13). Any lack of understanding of these adjustments can result in creating the engine operation less efficient.

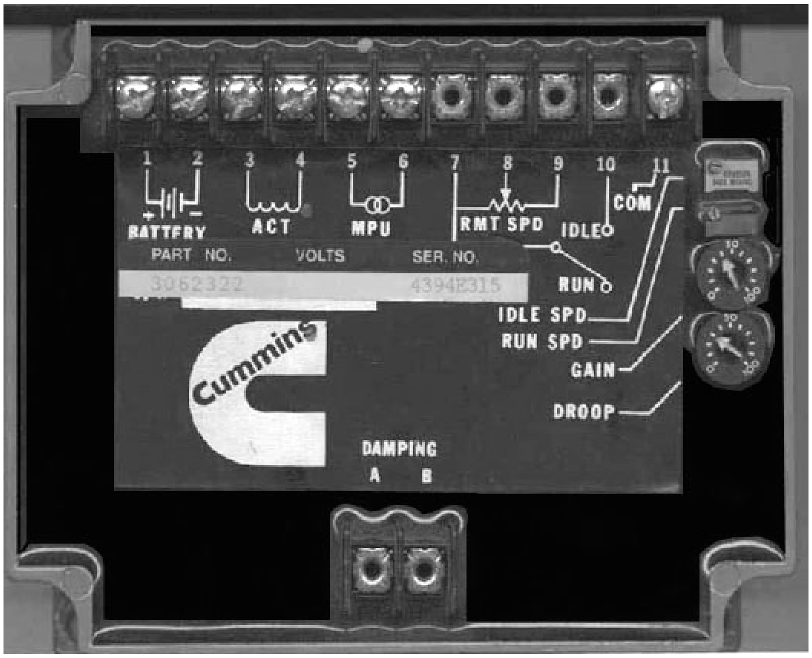


Figure 2–13. MEP-012 electronic governor module.

Gain adjustment

The gain adjustment sets the sensitivity of the module. This refers to the way the engine responds to load changes. You must make adjustments to the gain when recovery of load changes no longer meets specifications. If you set the gain too low, the generator reacts slowly to load changes. If you set the gain too high, the generator speed may be erratic. Normally you set the gain at 40, according to the technical manual.

Running speed adjustment

The running speed adjustment sets the normal operating speed of the engine. Make this adjustment whenever you need to make minor adjustments to the speed of the engine. To adjust the running speed, place the frequency adjust potentiometer on the engine control panel to the middle of its travel. Then take a small flat-tip screwdriver and turn the running speed potentiometer on the governor control module until the frequency meter indicates 60 cycles. Make this adjustment *only* when you initially install the governor control module in the unit.

Idle speed adjustment

The idle speed adjustment sets the speed at which the engine runs when the start-stop-run switch is held in the START position. You do this to allow the engine to lubricate itself before it ramps up to full rated speed. This also prevents damage to bearings and other internal components. When making this adjustment, ensure that the load circuit breaker is in the OPEN position. Place the Start/Run/Stop switch to the START position. While continuing to hold the switch in the START position (do not release it), adjust the idle speed potentiometer on the governor control module until the engine is running between 600-650 revolutions per minute (rpm). Now the idle speed is set. Release the Start/Run/Stop switch and allow it to return to the RUN position; the unit accelerates to rated speed. As with the running speed adjustment, you should only have to do this when you initially install the control module in the unit.

Droop adjustment

The droop adjustment adds droop to the module when you operate the unit in parallel. When this potentiometer is set at zero, the governor control module controls engine speed isochronously by correcting the voltage to the fuel actuator after load changes to maintain a set speed. This is, of course, a desirable condition when operating a single generator. However, when operating two or more generators in parallel, two isochronous generators would fight each other to control system frequency. Because of this, you must add droop to any incoming units. When you add droop to the governor control module, the generator effectively becomes a child unit and keeps a constant load until the operator manually increases the fuel to that unit. If you add too little droop to the unit, it will pick up some load as the load increases. If you add too much droop, the unit will lose load on a load increase. When setting up a unit as a DROOP unit, set the droop pointer to the three percent or the nine o’clock position according to the technical order.

Testing the governor’s speed switch

The overspeed trip device protects the generator from operating at an unsafe speed, which could cause catastrophic damage to the engine and possible injury to personnel in the area if not operational or working correctly. There are two basic types of speed switches, mechanical and electronic. You need to test these switches periodically to make sure they function as required, regardless of the type of governor you have on your generator. Typically you test the overspeed device by slowly increasing the speed of the engine using the frequency-adjusting knob until the engine shuts down on an overspeed fault. Often, you can determine the speed by observing the frequency meter.

Troubleshooting

The steps for troubleshooting electronic governors are the same as you have already read about. Take the time to determine the problem. Look at all of the information that you have available to you. Ask yourself questions about the problem. Make a list and scrub it into a plan to begin troubleshooting.

The troubleshooting chart listed below provides you a list of possible problems and their corrective action.

ELECTRONIC GOVERNOR TROUBLESHOOTING CHART			
Component	***Normal reading***	***Abnormal reading***	***Corrective action***
Magnetic pickup – *The higher the AC volts, the further away the magnetic pickup is from the teeth on flywheel.	Startup – between 0.5 volts and 2 volts DC (term #5, 6).	<0.5 volts and > 2.0 volts.	Readjust or replace magnetic pickup.
	Running – between 2 volts and 30 volts DC (term #5, 6).	<2 volts and >30 volts DC.	Readjust or replace magnetic pickup.

ELECTRONIC GOVERNOR TROUBLESHOOTING CHART			
Component	***Normal reading***	***Abnormal reading***	***Corrective action***
Control Module	Battery voltage (terminals #1&2) $\geq$ 24 volts DC.	Battery voltage (terminals #1&2) < 20 volts DC.	Charge system control battery, or battery-charging alternator defective.
	Engine running speed at 61.5 Hz (no load)/ 60.0 Hz. (load).	< or > 61.5 or 60Hz.	Adjust gross running speed on module or fine speed with variable potentiometer.
	Idle speed at 600 rpms.	< or > 600 rpms.	Adjust idle speed on module with jumper installed between terminal 7, & 10.
	Gain set to 40.	Vary slightly with “different engine personalities.”	Reset.
	Droop set to 30.	Vary slightly with “different engine personalities.”	Reset.

You must understand how to maintain electronic governors. Being able to inspect, replace, and adjust governors is one of the keys to keeping your engine operating in top condition.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

412. Components and theory of operation

1. What are the main components of an electronic governor?

2. What type of voltage does a magnetic pickup produce?

3. What does an ECU do?

4. What are the main components of an actuator?

413. Governor maintenance

1. What are the steps of an electronic governor inspection?

2. Faulty components can lead to what engine malfunctions?

3. Where do you find initial adjustments after replacing an ECU?

4. Why do you not turn a MPU in more than one eight of a turn at a time?

5. How would a generator respond of gain is set to high?

6. When would you make speed adjustments?

7. Why are droop adjustments needed?

8. How are speed switch typically tested?

Answers to Self-Test Questions

408

1. (1) Flanged.
   (2) Cylindrical.
2. The amount of pressure developed inside the cylinder during compression.
3. The number and arrangement of the orifices.
4. ECM.

409

1. (1) Multiple Plunger in-line.
   (2) Cummins PT.
   (3) Distributive.
   (4) Electronic.
2. About 250 psi.
3. The lower fuel pressure and longer time the injector is open.
4. (1) The drive shaft.
   (2) The distributor rotor.
   (3) The transfer pump.
5. (1) Pump.
   (2) Common rail.
   (3) Fuel injectors.
   (4) ECM.

410

1. When air-free fuel is flowing.
2. It over compresses the gasket and shortens its life, which could cause leaks. It also makes it nearly impossible to remove the filter the next time it is due service.
3. About the lower two inches.

411

1. (1) Improper fuel.
   (2) Defective injector.
2. Bleed the fuel lines.
3. Drain the fuel supply and replace with the proper fuel.

412

1. (1) Magnetic pickup .
   (2) Electronic control unit.
   (3) Actuator.
2. AC.
3. It takes the AC signal from the mag pickup, changes it to DC and compares it to a reference voltage. It then decides if the engine is operating too fast or slow or at the right speed. It then provides an output to the actuator that makes any adjustments necessary to the engine speed.
4. (1) Coil.
   (2) Swing arm.
   (3) Spring.

413

1. Visually inspecting the governor control unit, actuator, and Inspect the governor control unit wires for any signs of deterioration, cracking, or overheating.
2. (1) Incorrect engine responses to load changes.
   (2) Hunting and surging.
   (3) Total system shut down.
3. T.O. or manufacturer's manual.
4. Prevents damage to the MPU.
5. The engine would run erratically.
6. When you initially install the governor control module in the unit.
7. When operating two or more generators in parallel, two isochronous generators would fight each other to control system frequency.
8. Slowly increasing the speed of the engine using the frequency-adjusting knob until the engine shuts down on an overspeed fault.

Complete the unit review exercises before going to the next unit.

Unit Review Exercises

Note to Student: Consider all choices carefully, select the *best* answer to each question, and *circle* the corresponding letter. When you have completed all unit review exercises, transfer your answers to the Field-Scoring Answer Sheet.

Do not return your answer sheet to the Air Force Career Development Academy (AFCDA).

22. (408) Identify the component that maintains the day tanks at the correct level without overflowing them?
    a. Float valves.
    b. Holding relay.
    c. Limit switches.
    d. Laser level detectors.

23. (408) As the plunger of a mechanical injector moves up, what allows fuel to flow into the injector cup?
    a. Closing the spray cup.
    b. Opening the metering orifice.
    c. Opening the injector spray nozzle.
    d. Pressure of the fuel in the cup increases.

24. (408) How high can the pressure be in a hydraulic fuel injector?
    a. 500 pounds per square inch (psi).
    b. 1,500 psi.
    c. 5,000 psi.
    d. 10,000 psi.

25. (408) What happens when the pressure of the fuel overcomes the pressure of the spring in a hydraulic injector?
    a. Nozzle needle moves upward.
    b. Valve train opens the needle valve.
    c. Spring holds the needle valve closed.
    d. The fuel circulates through the injector.

26. (408) The type of hydraulic injector nozzle that only has one hole and creates a cone shaped spray pattern is called
    a. flat.
    b. hole.
    c. pintle.
    d. protruding.

27. (408) Which type of hydraulic injector nozzle uses multiple orifices set at an angle?
    a. Flat.
    b. Hole.
    c. Pintle.
    d. Protruding.

28. (409) Which component drives the pumps in a multiple plunger inline fuel injection system?
    a. Internal gear.
    b. External gear.
    c. Internal camshaft.
    d. External camshaft.

29. (409) Which factor determines the amount of fuel delivered to the cylinder for combustion in a port and helix fuel injection system?
    a. Height of the cam lobe.
    b. The rational speed of the camshaft.
    c. Position of the helix in relation to the port.
    d. Spring tension of the delivery valve.

30. (409) As engine speed increases with a pressure timed (PT) fuel injection system, what does the increase in pressure, fuel, and the shorter amount of time the injector opens determine?
    a. How long the fuel stays in the injector.
    b. The amount of fuel reaching the day tank.
    c. How much fuel reaches the combustion chamber.
    d. The amount of fuel that circulates through the pump.

31. (409) In a Roosa Master type of distributor-type injection pump, what do the pistons follow to pressurize the fuel?
    a. Plungers.
    b. Cam ring.
    c. Cam shaft.
    d. Valve train.

32. (410) Which fuel line do you open when bleeding and priming a diesel fuel system?
    a. It does not matter which one.
    b. The one at the lowest point.
    c. The one at the highest point.
    d. The one going to the first cylinder in the firing order.

33. (410) A helpful step when bleeding and priming a diesel fuel system is to
    a. make sure the fuel filters and strainers are full of fuel.
    b. make sure that only the fuel filters are full of fuel.
    c. fill the fuel filters and strainers with oil.
    d. fill the fuel filters with oil.

34. (410) Which item(s) is visually inspected on a fuel injection pump?
    a. Paint.
    b. Gears.
    c. Inlet strainer.
    d. Security of lines and mounting bolts.

35. (410) As a safety precaution why *must* you limit your exposure to diesel fuel?
    a. It may spontaneously ignite at room temperature.
    b. Fuel is a carcinogen and may cause cancer.
    c. Fuel will not wash off your hands.
    d. Fuel causes fingernails to fall off.

36. (410) Why is it *important* to mark the wires when replacing a fuel level sending unit?
    a. It allows maintenance without disconnecting the battery.
    b. So you can reinstall the sending unit correctly.
    c. Ensures the generator will not start.
    d. Tagging is not needed.

37. (411) Identify the possible cause(s) for *excessive* black engine smoke.
    a. Improper fuel only.
    b. Air in the fuel system.
    c. Improper fuel or defective injector.
    d. Defective injector only.

38. (411) What would be the corrective action if a generator has improper or contaminated fuel?
    a. Treat with Docosahexaenoic Acid (DHA).
    b. Add the proper amount of lubrication.
    c. Run it through the system till it is all gone.
    d. Drain the fuel and replace with proper fuel.

39. (412) Which electronic governor component uses a back and forth movement of a magnetic field to induce alternating current (AC) voltage in the coil?
    a. Actuator.
    b. Power piston.
    c. Magnetic pickup (MPU).
    d. Electronic control unit (ECU).

40. (412) Which electronic governor component is the brain of the governor?
    a. Actuator.
    b. Power piston.
    c. Magnetic pickup (MPU).
    d. Electronic control unit (ECU).

41. (413) When you are making adjustments to the magnetic pickup, the *maximum* distance you should turn it inward at any time is
    a. 1/8 turn.
    b. ¼ turn.
    c. ½ turn.
    d. 1 turn.

42. (413) What would you adjust on an electronic governor if a generator is running erratically?
    a. Gain.
    b. Droop.
    c. Stability.
    d. Running speed.

43. (413) Which electronic governor adjustment would you use if the generator is running below the desired speed?
    a. Gain.
    b. Droop.
    c. Stability.
    d. Running speed.

44. (413) Which electronic governor adjustment would you use if a generator running in parallel is taking too much of the load?
    a. Gain.
    b. Droop.
    c. Stability.
    d. Running speed.

Please read the unit menu for unit 3 and continue ➔

Unit 3. Lubricating Systems

3–1. Theory of Operation 3–1
414. Properties of oil 3–1
415. System components 3–3
416. Operation 3–6
3–2. Maintenance 3–8
417. Servicing the lubrication system 3–8
418. Component replacement 3–12
419. Troubleshooting lubricating oil systems 3–14

IN YOUR CAREER, YOU will perform countless oil and filter changes on a large array of equipment. The performance of the lubrication system can make the difference between an engine that operates efficiently and one that will not operate at all. There is more to the lubrication system, and its components, than changing the oil and filters. In this lesson, we will discuss the properties of oil, system components, system operation, and maintenance actions.

3–1. Theory of Operation

This unit discusses the importance of the lubricating system. There is probably no other system that contributes more toward lengthening an engine's life, increasing dependability, and reducing possibility of mechanical breakdown than an engine's lubricating system. This is the reason engineers have designed an elaborate and detailed lubricating system to fulfill the specific requirements for different types of engines.

414. Properties of oil

The main purpose of lubricating oil is to reduce friction between solid materials such as metals. In an internal combustion engine, oil reduces friction between moving parts. It also helps cool, clean, seal, and prevents corrosion. Friction results in wasted power, wear, and heat development. To reduce or minimize friction and meet all the requirements of a good lubricant, lubricating oil must affect an engine in particular ways.

Affects of oil to an engine

The following table provides examples of the different ways oil affect an engine.

Affects of Oil to an Engine
Makes starting easier.
Prevent wear.
Reduce friction.
Protect against corrosion.
Keep engine parts clear.
Minimize carbon deposits.
Cool the engine components.
Seal combustion pressures.
Aid fuel economy.

It is very important that you use the appropriate oil. There are a few factors that you must consider when you are choosing the type and grade of oil to use. *First*, what type of engine do you have? Is it a two-stroke or four-stroke, gasoline or diesel, large or small engine? The *second* factor is the climate your engine is operating. Are you in Alaska or Guatemala, is the air humid or dry, does it rain often, will the engine operate inside of a building or outside? These questions help you decide what oil to choose. Using the wrong type and grade of oil can lead to a catastrophic engine failure. Next we will go over the properties of oil. The following paragraphs explain oil properties.

Viscosity

Viscosity is a measure of oil's resistance to flow. Oil with low viscosity flows readily while oil with high viscosity has a greater resistance to flow and pours in a sluggish manner. Temperature affects viscosity; the hotter the oil, the lower is its viscosity. Top quality oil retains its specified viscosity at its highest temperature rating.

The Society of Automotive Engineers (SAE) has created a rating code to standardize the grade of oil. Numbers based on viscosity ranges designates these codes. SAE numbers start with low numbers for low viscosity and progress to higher numbers for oils with higher viscosity. For example, SAE 5 is low-viscosity oil and SAE 60 is high-viscosity oil. You also see the letter "W" in the grade on some oil. This indicates the oil is suitable for operation in cold temperature. Since viscosity changes as temperature changes, SAE 10W has slightly different viscosity requirement than SAE 10 oil.

Multi-grade oil is common today. This is due to improvements in the refinement process. Multi-grade refers to oil that meets the characteristics of two or more classifications. Oil with the grade of SAE 5W–40 contains the characteristics of SAE 5W oil during the cold winter months while maintaining the characteristics of SAE 40 during the hot summer months.

Another classification for oil is that of the American Petroleum Institute (API). This classification refers to a classification system that identifies the type of engine oil that is formulated based on operating requirements. There are two categories: S-series for gasoline and propane engines and C-series for diesel engines.

Film strength

Film strength is the ability of a thin layer of oil to hold together when we apply heavy loads to it. This ability allows the oil to absorb the pressures of the combustion in the cylinder without allowing metal-to-metal contact between the piston and connecting rod to include the connecting rod and crankshaft.

Pour point

The pour point of oil indicates the lowest temperature at which it flows. Oil used in any climate must have a pour point well below the lowest exposure temperature. If the temperature goes below the oil pour point, improper lubrication results when you start the engine.

Resistance to foaming

Foaming is the result of small air bubbles combining with oil and whipping into an oily froth. The air does not mix with the oil, but pushes in between the oil molecules to separate them. This creation of froth has very little ability to lubricate or aid in cooling the engine components. An addition of silicone or other compounds to the oil reduces foaming because these compounds weaken the air bubbles, causing them to pop almost immediately. This allows the oil particles to maintain their cohesiveness and to perform their task.

Detergency

Detergency is the property that makes oil capable of holding foreign particles suspended until the filter can remove them. The detergent characteristics are actually the cleaning qualities of the oil. Oil has some capabilities to do this on its own, but additives increase its efficiency. The additives typically gather the carbon and soot deposits that would ordinarily combine with the oil. This allows the oil to remove the combustion byproducts from the engine.

Corrosion prevention

If moisture or air makes contact with exposed metal, oxidation, often referred to as rust, can occur. Since heat speeds chemical action, engine parts have a tendency to corrode at a very high rate. You can reduce this tendency considerably when the lubricating oil provides a protective film on all internal parts. This protective film seals the parts against the oxygen and moisture in the air. Therefore, top quality oil must have adhesiveness, which is the tendency to stick to any surface, and cohesiveness, which is the tendency of the molecules of the oil to stick together.

Synthetic oil

Conventional oils are refined from crude oil. This type of oil has molecule strings that are different sizes and shapes. No matter how well refined conventional oils are, there are still these different molecules. Oil companies produce synthetic oil by creating molecules that fit a specific molecular design. This creates oil that consistently has the same size and shape of molecules to provide specific performance properties. This improvement allows synthetic oil to out perform convention oil. Synthetic oils provide the following characteristics:

- Superior wear protection, which aids longer engine life.
- Reduced cost by increasing the life of the oil.
- Reduced deposits on engine components.
- Superior high temperature performance.
- Easier starting of an engine.
- Reduced oil consumption.
- Improved fuel economy.

Understanding the properties of oil is a key factor in the proper operation of your engines. This knowledge prolongs the life of the engines and reduces mechanical breakdowns. This also saves money in replacement parts.

415. System components

The lubricating system uses many components to lubricate all of the engine components. Understanding the operation of these components allows you to detect problems as they arise. This lesson identifies and explains the lubricating system components.

Oil sump

The oil sump stores the engine oil. We often refer to it as an oil pan. You typically find it at the bottom of the engine block forming the bottom of the crankcase.

Oil strainer

The oil strainer is usually located on the input tube for the oil pump. It is a screen that removes large particles from the oil to protect the oil pump and other system components.

Oil pump

The oil pump is usually a gear type, positive displacement pump. Positive displacement pumps discharge all of the fluid they take in. The pump provides pressurized oil to the system to move oil throughout the engine.

Gear pump

There are two different designs of the gear pump. The external gear pump (fig. 3–1) is the most commonly used in diesels engines. The pump draws oil into the rotating gear teeth and carries it next to the outside housing. As the teeth of the two gears come together, they squeeze oil out on the discharge side on the housing. This action pressurizes the oil on the discharge side of the pump. In the internal gear pump, (fig. 3–2) oil is drawn into the internal gear at the inlet. The drive gear rotates the internal gear, carrying the oil from the inlet to the discharge between the crescent and housing. The two gears mesh together at the discharge, pressurizing the oil.

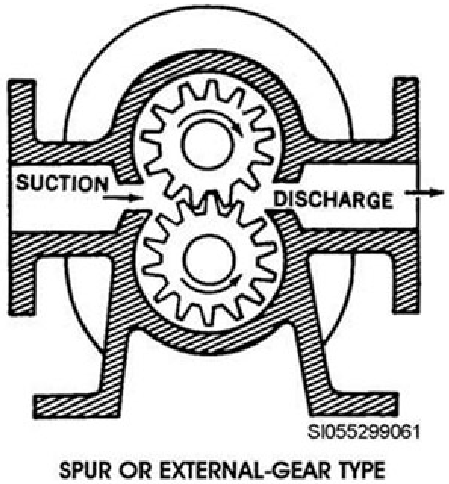


Figure 3–1. External gear pump.

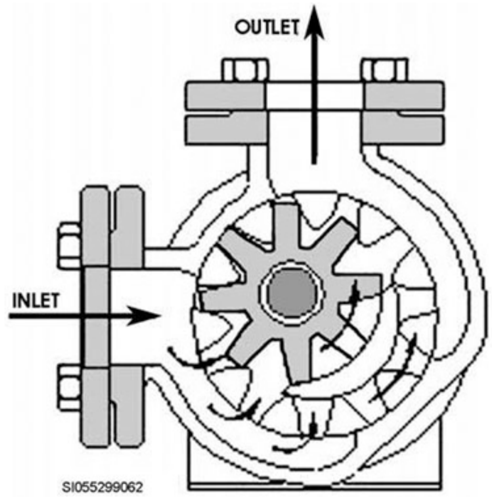


Figure 3–2. Internal gear pump.

Relief valve

The relief valve (fig. 3–3) is located on the output side of the oil pump. It prevents excess pressure from building up in the lubrication system by providing a bypass back to the oil sump when the pressure increases above the maximum level.

Oil filter

The oil filter (fig. 3–4) is commonly located after the output of the oil pump. It removes small particles before they reach critical engine components. The oil moves from the outside of the filtering element to the inside tube. The filter is often a spin-on or canister design.

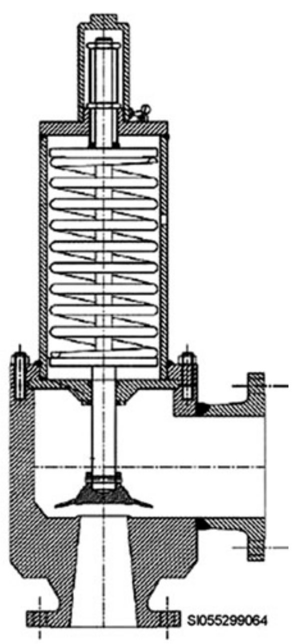


Figure 3–3. Relief valve.

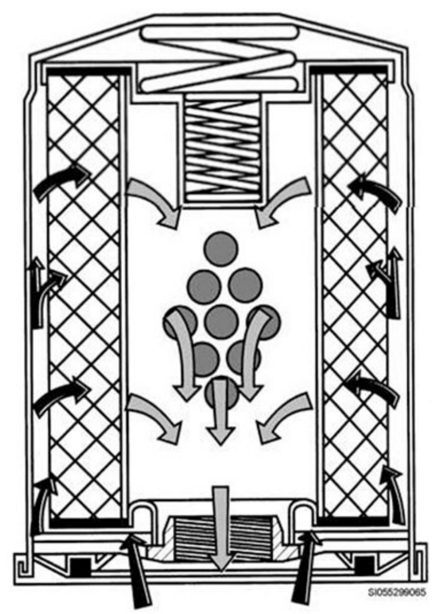


Figure 3–4. Oil filter.

Oil galleries

Oil galleries are passages located throughout the engine. These passages are drilled in the cylinder block, head and internal components. They allow oil to move throughout the engine to lubricate components.

Oil cooler

The oil cooler (fig. 3–5) removes heat from the engine oil by transferring it to the coolant. Coolers usually have a tube and shell design. The oil and coolant flow in opposite directions to aid cooling. We refer to this as the counter flow principle.

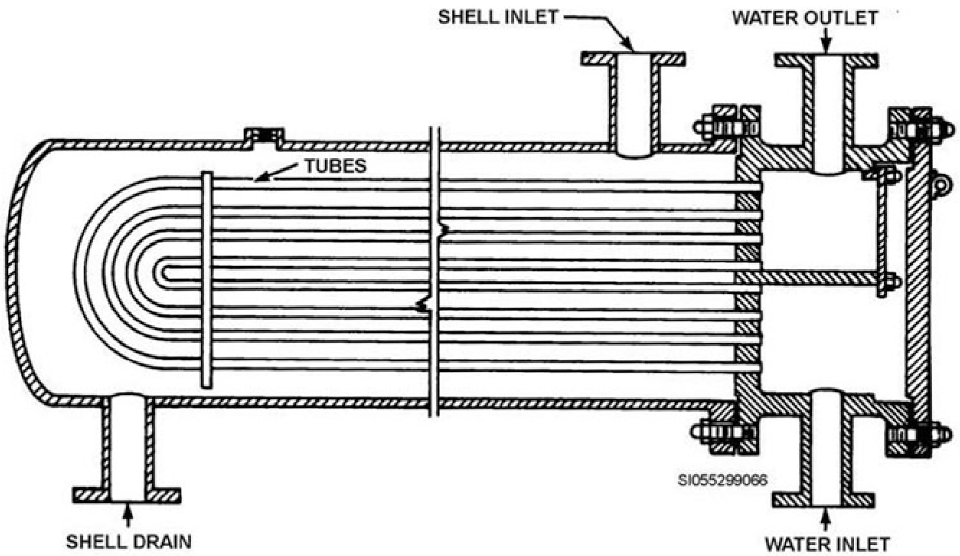


Figure 3–5. Oil cooler.

Oil cooler bypass

The oil cooler requires a bypass to prevent engine starvation of oil if the oil cooler clogs. The bypass remains closed unless the pressure builds up. This only occurs if the oil cooler blocks the flow of oil to the engine.

Oil pressure gauge

The oil pressure gauge indicates the pressure the engine oil is at. There are two different types of gauges—mechanical and electronic. The mechanical gauge uses direct pressure on the gauge to indicate the pressure while the electronic gauge uses an oil-sending unit that varies internal resistance to change the amount of current reaching the gauge. The electronic gauge is the most common type you will see.

Oil pressure switch

The oil pressure switch is a protective device that shuts the engine down if oil pressure gets low. Normally the switch is closed when the oil pressure is above the preset value. The switch opens if the oil pressure drops below the preset level to de-energize the electrical circuit that keeps the engine running. This shuts the engine down preventing operation without oil pressure, which would cause catastrophic damage to the engine.

Crankcase ventilation

The crankcase ventilation allows any pressure building up in the crankcase to escape. It may vent into the intake system or directly to the atmosphere. It commonly has a screen filter to prevent small particles of oil and combustion byproducts from escaping.

Friction and heat are two major enemies of an engine system. The lubrication system works together to reduce these. Understanding their functions allows you to accomplish maintenance to keep your engine in top operating condition.

416. Operation

Now that you understand the different components that make up the lubrication system inside of an engine, we will look at how these components work together. It is easiest if we visualize the journey that the oil takes inside of the engine while it is running.

Oil flow

Most lubrication systems of typical small engines operate as shown in figure 3–6. In the lubricating system operation, the oil sump stores the lubricating oil. The lubricating pump, which may be located in the engine sump or mounted externally, draws oil through the strainer and pressurizes it. The strainer removes any large particles from the oil that could damage the pump. The pressurized oil then flows through the oil cooler. This ensures the oil is cool before it reaches any of the engine components. Next, the oil moves into the oil filter. This cleans the oil to prevent any foreign particles from reaching engine components. The completion of this maintenance results in cool and clean oil leaving the filter and passing into the main oil gallery.

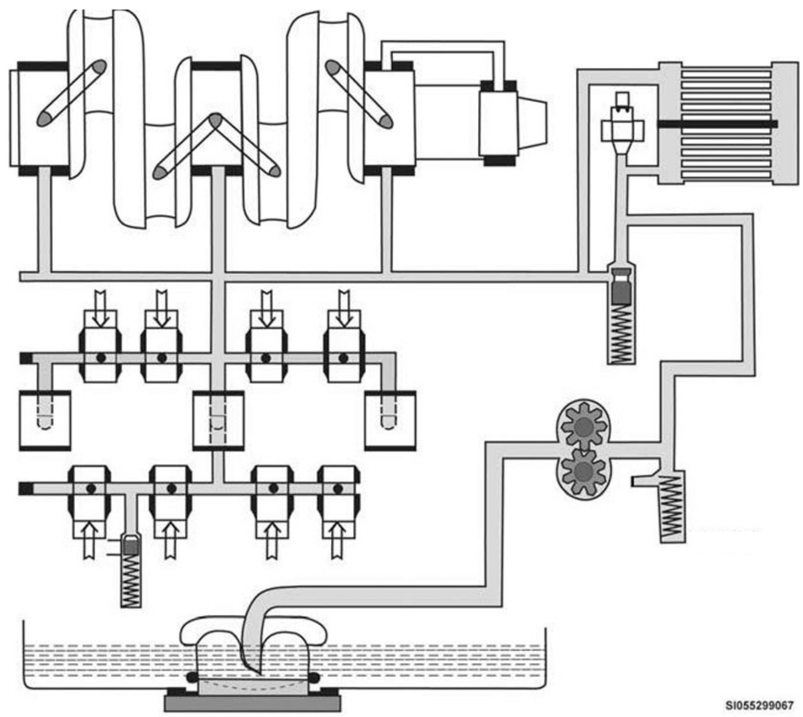


Figure 3–6. Typical small-unit lubricating system.

The oil then flows from the main oil gallery to the crankshaft. The pressurized oil flows through passages in the crankshaft to reach all of the journals, main and connecting rods, to provide a thin film of oil to prevent metal-on-metal contact between the bearings and journal. Oil then passes through an opening in the connecting rod and flows to the piston pin and piston. This provides oil to lubricate the piston pin and coats the cylinder walls with oil. This oil coating prevents metal-to-metal contact and seals the combustion chamber.

The main oil gallery supplies oil to the camshaft to provide lubrication. Oil passes through internal passages in the camshaft to supply oil to the journals, preventing metal-to-metal contact with the camshaft bearing. The camshaft lobes are covered by spraying oil to prevent metal-to-metal contact between the camshaft lobe and cam follower.

The next area requiring oil is the valve train. There are two common ways the valve train receives its oil. The first way uses oil galleries in the cylinder block and head. The pressurized oil flows through the galleries and sprays onto the valve train components. The second way is for oil to pass through hollow push rods and spray onto the valve train components. This occurs when oil moves from galleries into the cam follower and then passes through the push rods. Both methods create plenty of lubrication between the push rod, rocker arms, and valves. The excess oil then drains back into the oil sump.

If your engine is equipped with a turbocharger, pressurized oil moves from the main galleries to the turbocharger through tubing. The oil lubricates the shaft and bearings within the center portion of the turbocharger. The oil then returns to the oil sump.

Protective devices

The lubricating system also has a few protective devices installed, the first is an oil pressure gauge. These gauges can be mechanical or electrical. Regardless of which type the engine has, its gauge is typically connected to the main oil gallery. This provides the pressure of the oil as it leaves the filter. The second protective device is the oil shutdown switch. It, too, connects to the main oil gallery. The operation of the lubrication system is dependent on an essential item, the oil being filled to the proper level. Low oil levels can reduce the cooling capacity of the storage system. This can increase the heat of the oil, reducing the viscosity and causing the engine to not be properly lubricated. The lack of lubrication increases the heat more, multiplying the problem until the engine destroys itself. The solution to this is to keep the oil filled to the proper level at all times. Continually monitor the oil level using the dipstick.

The proper operation of the lubricating system is essential to flawless operation of your generators. Understanding the operating principles can help you see troubles as they begin to show themselves, before they become a problem.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

414. Properties of oil

1. What is the purpose of lubricating oil in an engine?

2. What are the characteristics of oil with the grade of SAE 5W–40?

3. How do additives reduce foaming in lubricating oil?

4. What qualities must top quality oil have to prevent corrosion?

415. System components

1. How does oil pass through an external gear type pump?

2. What is the purpose of the pressure relief valve on an oil pump?

3. Describe the counterflow principle.

4. What is the purpose of crankcase ventilation?

416. Operation

1. Where does oil move to once it becomes pressurized?

2. Where does the cool, clean oil move to when it leaves the filter?

3. What are the two ways oil reaches the valve train?

4. What are the two types of lubricating oil protective devices?

3–2. Maintenance

Performing maintenance on any machinery is essential to its upkeep. There is always one system that is more important than another system. In an engine, the lubricating system is one of the systems needing more maintenance attention to keep the engine operating at peak efficiency. The material you are about to read in this section deals with one of the more common and important jobs you will perform throughout your Air Force career.

417. Servicing the lubrication system

The most common maintenance you do to a lubrication system is to service it. This preventative maintenance keeps your engine in top operating condition and is accomplished at regular intervals. Refer to your manufacturer's manuals for specific intervals for your varied generation systems. You also need to look at the climatic conditions as you determine the intervals to complete service. This lesson explores the aspects of servicing the lubrication system.

Oil change

Changing the oil is one of the primary components of servicing the lubricating system. The engine oil collects impurities as the engine operates. Most of these contaminates are collected by the oil filter, but some remain in the oil. This is especially true of carbon and soot because they are oil based. The result of this circumstance causes your engine oil to become very black. The only way to remove contaminates from the oil is to change the oil in the engine.

Before we discuss the steps involved in changing engine oil, let's look at safety for a minute. You work with loud, hot, rotating machinery to include the space in which you have to work can be very tight in many cases. You also may have to work in less than desirable weather and lighting conditions. Within these undesirable conditions you must take the appropriate safety precautions to ensure the safety of you and your co-workers. Wear hearing protection any time you are operating a generator or other engine system. Perform housekeeping throughout the job; this prevents tripping and falling hazards. These hazards are more prominent especially if you spill oil on the floor. Clean the hazard immediately to prevent slipping hazards. Remember, you are working with systems that contain protruding objects that could cause severe injury if you fall on them. You also work with hot objects. If you get hot oil on you, it can cause severe burns because it coats the skin and continues to damage it until you can remove it. You must use extreme care when you are working with the hot oil. The key is to think safe to be safe.

The *first* step in changing the engine oil is to operate the engine until it reaches operating temperature. This allows the heavy particles in the oil that have had the time to settle to the bottom of the oil sump to be suspended in the oil. This way they are removed with the dirty oil. Some oils have a tendency to leave waxy deposits throughout the engine. Heating the oil liquefies these deposits and allows the oil to remove them from the engine. Once the engine reaches operating temperature, turn it off and disable it from starting.

You can drain the oil several ways. Remember, you are working with hot oil so you need to take the appropriate safety precautions. The most common way is to use the drain on the bottom of the oil sump. Many of your generators contain a drain tube with a valve connected to the drain plug. This allows you to place a drain pan under the outlet of the tube and open the valve. Other generators may use hand pumps to remove the oil from the engine. You may find some of these pumps connected to the drain on the oil sump. Other pumps use the dipstick tube to drain the oil. Regardless of what mechanism your engine uses to drain the oil, be sure to pay attention so you don't overfill the drain pan and make a mess. Allow the oil to drain until the sump is completely empty.

Once you finish draining the oil from the sump, it is always a good idea to pour about a gallon of new oil into the system before you close the drain. This allows the new oil to push the old oil remaining in the bottom of the sump out. Once the oil pouring out of the drain become clear, close the drain, now you can fill the sump with new oil to the recommended level.

Flushing

You may find you need to clean the lubricating system. It may become filled with carbon and soot buildups that normal oil changes do not remove. How do you tell if there are carbon and soot build-ups? One way is when the new oil you put into an engine turns black very quickly. The only way to clean the system is to flush it. Not many shops generally do this because of the low operation hours most of our generators have, but it can correct problems and lengthen the life of the engine. Engines that operate with low loads tend to build carbon and soot very quickly. It is a good idea to flush these engines periodically to remove these contaminates.

The main idea of flushing the lubricating system is to clean all of the deposits out of the engine. To do this, you must operate the engine with a chemical additive in the oil to break these deposits up. This chemical must also maintain some lubricating qualities because the engine needs to operate without creating friction. There are several commercial oil additives that will flush the system to include adding diesel fuel or kerosene to the oil.

To flush the lubricating system, drain the amount of oil equal to the amount of additive you will be putting in the engine. This prevents overfilling the lubricating system. Once you drain the oil, add the additive to the system. The amount of additive is marked on the bottle of a commercial grade item or should be no more than 50 percent of the lubricating system capacity if you use diesel or kerosene. Operate the engine, without load, for approximately thirty minutes once it reaches operating temperature. This time may vary for commercial additives.

Once you have shut the engine down, drain the oil and additive mixture. After the oil/additive mixture drains, close the drain and fill the engine with oil. Drain this oil to remove any remaining additive and contaminate from the sump. Fill the engine with oil again and change the filter.

Oil filters

Today's filters are extremely effective at removing particles from oil, but you must change them at regular intervals to ensure the oil remain free of contaminates. Spin-on filters, are simple to service. Many times you must drain the filter into a pan to minimize the mess. You can do this by placing a pan under the filter and punching a hole in the bottom portion of the filter body. After the oil finishes draining out, use a strap wrench to loosen the filter body. Once the body is loose, a little more oil may drain out of the hole you punched in the body. This is because the draining oil creates a vacuum above the oil. Breaking the seal releases the vacuum allowing the rest of the oil to drain until the level is below the drain hole you punched. Rotate the filter off and wipe the filter head clean. Inspect the filter head for damage, especially around the seal surface.

Before you install the new filter, fill it with oil. This allows the engine to receive oil more quickly after the initial startup, which prevents friction between engine components. Thread the oil filter onto the filter head ensuring you do not cross-thread the filter. Rotate the filter until it makes contact with the filter head. Take the time to note the position of the filter and then rotate it ¼ of a turn. This is tight enough to secure the filter in place without leaking. Do *not* use a strap wrench to install a new oil filter. This only causes the seal to be damaged and makes it very difficult to remove the filter the next time you are due to replace it.

Crankcase vent

The crankcase collects pressure from the combustion that moves past the piston rings. We refer to it as blow-by. As blow-by continues to move gases into the crankcase, the pressure begins to build. The crankcase is not designed to deal with high pressure so it must be vented. The crankcase vent relieves the pressure caused by blow-by; there are two ways of doing this.

The first way to ventilate the crankcase is by using a filter at the top of the crankcase. As pressure builds up, it vents into the atmosphere. This is an older type of system that you find today on some engines. The only maintenance you do to this type of system is to remove the filter and clean it with an approved solvent. The filter is typically wire mesh clamped down by a cover. The wire mesh collects any oil vapors in the air from the crankcase.

The second way to ventilate the crankcase is by using a tube and filter connected to the air intake system. This is often referred to as a positive crankcase ventilation system. It is more common due to today's more strict emission standards. This system creates a vacuum that draws the crankcase gases through the filter and sends it back into the air intake system. This allows the burned gases to be ran through the system and disposed of properly. The only maintenance is to clean the filter with an approved solvent.

Engine operation

Once you complete the service on the lubrication system, you must ensure everything works properly. Do this by taking a minute to look everything over to make sure you didn't miss anything. Next, start the engine paying particular attention to the oil pressure to make sure it comes up. This typically takes a few seconds because you have just drained the system. Once you see there is oil pressure, allow the engine to reach operating temperature. Walk around the engine and look for leaks and other abnormalities. Shut the engine down and allow it to sit for approximately three to five minutes. Check the oil level and ensure it is at the full mark. Add or drain oil as necessary. One of the most common mistakes is checking the oil level and adding oil to the engine before all of the oil drains back into the sump. This creates an overfilled condition, which can be as bad as or worse than a low oil level. The key to proper maintenance on the lubrication system is taking your time and verifying the work.

Testing lube oil

As you have read, oil collects contaminates to keep the engine components clean. The oil filter collects most of these contaminates but not all. This is why you must change the oil on a regular basis. Some of the generators you service only operate for a very short period of time between oil changes. This type of operation makes the generator a candidate for oil testing.

Oil testing determines the condition of the oil and allows you to, with permission from the manufacturer and command, waive the oil change when the oil passes the tests. This saves the Air Force money for oil, filters, and labor. We discuss two types of testing programs—the field test and Spectrometric Oil Analysis Program (SOAP).

Field test

The field test allows you, the technician, to analyze lubrication oil and determine its condition. An oil test kit contains all of the necessary items to perform the test at the generator site. The testing process consists of three separate tests that provide a general condition of the oil. The three tests are the solid contaminates test, reaction test, and fuel dilution test.

The tests uses a sample of oil collected form the engine. You must collect this sample properly to ensure the results provide an accurate picture of the oil's condition. Start the engine and allow it to operate for at least five minutes. This allows the oil to heat up to collect any waxy deposits and disperse any heavy contaminates that may have settled to the bottom of the sump throughout the oil. Once you shut the engine down, it is time to collect the sample; you can do this several ways. The kit contains a tube and bulb that fits through most dipstick tubes. This allows you to suck the oil from the center of the sump to get a quality sample. The other way is to use the drain in the sump. The problem with this method is that most drains use a piece of hose or tubing with a valve. This oil in this hose does not circulate with the rest of the oil. Therefore if you use the drain to collect your sample, you must drain enough oil into a pan to remove this stagnated oil so your sample is from the engine sump. Failure to do this will not give you valid results from the test. Remember, the results from your test are only as good as your oil sample.

Solid contaminates test

The solid contaminate test, often referred to as the blotter test, detects the presence of dirt, carbon, and sludge in the oil. Begin the test by taking one of the white filter papers from the container and placing it on the holding tray in the kit. Next, stir the oil to mix any contaminates that have settled and place a drop of oil on a white blotter. The paper absorbs the oil but leaves all dirt and foreign particles on the surface. Allow the drop of oil to penetrate the blotter for five to 10 minutes or when it is no longer shiny or wet. This process can often take longer than ten minutes. Once the sample is ready, place the Solid Contaminates Chart three grey circles over the drop of oil to compare the drop with the chart. If the oil spot is the same shade as the "unsatisfactory" circle on the chart, you must change the oil and filter.

Reaction test

The reaction test, often referred to as the acidity test, determines if any acids are present in the oil. These harmful acids, usually sulfuric, are chemically formed from fuel contaminants and condensation. Sulfur, from the fuel, and water, from the cooling system or condensation, may get into the engine oil and form sulfuric acid. It is very important you test for this condition.

Begin the test by filling a "reaction vial" to a specific level with the reaction indicator solution provided in the kit. Next, pour a sample of the engine oil into the same vial to the line marked "oil level." Cover the vial and shake it vigorously for 20 seconds. This allows the reaction indicator solution to interact with any acids in the oil. The reaction fluid and oil will not mix. Letting the vial stand allows the oil and indicator to separate. Once they separate, compare the color of the reaction indicator fluid (lower level) with the color on a Reactions of Used Oils chart, three color circles. If the indicator color is yellowish, the engine oil contains acids and is unsatisfactory. In this case, change the oil and filters. Determine the cause of the fuel and moisture getting into the engine oil.

Fuel dilution test

The purpose of this test is to determine changes in the viscosity of lubricating oil due to fuel dilution. First, you must create a test sample by adding the dilution vial filled to the five percent mark with the fuel to a sample of new oil. You must use the same oil and fuel the engine uses. Allow the engine oil sample and test sample to sit in the same place to make sure they are at the same temperature. This is important because, as you know, temperature changes viscosity. After they reach the same temperature, place each of the samples under one of the viscosity cups located in the kit. Raise the sample to the viscosity cups and allow them to fill. Lower the sample containers simultaneously and place them under the viscosity cups. If the test sample flows out faster than the engine oil, the engine oil is fine. If the engine oil flows out faster than the test sample, the engine oil is diluted beyond five percent.This means you must change the oil and the filters and determine where the fuel is entering the lubricating system.

Spectrometric Oil Analysis Program

The SOAP looks at oil on the atomic level. This is a computer analysis process that provides you with a detailed look at the engine oil. The SOAP not only determines the condition of your oil but also can identify internal problems with the engine before they become major. The SOAP does this by identifying different metal particles and their concentration in the oil. These different metals relate back to specific components in the engine. High concentrations of a particular type of metal indicate the unusual wear of a component.

Using test to defer maintenance

When testing oil to defer an oil change, there are very specific requirements. Ensure you check with local requirements to understand which engines may or may not be able to go longer than the prescribed time between oil changes.

Criteria

The following requirements will determine if an oil change can be deferred:

- Does the generator fall into the correct category according to federal or state laws.
- Are the operating hours less than 150 within the last 12 months and does not exceed the manufacturer’s recommendation for engine hours.
- Also did the oil analysis meet fuel dilution, viscosity, and total base or acid content meet manufactures’ recommendations and field test using oil analysis kit NSN 6630-01-096-4792, Test Kit, Oil Condition, or an independent oil analysis kit.

Documentation

Record results on Inspection Checklist for the Generator Operating Log and AF IMT 719. If an approved field test kit is not available or the above tests are not performed, the oil must be changed.

Servicing the lubricating system is the most common type of maintenance you do. It is also some of the most important work you do because the condition of the lubricating system determines the life of the engine. Always take the time to accomplish the maintenance as prescribed in the technical manuals for your equipment.

418. Component replacement

Lubricating system components, like all mechanical items, sometimes break. Knowing how to replace these components is essential to keeping the engine operating. The components we look at in this lesson are the oil pump, oil cooler, oil pressure sending unit, and oil pressure switch.

Oil pump

The lubricating oil pump pressurizes the lubricating oil to move it to the internal engine components requiring the lubrication. If it requires replacement, be sure the engine is cool because you must remove the oil pan to replace the pump. Begin by disconnecting the batteries and draining the oil from the sump. You may find it necessary to remove some external components to gain access to the oil pan. Once you remove all necessary components, remove the oil pan bolts. It is a good idea to leave the four corner bolts for last to support the oil pan until you are ready to remove it. Letting it sag on one side could cause it to warp, making it difficult, if not impossible to seal when you replace it. Once you remove all of the bolts, drop the pan down and slide it out of the way. You may need to twist and turn the pan to remove it depending on the clearance.

Now that the oil pan is out of your way, you can get to the oil pump. Different manufacturers use different ways to mount the pump. There is a chance you may need to remove the oil pick up tube and strainer before you remove the pump. Generally you find the pump held in place by two bolts. Once you remove these bolts the pump housing should slide out. In some cases you may find it necessary to pry the pump housing from the mounting position on the cylinder block. Remove the remaining components from the oil pump and clean them with an approved solvent and pay particular attention to the strainer.

You may find it necessary to install some components to the oil pump prior to installing the oil pump onto the block. To install the new oil pump, slide it into place. Be sure to align and mesh the drive gear; otherwise, the pump will not operate. Always use new gaskets, seals, and washers for any components you install. Next install the oil pan. Take care to keep the oil pan gasket in place. You may use a light coat of grease or sealant to do this. Start tightening all of the bolts hand tight before you begin tightening them according to specifications.

Once you install all of the components, fill the system with oil. Operate the engine, paying close attention to the oil pressure. Once the engine reaches operating temperature, look for leaks throughout the system.

Oil cooler

The oil cooler removes heat from engine oil. If it requires replacement, be sure that the engine has had time to completely cool because you will be working with the coolant and lubrication oil. First, remove the coolant drain hose from the oil cooler and drain the coolant into a suitable container and preserve the coolant to refill the system. Next, remove the bolts that hold the oil cooler to the cylinder block. Then, remove the bolts that hold the oil cooler to the coolant inlet line and the bolts that hold it to the bypass.

Reinstall the oil cooler and secure it to the bypass with bolts, then install the bolts that secure the oil cooler to the coolant inlet line. Install the bolts that secure the oil cooler to the cylinder block. Lastly, install the coolant drain hose, close the coolant drain and refill the cooling system.

Oil pressure sending unit

The oil pressure sending unit, shown in figure 3–7, provides the oil pressure gage with an electrical signal to allow you to read the oil pressure at which the engine is operating. If the oil pressure gage is not reading properly, you may need to replace the oil pressure sending unit. To do this, disconnect the negative side of the battery to prevent the generator from starting. Disconnect the oil pressure sending unit's electrical lead and unscrew the sending unit from the engine block. If the sending unit has two or more wires, be sure to tag them so you can reinstall them correctly.

To install a new sending unit, screw it into the engine block and connect the electrical lead to the sending unit. Connect the negative side of the battery and start the generator to make sure that the oil pressure gage reads correctly and that there are no leaks around the sending unit.

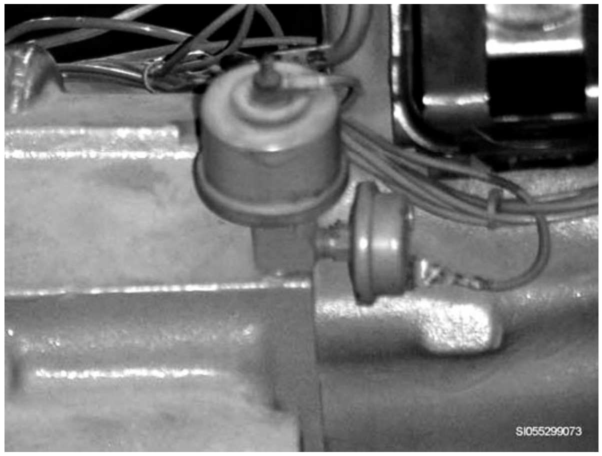


Figure 3–7. Oil pressure sending unit and switch.

Oil pressure switch

The oil pressure switch prevents the engine from operating if there is a loss of oil pressure. This protects the internal engine components from severe damage. To replace an oil pressure switch, disconnect the negative side of the battery to prevent the generator from starting. Disconnect the oil pressure switch electrical lead and unscrew it from the engine block.

To install a new pressure switch, screw it into the engine block and connect the electrical lead to it. Connect the negative side of the battery and start the generator to make sure that there are no leaks around the pressure switch.

419. Troubleshooting lubricating oil systems

As a power production technician, you are responsible for making repairs to the lubrication system so that the unit can be placed back into service. This lesson covers a few malfunctions that are likely to have occurred. Each situation is different and may require further investigation; this is where your knowledge of the system is used to find any unique malfunctions that may not be covered in this lesson.

Troubleshooting

There are three typical problems that you should troubleshoot first when trying to repair the lubrication system. The most common faults are high lubricating oil consumption, excessive crankcase pressure, and low lube oil pressure. The following chart explains some likely causes and the corrective actions you should take as a skilled technician to restore normal working operation of the system.

Troubleshooting Lubricating Oil System		
Malfunction	***Cause***	***Corrective Action Needed***
High lubricating oil consumption.	External leaks.	Oil lines or connections leaking. Gasket or oil seal leaking. High crankcase pressure. Excessive oil in air box (two-stroke engines).
High lubricating oil consumption.	Internal leaks.	Blower seal leaking (two-stroke engines). Oil cooler core leaking.

Troubleshooting Lubricating Oil System		
Malfunction	***Cause***	***Corrective Action Needed***
High lubricating oil consumption.	Oil control at cylinder.	Oil control rings worn, broken, or improperly installed. Piston ring retainer loose. Liners, pistons, or oil rings scored. Piston and rod misalignment caused by worn crankshaft thrust washers. Excessive installation angle.
Excessive crankcase pressure.	Cylinder blow by.	Cylinder head gasket leaking. Piston or liner damaged. Piston rings worn or broken.
Excessive crankcase pressure.	Obstruction or damage to breather.	Remove obstruction. Replace breather.
Excessive crankcase pressure.	Excessive exhaust back pressure.	Excessive muffler resistance. Exhaust piping faulty.
Low lubricating oil pressure.	Lubricating oil.	Suction loss. Lubricating oil viscosity too low.
Low lubricating oil pressure.	Poor circulation.	Strainer clogged.Cooler clogged. Cooler bypass valve not functioning properly. Pressure regulator valve not functioning properly. Excessive wear on crankshaft bearings.
Low lubricating oil pressure.	Pressure gauge.	Gauge faulty. Gauge line obstructed. Gauge orifice plugged. Electrical instrument panel sending units a faulty signal.
Low lubricating oil pressure.	Oil pump.	Intake screen partially blocked. Relief valve faulty. Air leak in pump suction. Pump worn or damaged.

Being able to replace lubricating systems components is essential to the operation of your engines. This helps you meet mission requirements. When working in the lubrication system always refer to the appropriate technical order before you start any maintenance.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

417. Servicing the lubrication system

1. What contaminates does the oil filter typically not remove from the oil?

2. Why do you operate the engine and allow it to get to operating temperature before you drain the oil?

3. What is the main idea of flushing the lubricating system?

4. What do you do before installing a new spin-on oil filter?

5. How much do you turn a spin-on oil filter once it makes contact with the filter head?

6. What must you do if you use the drain to collect your oil sample for an oil test?

7. In a solid contaminate test, how long do you allow the drop of oil to penetrate the blotter paper?

8. In a reaction test, for how long do you vigorously shake the vial?

9. In a dilution test, what is indicated if the engine oil flows out faster than the test sample?

10. How does the SOAP test help you determine internal problems in an engine before they become serious?

418. Component replacement

1. Why is it a good idea to leave the four corner bolts for last to support the oil pan until prior to removal?

2. What must you do before replacing the sending unit if it has two or more wires?

419. Troubleshooting lubricating oil systems

1. What are possible corrective actions for external leaks?

2. What is the possible cause if an engine has excessive crankcase pressure?

3. What would poor oil circulation cause?

4. What condition would cause high oil consumption?

Answers to Self-Test Questions

414

1. The oil reduces friction between moving parts. It also helps cool, clean, seal, and prevent corrosion.
2. It has characteristics of SAE 5W oil during the cold winter months while maintaining the characteristics of SAE 40 during the hot summer months.
3. They weaken the air bubbles, causing them to pop almost immediately.
4. Adhesiveness, which is the tendency to stick to any surface, and cohesiveness, which is the tendency of the molecules of the oil to stick together.

415

1. The pump draws oil into the rotating gear teeth and carries it next to the outside housing.
2. It prevents excess pressure from building up in the lubrication system by providing a bypass back to the oil sump when the pressure increases above the maximum level.
3. The oil and coolant flow in opposite directions to aid cooling.
4. It allows any pressure building up in the crankcase to escape.

416

1. It flows through the oil cooler.
2. It passes into the main oil gallery.
3. (1) It uses oil galleries in the cylinder block and head or
   (2) Passes through hollow push rods and sprays onto the valve train components.
4. (1) An oil pressure gauge.
   (2) An oil shutdown switch.

417

1. Carbon and soot because they are oil based.
2. To allow the heavy particles in the oil that has had the time to settle to the bottom of the oil sump to be suspended in the oil and liquefies waxy deposits to allow the oil to remove them from the engine.
3. To clean all of the deposits out of the engine.
4. Fill with new oil.
5. One-fourth of a turn.
6. Drain enough oil into a pan to remove this stagnate oil so your sample is from the engine sump
7. To 10 minutes or when it is no longer shiny or wet.
8. 20 seconds.
9. The engine oil is diluted beyond five percent.
10. By identifying different metal particles and their concentration in the oil.

418

1. Letting it sag on one side could cause it to warp, making it difficult, if not impossible to seal when you replace it.
2. Tag them so you can reinstall them correctly.

419

1. (1) Oil lines or connections leaking.
   (2) Gasket or oil seal leaking.

   (3) High crankcase pressure.
   (4) Excessive oil in air box (two-stroke engines

2. Cylinder blow by
3. Low lubricating oil pressure
4. (1) Internal leaks.
   (2) External leaks
   (3) Oil control at cylinder

Complete the unit review exercises before going to the next unit.

Unit Review Exercises

Note to Student: Consider all choices carefully, select the *best* answer to each question, and *circle* the corresponding letter. When you have completed all unit review exercises, transfer your answers to the Field-Scoring Answer Sheet.

Do not return your answer sheet to the Air Force Career Development Academy (AFCDA).

45. (414) How does oil with high viscosity flow and pour?
    a. Readily.
    b. Quickly.
    c. Effortlessly.
    d. In a sluggish manner.

46. (414) Which characteristic does oil with the grade of Society of Automotive Engineers (SAE) 5W–40 contain during cold winter months?
    a. SAE 5W.
    b. SAE 20W.
    c. SAE 40.
    d. SAE 45.

47. (414) When we apply heavy loads to oil what is the ability of a thin layer of oil to hold together called?
    a. Film strength.
    b. Detergency.
    c. Pour point.
    d. Viscosity.

48. (414) Against what does the protective film of oil seal the internal engine parts when trying to protect the engine parts from corrosion?
    a. Fuel in the oil.
    b. Coolant in the crankcase.
    c. Oxygen and moisture in the air.
    d. Condensation in the combustion chamber.

49. (415) Where is the relief valve located in the lubrication system?
    a. Input side of the strainer.
    b. Output side of the oil filter.
    c. Input side of the oil gallery.
    d. Output side of the oil pump.

50. (415) Identify the term that describes how oil and coolant flow in opposite directions to aid cooling.
    a. Crisscross principle.
    b. Counter flow principle.
    c. Directional flow theory.
    d. Opposite movement theory.

51. (415) Which oil pressure gauge uses direct pressure on the gauge to indicate the pressure?
    a. Electrical.
    b. Hydraulic.
    c. Pnuematic.
    d. Mechanical.

52. (415) Identify a protective device that shuts the engine down if oil pressure gets low.
    a. Oil pressure switch.
    b. Oil temperature switch.
    c. Oil pressure sending unit.
    d. Oil temperature sending unit.

53. (416) Which component does oil pass through to flow to the piston pin and piston?
    a. Camshaft.
    b. Push rods.
    c. Cylinder head.
    d. Connecting rod.

54. (416) What is one way oil is transported to the valve train components?
    a. Connecting rods.
    b. Hollow push rods.
    c. Camshaft passages.
    d. Crankshaft passages.

55. (416) Which type of oil or coolant levels can *reduce* the cooling capacity of the oil storage system?
    a. Low oil.
    b. High oil.
    c. Low coolant.
    d. High coolant.

56. (417) Which component collects *most* contaminates in the lubricating oil?
    a. Oil filter.
    b. Oil cooler.
    c. Oil strainer.
    d. Relief valve.

57. (417) You are adding new oil into the system; before you close the drain to push the old oil remaining in the bottom of the sump out, when do you close the drain?
    a. After you add a quart of oil.
    b. After oil begins to pour out of the drain again.
    c. Once you can begin to see some of the new oil.
    d. Once the oil pouring out of the drain becomes clear.

58. (417) The type of oil filter you would use a strap wrench in order to loosen the filter body is the
    a. spin on filters.
    b. clamp-on filters.
    c. top mount cartridges.
    d. bottom mounted cartridges.

59. (417) In addition to sulfur what other substance from the fuel may get into the engine oil and form sulfuric acid?
    a. Sodium from the cooling system.
    b. Nitrogen from the lubricating system.
    c. Air from the intake or exhaust system.
    d. Water from the cooling system or condensation.

60. (417) What is the dilution level of fuel of the test sample you create by adding fuel to a sample of new oil?
    a. 1 percent.
    b. 3 percent.
    c. 5 percent.
    d. 10 percent.

61. (417) Which oil testing method uses a computer analysis process that provides you with a detailed look at the engine oil?
    a. Field Lubricating Oil Test (FLOT).
    b. Systematic Contaminate Oil Test (SCOT).
    c. Spectrometric Oil Analysis Program (SOAP).
    d. Lubricating Oil Graphic Observation (LOGO).

62. (417) Where *must* you document oil test results?
    a. Inspection Checklist for the Generator Operating Log and AF IMT 719.
    b. Inspection Checklist for the Generator Operating Log only.
    c. Appropriate MAJCOM approved form.
    d. AF IMT 719 only.

63. (418) What is your *first* step in removing the oil cooler from the engine?
    a. Drain the coolant.
    b. Drain the lubricating oil.
    c. Remove the turbocharger.
    d. Remove the exhaust manifold.

64. (419) What is a possible cause of excessive crankcase pressure?
    a. Poor circulation of oil.
    b. Cylinder blow by.
    c. Worn oil pump.
    d. Internal oil leak.

Please read the unit menu for unit 4 and continue ➔

Student Notes

Unit 4. Cooling Systems and Engine Starting Aids

4–1. Theory of Operation **4–1**
420. Components 4–1
421. Operation 4–6
4–2. Maintenance **4–9**
422. Servicing an engine’s cooling system 4–9
423. Replacing components 4–12
4–3. Engine Starting Aids and Troubleshooting **4–17**
424. Winter starting 4–17
425. Troubleshooting 4–19

THE EQUIPMENT YOU ARE tasked with operating and maintaining is designed to be used anywhere on the globe. In order to function in these widely varying climates, the cooling systems must be robust and reliable. All internal combustion engines produce heat. The heat must be removed from the engine in order for it to continue to operate at peak efficiency. In this lesson, we will discuss the different types of engine cooling systems along with maintenance procedures.

4–1. Theory of Operation

Engines, as you know, are machines that convert heat energy into mechanical energy. The heat generated by an internal combustion engine gets hot enough to expand metals. Engines must have a way to control how hot an engine gets to prevent expansion that could cause damage to components. The purpose of the cooling system is to transfer this heat from the engine to some outside source. Coolant circulates throughout the engine collecting the heat and transferring it to the atmosphere.

420. Components

The cooling system, like all of the other engine systems, contains a group of components designed to complete a specific job. Each type of cooling system has unique components that work together to keep the engine cool. We take a closer look at the components for the two most common systems you see in the power production field, which are the liquid-cooled and air-cooled systems, which is described in this lesson.

Engine water jacket

The water jacket is a series of passages and openings in the cylinder block and head used for cooling. The jacket directs coolant around vital engine components to collect heat. Many of these passages circulate around the combustion chamber since this is the source of most of the heat in an engine.

Coolant manifold

The coolant manifold collects coolant from the water jacket and directs it toward the thermostat. The manifold could be a pipe or just a passage in the engine.

Circulating water pump

The circulating pump (fig. 4–1) circulates coolant through the water jacket. Centrifugal pumps are the most common type of pump used in the cooling system, although gear pumps are sometimes used. Centrifugal pumps draw coolant into the center of the pump and throw it to the surrounding case at high velocities. The coolant hits the case, slowing the velocity and increasing the pressure. The case then directs the pressurized coolant to the outlet of the pump. As the pressure builds up, the amount of fluid flowing from the pump decreases to prevent over pressurization.

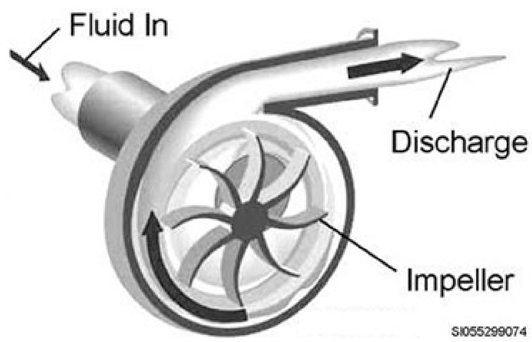


Figure 4–1. Circulating water pump.

Thermostat

The thermostat (fig. 4–2) is a temperature-controlled valve. It controls the flow of the coolant through the cooling system. If the coolant is cool, the thermostat closes causing the coolant to recirculate through the engine water jacket. When the coolant reaches operating temperature, the thermostat opens allowing the hot coolant to move to the radiator. Once cool coolant replaces the hot coolant, the thermostat closes to repeat the process. This allows the engine to maintain a reiteratively constant temperature and allows the radiator to cool the coolant better before it recirculates through the engine.

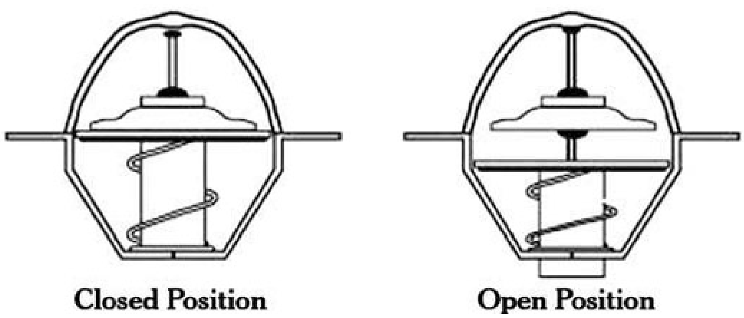


Figure 4–2. Thermostat.

The thermostat operates using the theory of expansion and contraction. A high-tension spring pushes against the valve keeping it closed. The bulb of the thermostat contains a material that responds to heat by expanding. This expanding material builds pressure against the movable end of the bulb. This pressure overcomes the spring tension causing the valve to begin to open. The hotter the coolant gets the most pressure the bulb material produces, which opens the valve more. As the coolant temperature decreases, the bulb material begins to contract. This reduces the pressure allowing the valve to begin to close. The bulb material and spring tension work together to determine at what temperature the thermostat opens and closes; this controls the engine temperature.

Hoses

Coolant hoses connect the radiator to the engine. This allows the flow of coolant to and from the radiator for cooling. Hoses also absorb any vibrations from the engine. Three common types of coolant hoses are straight, wire-reinforced, and flex hoses. The lower radiator hose carries coolant from the radiator to the engine. It is typically a wire-reinforced hose to prevent its collapse due to the high suction from the water pump. The upper radiator hose moves coolant from the engine to the radiator and handles the roughest treatment of all hoses. It receives coolant at the highest temperature it gets and absorbs most of the engine vibrations. The upper radiator hose is the one most likely to fail.

Radiator

The radiator (fig. 4–3) removes heat from the coolant once it leaves the engine. There are two basic types of radiator designs—the vertical flow with top and bottom tanks, and the cross flow with side tanks. Regardless of the design, radiators have tanks, a core, and a pressure cap. The tanks, one at the inlet and one at the outlet of the radiator, store enough coolant to properly cool the engine. The core consists of tubes that connect the two tanks. Each of these tubes has a set of fins built onto it. These fins collect the heat from the coolant. As air passes across the fins, heat transfers to the air. This process lowers the coolant temperature. The pressure cap seals the radiator while preventing over pressurization of the system.

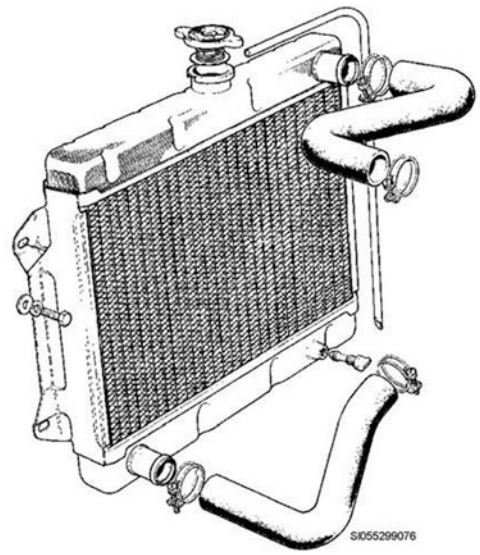


Figure 4–3. Radiator.

Shroud

The shroud directs air from the cooling fan and directs it across the core. This makes the air flow created by the fan more effective. This increases the amount of airflow moving across the radiator fins. Manufacturers design the fan shrouds for an airtight fit onto the radiator and close tolerances with the cooling fan to prevent recirculation of the hot air into the radiator.

Shutters

The shutters open and close to help maintain engine temperature. When they are closed, they prevent air from passing through the radiator. This increases engine temperature. Once the engine reaches operating temperature, the shutters open allowing cooling air to pass through the radiator. This allows your engine to reach operating temperature more quickly. A thermostatic control device typically opens and shuts the shutter assembly as temperature increases and decreases.

Expansion tank

The expansion tank is a small container connected to the overflow tube on the radiator. When the pressure cap relieves the system pressure, the excess coolant flows out of the overflow tube and into the expansion tank. Once the engine cools, the reduction in pressure creates a vacuum that draws coolant back into the radiator. This prevents coolant from spilling on the ground and ensures the radiator remains full at all times. We sometimes refer to the expansion tank as a surge tank or a coolant recovery tank.

Cooling fan

The cooling fan is an engine-driven fan that creates airflow across the radiator fins. These fans cause airflow through the radiator in one of two ways, using suction or by blowing, as shown in figure 4–4. The pitch of the blade and the direction that the fan spins determines whether the fan is suction or blowing. Generators typically employ a blowing fan. This allows cool air to flow across the radiator to cool it before the hot coolant heats up the air.

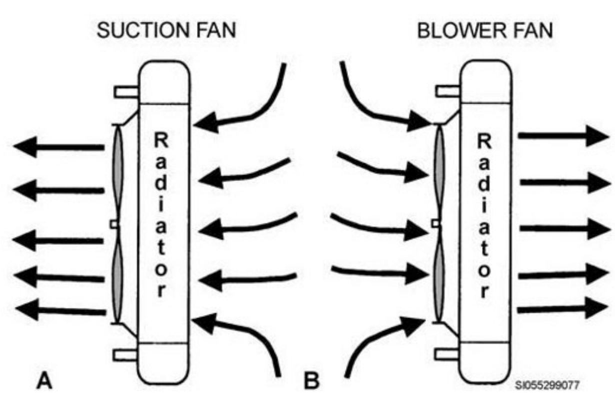


Figure 4–4. Cooling fan arrangement.

Clutch

The clutch (fig. 4–5) allows the fan to slip based on either temperature or speed. Its primary purpose is to reduce noise and lower the loss of horsepower. Speed control clutches use liquid to connect the fan drive to the fan blades. As the drive rotates, the liquid causes the blades to rotate. The liquid begins to slip as the speed increases so the blades do not turn as fast as the drive. Temperature controlled clutches use a sensor to determine the temperature of the air leaving the radiator. This sensor controls a valve that allows more liquid into the clutch when the temperature is high causing the fan to turn and cool more. Once the temperature lowers, the sensor allows the liquid to return to the reservoir allowing the fan to freewheel.

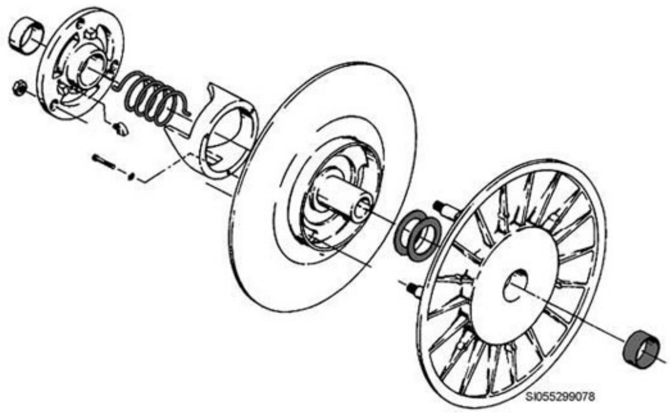


Figure 4–5. Fan clutch.

Guard

Fan guards are wire frames that wrap around the fan to prevent accidental touching of the rotating fan. Fan guards are essential to prevent safety mishaps. Never operate an engine without the guard in place. The use of guards could prevent severe cuts, loss of limbs, or even death.

Drive belts

Drive belts drive various components that include the camshaft, battery charging alternator, fan, and water pump. The choice of belts is used by manufacturers because they are less expensive and much quieter.

Coolant

Coolant is the liquid running through the water jackets to remove heat from the engine. Water is the primary liquid used as coolant. The only problem is it can leave corrosion and mineral deposits in the engine. This is why we mix it with other chemicals. The chemicals of choice are ethylene glycol or propylene glycol as antifreeze and some type of corrosion inhibitor. Antifreeze mixes with the water to change the specific gravity, thereby lowering the freezing point. This change in specific gravity raises the boiling point as well. A common mixture is 60 percent ethylene glycol to 40 percent water. Inhibitors prevent corrosion, primarily rust and scale, from building up in the water jacket. Failure to use an inhibitor can cause corrosion buildup, which reduces the heat transfer from the engine components to the coolant. This creates hot spots in the engine that could cause catastrophic damage.

Coolant filters

Coolant filters remove particles from the coolant. These particles can cause damage to the water pump and clog the radiator. Engine manufacturers use both spin on and cartridge filters. Some of these filters contain chemicals to add to the coolant. We refer to these filters as conditioners, shown in figure 4–6. You must change them regularly to keep the coolant charged with the necessary chemicals.

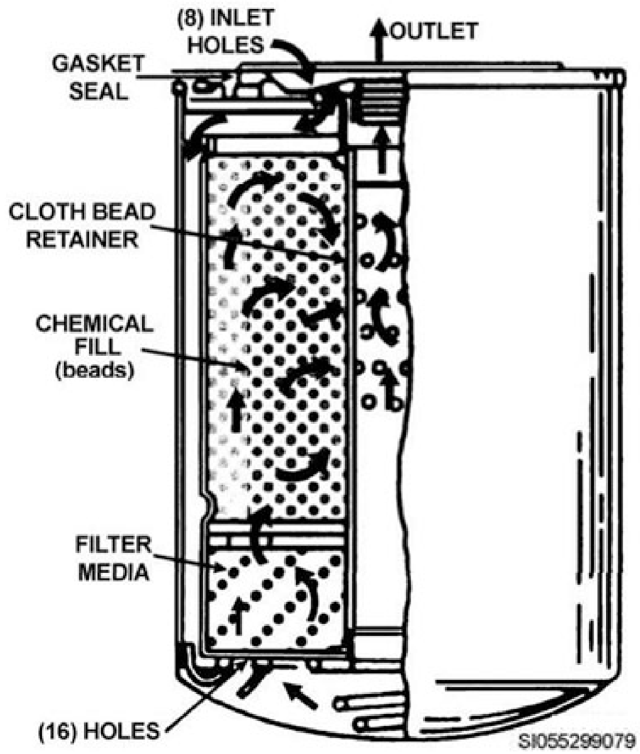


Figure 4–6. Coolant conditioner.

Coolant gauge

The coolant temperature gauge indicates the temperature of the coolant. There are two different types of gauges—mechanical and electronic. The mechanical gauge uses a temperature sensitive material that causes the gauge to indicate the temperature, while the electronic gauge uses a temperature-sending unit that varies internal resistance to change the amount of current reaching the gauge. The electronic gauge is the most common type.

Coolant temperature switch

The coolant temperature switch is a protective device that shuts the engine down if coolant temperature gets high. Normally the switch is closed when the temperature is below the preset value. The switch opens if the temperature rises above the preset level to de-energize the electrical circuit that keeps the engine running. This shuts the engine down preventing operation with high engine temperature, which would cause catastrophic damage to the engine.

Air cooled cooling system

Air-cooled engines, like the one on your lawn mower or weed eater, are used on our aircraft arresting systems and small generators. These cooling systems have different components than the ones you have just read about. The next few paragraphs describe these components.

Cooling fins

The cooling fins are thin strips of metal built into the cylinder heads and other portions of the engine. They collect heat from the engine and transfer it to the atmosphere as the air passes through the fins.

Cooling fan

The cooling fan provides airflow to the fins for cooling. You often find a centrifugal or axial-flow type fan used. The crankshaft drives this fan either directly or through gears. The fan must produce sufficient airflow to keep the fins cool.

Shroud

The shroud is ductwork that directs air from the fan to the fins and then away from the engine. Manufacturers generally construct the shroud from lightweight metal. Never operate air-cooled engines without the shroud in place.

Temperature sensors

Some air-cooled engines have temperature sensors mounted in the cylinder heads. This allows you to see the operating temperature of the engine. Manufacturers' manuals specify normal operating temperatures for these engines.

You must understand each of the components you have just read about to understand the operation of the cooling system. These components are common to most engines. Remember, these components work together to create the cooling system. The next section takes these components and discusses the operation of the cooling system.

421. Operation

The cooling system's purpose is to remove heat created by the combustion of an engine. You have read about two types of cooling systems and looked at the specific components for each. The next few paragraphs take a look at the operation of these two types of systems—liquid-cooled and air-cooled. Understanding this greatly aids your capabilities of maintaining and troubleshooting these systems.

Liquid cooling system

To look at the operation of the cooling system, let's start with the engine shut down and cool. Refer to figure 4–7 as you read through the operation of the cooling system. The radiator and engine are full of coolant. When the engine starts, the water pump rotates and begins to move coolant. The initial movement of coolant begins in the bypass tube into the pump since the thermostat is closed. The pump then pressurizes the coolant and forces it into the water jacket. The coolant enters the lower portion of the water jacket, pushing upward. This ensures there is always coolant in contact with all internal engine components at all times. If the coolant moved from the top to bottom, it could possibly descend like a waterfall, missing some of the crevasses in the water jacket. This would create hot spots. Once the coolant moves through the water jacket, it reaches the manifold. This collects all of the heated coolant and directs it to the thermostat.

The coolant is still cool when it reaches the thermostat immediately after startup. The thermostat senses this and remains closed. The coolant then flows into the bypass tube. This recirculates the coolant back to the water pump to pass through the water jacket again. The coolant in the radiator holds its position because the water pump is drawing its coolant from the bypass tube. This process allows the engine to reach operating temperature quickly. The engine operates much more efficiently at the operating temperature determined by the manufacturer.

Once the coolant reaches operating temperature, the thermostat senses this and opens. The coolant then flows through the thermostat, through the upper radiator hose and into the upper radiator tank. Coolant from the lower radiator tank moves through the water pump and into the water jacket to replace the coolant moving into the radiator. Coolant from the radiator core moves to the lower radiator tank and coolant from the upper radiator tank moves into the radiator core as this is happening.

The new coolant passes through the water jacket, picking up heat, and moves into the water manifold. This coolant reaches the thermostat at a lower temperature than the coolant that caused it to open. The thermostat senses the lower temperature and closes causing the coolant to move to the bypass and recirculate. Once the coolant reaches operating temperature, the thermostat reopens allowing coolant to flow into and out of the radiator.

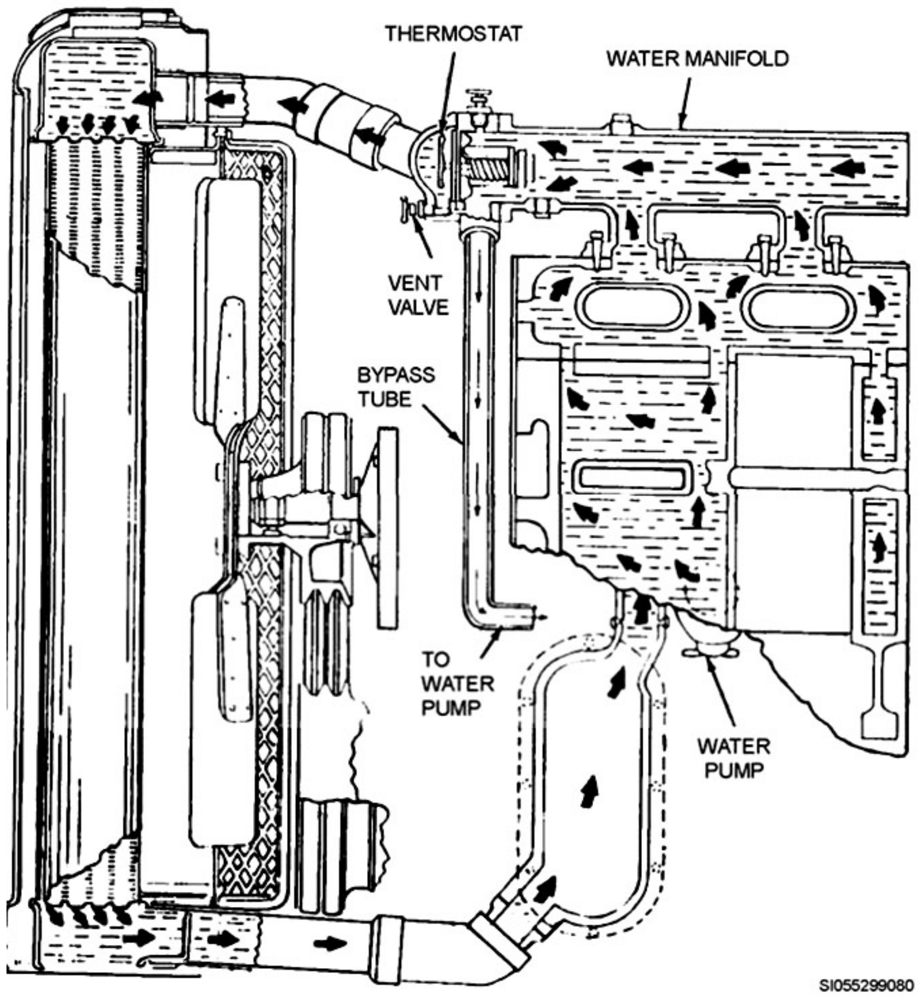


Figure 4–7. Typical closed cooling system.

This process of opening and closing of the thermostat continues throughout the operation of the engine. The thermostat rarely opens or closes completely during operation. It simply increases or decreases the amount of fluid moving past it. This process accomplishes two things for you. First, it keeps the engine at a relatively constant temperature. Second, it allows coolant in the radiator core to cool for a longer period of time before it reenters the water jacket.

Without the constant opening and closing of the thermostat, the engine temperature could be high or low. If your engine has a large radiator with good airflow, the engine temperature tends to be lower than is recommended by the manufacturer. If the radiator is on the small side and airflow is not very good, the engine can run on the high side of the recommended operating temperature.

As the heat builds in the cooling system, the coolant begins to expand. The hotter the coolant gets, the more it expands. Once the coolant expands to fill all of the space in the cooling system, pressure begins to build. Most cooling systems operate at a pressure of 10 to 15 pounds per square inch (psi). The radiator cap controls this pressure, as shown on figure 4–8, A by acting as a relief valve when excessive pressure builds. When pressure overcomes the spring tension, the valve opens. Coolant flows out of the overflow tube. Your engine's expansion tank collects this coolant. Once the coolant temperature lowers, it contracts and creates a vacuum in the system. This vacuum opens a valve, as shown in figure 4–8, B allowing coolant to move from the expansion tank to the radiator.

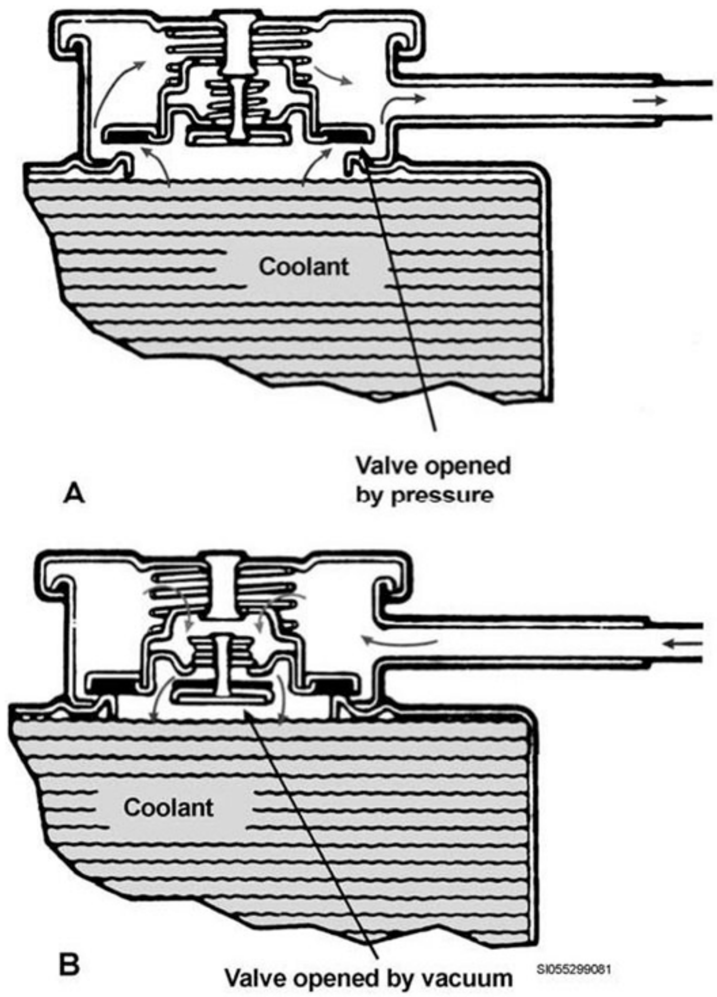


Figure 4–8. Radiator cap operation.

Air cooled cooling system

The air-cooled system works on very simple principles. When the engine starts, the fan begins to rotate. This increases the pressure of the air in the shroud. As the pressure increases, the air moves through the shroud. As the air moves, it makes contact with the cooling fins on the engine. The longer the engine operates the warmer these fins become. The air moving across the fins collects the heat. The heated air then continues its journey through the shroud. The shroud directs the air from the fan, across the cooling fins, and out away from the engine. The hot air always blows away from the intake area of the fan so the engine continually draws cool air into the shroud. If hot air makes it into the shroud, it does not cool the fins as well and the engine can overheat.

Many engines, especially throughout Europe, have temperature sensors in the cylinder heads. Always monitor the temperature to ensure the effectiveness of the cooling system.

Understanding the operation of these two cooling systems allows you to maintain your engines in peak operating conditions. Take the time to answer the following questions before moving into the maintenance section.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

420. Components

1. What happens to the thermostat when the coolant reaches operating temperature?

2. What are the three common types of coolant hoses?

3. Regardless of the design, what three parts make up a radiator?

4. What determines whether the fan is suction or blowing?

5. What is the common mixture you find as your coolant?

6. What types of fans might you find on an air-cooled engine?

421. Operation

1. Why does the coolant enter the lower portion of the water jacket pushing upward?

2. At what pressure do most cooling systems operate?

3. Where does the shroud direct the air on an air-cooled engine?

4–2. Maintenance

Performing maintenance on any machinery is essential to its upkeep. The cooling system of your engine is no different. Keeping the cooling system operating is essential to meeting mission requirements. You will find this to be especially true in deployed locations. What you are about to read concerns one of the more common jobs you perform throughout your Air Force career.

422. Servicing an engine’s cooling system

A prime concern of a power production operator is the condition of your cooling system. You operate generators in temperatures ranging from 140˚F to negative 40˚F, depending on where you are located. Regardless of which extreme you are in, the coolant must contain the proper amount of ethylene glycol at all times. We often refer to ethylene glycol as antifreeze because it lowers the freezing temperature of water when you add it. This becomes critical during winter operations. Ethylene glycol is also critical for summer time operations because it raises the temperature at which water boils. We refer to this mixture as coolant.

Engine antifreeze coolent

You must service the cooling system with the proper amount of antifreeze. The Air Force specifies the use of a permanent type of antifreeze only. Local policy generally directs the proper mixture of antifreeze and water according to the local climatic conditions. A mixture of 60 percent ethylene glycol to 40 percent water mixture provides protection to –60°F. This mixture also raises the boiling point to around 276°F and is adequate for all conditions in which the generator set operates.

Test coolant regularly to determine the mixture. If the test shows that the temperature rating of the coolant does not meet your local policy, add ethylene glycol to the system. Do not pour it directly into the radiator. Mix it thoroughly with a small amount of water and add it to the system while the engine is operating. Drain the system enough to allow sufficient room for the new mixture. You must determine the exact amount to add from the chart provided by the antifreeze manufacturer. After the new mixture sufficiently circulates with the original coolant, test it to determine the status of the newly mixed coolant. If the protection is still not within the required range, you must repeat the process and always follow the manufacturer’s recommendations.

Coolant additives

Coolant additives are necessary to prevent liner pitting, corrosion and scale build-up on your cooling system components. The most common additive you find today is diesel coolant additive (DCA). DCA provides good engine protection in heavy-duty diesel applications where glycol-based coolants are used. It contains a unique blend of phosphate, nitrite, and molybdate that result in superior competitive advantages. The following list provides the advantages of using coolent additives.

- Improved engine protection with less chemical so solids don’t build up faster in the coolant.
- Improved solder and aluminum protections.
- Improved liner pitting protection. Coolant reaching temperatures high enough to boil the liquid causes pitting. This boiling action causes tiny bubbles, which eat away at the cylinder liner, eventually getting through the liner.
- More tolerant of solder bloom and gelation when over treatment occurs. Solder blooms occur when liquid gets under the edge of the solder and blows it up like a balloon. Solder gelation occurs when the solder softens due to the additives.
- Less solder bloom and fewer water pump leaks.
- Less silicate gel.

You must test the coolant to determine its condition during the preventive maintenance inspection. The two areas you can test are freeze point and coolant quality. The most common way you would perform these tests is to use either test strips or a refractometer.

Not all engines use DCA. You can harm cooling systems if you add DCA to some engines. In the same respect, adding too much DCA to a system that uses it can degrade the coolant system. You must always follow the additive manufacturer’s specifications when adding coolant additives of any kind to an engine.

Flushing engine cooling system

The cooling system must be clean to do its work properly. Scale in the system slows down heat transfer from the water jackets and also heat dissipation from the radiator. Untreated water forms scale in the radiator, engine block, and cylinder heads. The scale causes hot spots within the engine and clogs the tubes in the radiator core. Dirty water can close the tubes in the core and restrict the flow through the radiator causing overheating. If you encounter this condition, you need to flush and clean the cooling system.

Remove scale formation with a safe descaling solvent. Most engine manufacturers recommend a cooling system cleaner, such as sodium bisulfate or oxalic acid. After you use these cleaners, you must follow them with a neutralizer with a good flushing of the engine.

Remember to remove the thermostats on small engines when flushing. Flushing the radiator and the engine block consist of nothing more than running clean water through them. You can take the radiator to a commercial shop for reverse flushing, if needed.

Water conditioner assembly

The water conditioner assembly is a filter that removes foreign matter from engine coolant and conditions the pH factor of the coolant. Many of these conditioners contain DCA. Inspect the coolant conditioners for leaks around the point where the gasket meets the mounting head. Also look at the conditioner body to make sure there are no dents or other damage to it.

To remove the water conditioner, disable the engine from starting and tag the control panel. Make sure that the engine is cool to prevent any burns. Turn the valve on the conditioner filter head to the OFF position. Remove the conditioners by turning them in a counterclockwise direction.

To install new coolant conditioners, wet the seal with coolant and install the coolant conditioners by turning them in a clockwise direction. Make sure to turn the valve to the ON position. Refill the cooling system with engine coolant. Operate the engine and observe for leaks around the coolant conditioners.

Testing antifreeze

As you already know, the cooling water must contain the proper amount of antifreeze at all times. Use a hydrometer to check the specific gravity of the coolant. The hydometer measures the specific gravity of the coolant solution. This specific gravity determines the temperature where a liquid freezes and boils.

Since temperature affects the density of a liquid, you must make a correction corresponding to the temperature of the coolant. A scale on the hydrometer shows the amount of protection provided according to the float reading in the hydrometer. You can read the temperature of the coolant from a thermometer on the hydrometer. Generally the hydrometer is the most accurate and easiest to read when you take the reading with the coolant near the normal operating temperature.

Take the reading by opening the radiator cap. You must use caution if the engine is hot because the pressure buildup causes the coolant to surge out of the radiator when you remove the cap. It is best to wait for 10 to 15 minutes after shutting the engine down before you remove the cap. This allows some of the pressure to bleed off. When you are ready to open the cap, it is best to place a rag over the cap and turn it partially off. Most radiator caps have a notch that prevents you from removing the cap but allows some pressure to be released. Once the pressure bleeds off of the systems completely, remove the cap.

Next place the hydrometer fill tube into the coolant in the radiator. Squeeze the bulb and slowly release it, drawing coolant into the hydrometer. Fill the hydrometer until the bulb floats in the coolant. Too little coolant can give you a bad reading. Allow the bulb to settle in the coolant and then take the reading where the bulb meets the coolant. Once you get this reading, take note of the temperature. Squeeze the coolant back into the radiator and return the cap. Compare your readings to the chart provided with the hydrometer to determine the freezing temperature of the coolant.

You must service the cooling system regularly to keep the engine operating at its peak efficiency. Failure to complete this maintenance can cause the engine to overheat and shut down. This can lead to a power outage deterring the mission at a critical time. The next section we look at is how to replace components.

423. Replacing components

Cooling system components, like all mechanical items, sometime break. Knowing how to replace these components is essential to keeping the engine operating. The components we look at are the water pump, radiator, hoses, drive belts, thermostat, coolant temperature sending unit, and high engine temperature switch.

Water pump

The water pump circulates coolant throughout the cooling system. We often refer to it as the heart of the cooling system. If the water pump fails, you need to replace it to return the engine to operational condition. Refer to figure 4–9 as you read through the process of removing the water pump.

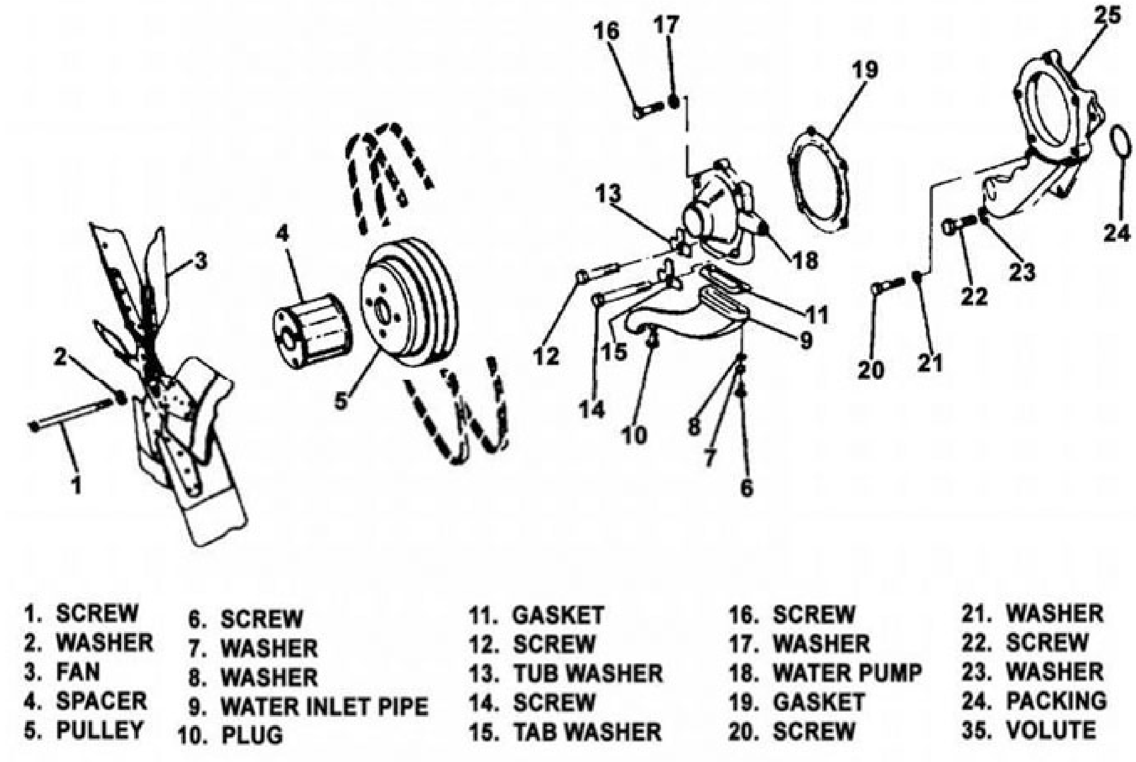


Figure 4–9. Water pump replacement.

The first step in replacing the water pump is to disable the engine from starting. Next, drain the coolant to a level at least below the water pump. Use a clean container if you plan to reuse the coolant. Next, you must remove the fan guards. This usually consists of the removal of six to ten bolts that hold the guard in place. Be careful not to bend the guard as you remove it. Next, remove the fan belts. Engines use many different ways to loosen the belts so you can remove them. Make note of the position of the belts so you can return them to their same position during reassembly. Next, you need to remove the fan. Four to eight bolts hold most fans in place. Hold the fan in place as you break the bolts loose. It is a good idea to loosen all of the bolts before you remove any. This allows you to support the fan better to prevent it from making contact with the radiator, which might damage it. Some fans have spacers you must remove with the fan. Also remove the belt pulley at this time.

Now you are ready to start working on the water pump. Start by removing the coolant hoses. If you plan to reuse the hoses, do not use a sharp object to assist with the removal. If you plan to replace the hoses, the easiest way to remove the old ones is to cut them off. Take care not to cut yourself in the process. Next, remove the water inlet pipe. Loosen the bolts holding the water pump in place. Once you remove the bolts, remove the pump. You may find it necessary to tap it with a hammer to break its seal to the engine.

Once you remove the water pump, you can inspect it. The items you inspect are the seals, impeller, shaft, and bearing. You must disassemble the pump by pressing the shaft out and removing the seal with a drift pin or rod and hammer. Once you disassemble the pump, begin the inspection by looking at the bearing and shaft. You must replace the bearing and shaft if you find any binding, rough feeling, or signs of dry running due to the lack of lubricant. Next, inspect the impeller's ceramic seal for chips, cracks, and rough conditions. Check the pump housing for cracks and any other unusual conditions. Clean the pump components with an approved solvent and reassemble the pump. Be sure to use new seals as you perform the reassembly.

Before you install the water pump, you must clean all of the connecting surfaces to ensure a proper seal. Install a new gasket on the water pump and bolt the pump into place. Install the water inlet pipe onto the water pump, using a new gasket. Install the hoses onto the hose connections. Be sure to clean the connections well before you install the hoses. Next, install the pulley, spacer, and fan then bolt everything down. Install the drive belts and tighten them to the proper tension. Check this tension midway between the pulleys. Install the fan guard and fill the system with coolant. You may find it necessary to bleed air from the system to prevent any air locks. Start the engine and observe the system for leaks.

Radiator

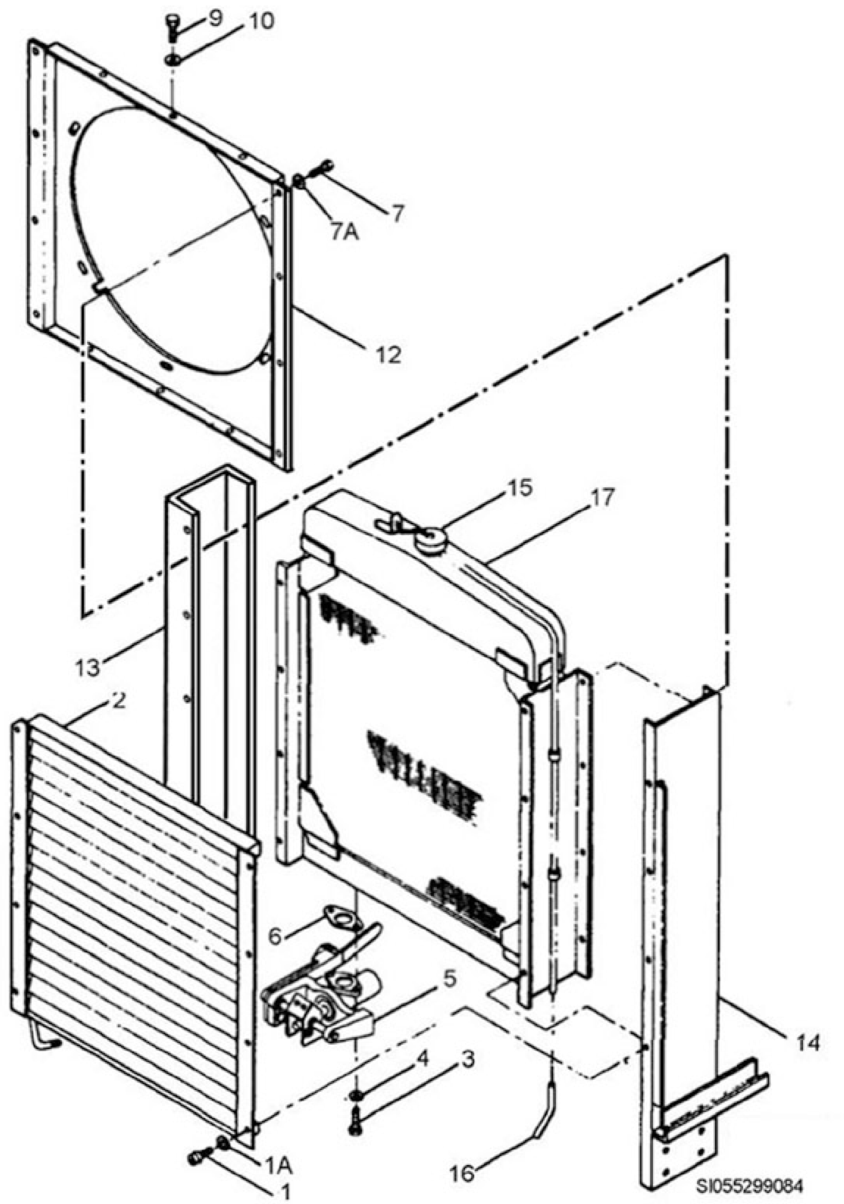
You may find it necessary to replace a radiator on one of your engines. This could be necessary because the radiator is leaking or simply not cooling as well as it should. You will find a wide variety of procedures to remove the radiator due to the different types of housings on the equipment. Always refer to the manufacturer's manual as you complete the maintenance. The next few paragraphs discuss a common radiator removal. Refer to figure 4–10 as you read through the procedures for a better understanding.

The first step to replacing the radiator is to disable the engine. Once you have it disabled, drain the coolant. If you plan to reuse the coolant, make sure the container is free from contaminates. Remove the radiator cap before you drain the coolant to prevent any vacuum hindering the coolant from draining. Once the coolant completely drains, loosen and remove the hose clamps from the radiator connectors. Remove the hoses taking care not to damage them. Next, remove the radiator shutter assembly. This usually consists of removing between six and ten bolts. You may also find it necessary to remove the linkage for the shutter thermostat. Next, remove the fan guard and shroud.

Now you are ready to start removing the radiator. You may find it necessary to remove some of the housing to get to the radiator. You manufacturer's manual describes exactly what you need to remove. Once you remove the housing, loosen the bolts holding the radiator in place. Support the radiator and remove the bolts, lifting the radiator out. Radiators can be extremely heavy; take the necessary precautions to prevent dropping it.

Inspecting the radiator is a simple process. Start by looking at the fins on the tubes. They should be straight and free of debris. Slight dents or bends are acceptable if not too many exist. Next, look at the area where the tank meets the core. Make sure the joints are secure. Next, look at the joint between the hose connections and the tanks and the filler neck and tank. These joints are most susceptible to the vibrations of the engine. If you find any items needing repair, take the radiator to a qualified technician for the repairs.

To install a radiator, begin by setting it in place and aligning the holes on the mounting bracket with the support holes. Install all of the mounting bolts hand tight before securing them. Install all of the housings that you removed and secure them. Install the fan shroud, fan guard and the shutter. Ensure the linkage works properly if your radiator has the thermostat to open and close the shutters. Install the hoses and clamps. Fill the system with coolant. You may find it necessary to bleed air from the system to prevent any air locks. Start the engine and observe the system for leaks.



1. Screw
1A. Washer
2. Shutter
3. Screw
4. Washer
5. Shutter control assy
6. Gasket
7. Screw
7A. Washer
8. (Delete)
9. Screw
10. Washer
11. (Delete)
12. Shroud
13. RH radiator support
14. LH radiator support
15. Cap
16. Drain hose
17. Radiator

4–10. Radiator replacement.

Inspecting hoses

Coolant hoses are critical to the proper operation of the engine. If they are not in good condition, they could leak and cause the engine to overheat. You can easily overlook them during generator inspections because they do not require periodic replacement like the oil and fuel filters. Because they are just as important, inspect them with the same significance you give to the oil, coolant, and fuel levels.

Inspect the hoses every time you operate the generator for leaks at the connections, tightness of the hose clamps, cracks, dry rot, and pliability. If the hose is getting hard, it is a good sign that something bad is about to happen; replace it. Also, a hose swelling is a good sign the engine temperature is getting high during operation.

To replace the hose, disable the engine from starting and tag the control panel. Drain the engine coolant into a container and preserve it for reuse. Cover the coolant to prevent contamination. Loosen the hose clamps and remove the hoses. Clean the hose connector completely. Corroded hose connectors are the most common cause of leaks with hoses. Slide the hose clamps over the hose, and place the new hoses onto the hose fittings. Slide the hoses all the way to the base of the fittings. Place the clamps half way between the end of the hose and the end of the hose fitting. Tighten the clamps to secure the hoses to the fittings. Refill the cooling system and replace the radiator cap. Start the engine and look for leaks around the hoses.

Replacing engine drive belts

Drive belts (alternator and fan belts) (fig. 4–11), are also critical to the operation of an engine. They drive items such as water pumps and battery-charging alternators. Failure to inspect them can lead to breaks that cause the generator to shut down. Inspect the belts for cracks, fraying, signs of unusual wear, and proper tension. Before checking belt tension, make sure to disable the generator to prevent startup. Check the tension midway between the pulleys, using the back of your hand and a ruler. The amount of tension varies slightly from generator to generator, but usually it is around one-half of an inch. Be sure to consult the technical order or manufacturer's manual to determine the proper tension for the generator you are checking.

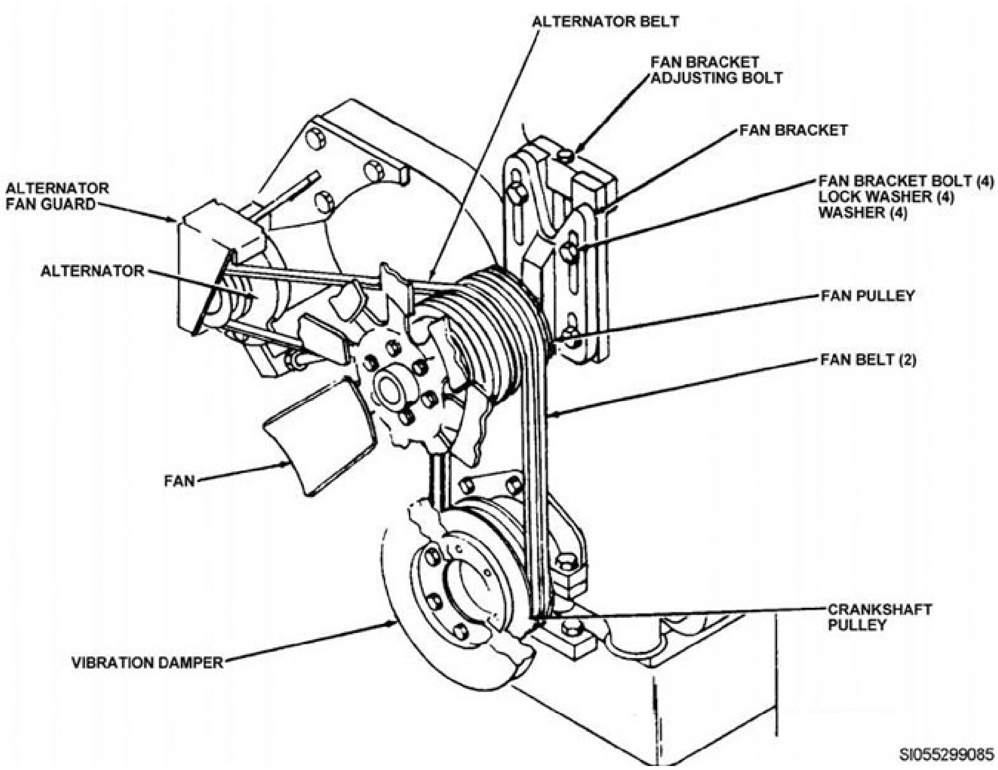


Figure 4–11. Belt diagram.

To replace engine drive belts, make sure that you disable the engine from starting and tag the control panel. For the battery-charging alternator belt, remove the fan guard and loosen the alternator bolt that allows the alternator to pivot. Rotate the alternator until the alternator belt is loose enough for removal and remove the belt. For the water pump belt, remove any remaining fan guards. Engines use slightly different ways to apply tension to the belt. Some use a spring loaded tensioning pulley; others use a pulley with a jacking bolt. Determine the type of tensioning device and release tension from the belts. Work the belts over the fan blades to remove them from the engine. Some engines may require you to pull the fan to remove the belts.

Before you install new belts, inspect the pulleys for nicks or burs that could damage the belt. If the belts that you are replacing are a set, never replace only one of the belts. Always replace them as a set because belts stretch slightly over time. If you replace only one belt, the newer belt may have more pressure applied to it; this could cause its failure. Install the new belts over the fan. Set them on the pulleys and apply tension to them. Using the back of your hand and a ruler, check the tension midway between the pulleys. Be sure to check the technical order or manufacturer's manual to determine the proper tension. Install the fan guards, start the engine, and observe the belts for unusual wobble.

Replacing a thermostat

Thermostats open and close based on the temperature of the coolant around them. They control the flow of coolant from the radiator to the engine to keep the temperature constant. If they fail, the engine could overheat or run cooler than normal. Before replacing a thermostat, make sure that the engine has completely cooled to prevent burning yourself. Disable the engine for starting, and tag the control panel. Loosen the upper radiator hose at the thermostat housing and slide it off. Remove the thermostat housing and the thermostat from the cylinder head. Be sure to get all of the old gasket material removed from the housing and block. Install a new thermostat into the cylinder head. Install a new gasket and position the housing on the cylinder head securing it with bolts. Attach the upper radiator hose and secure it with a clamp. Replace any lost coolant and install the radiator cap.

Coolant temperature sending unit

Replacing this sending unit is very much like replacing the oil pressure sending unit that you read about earlier. As before, disconnect the battery to prevent the generator from starting. You need to drain the coolant to a level below the sending unit. Be sure to use a clean container to prevent contamination of the coolant so you can reuse it. Next, disconnect the electrical leads and remove the sending unit.

To install a new sending unit, screw it into the engine block and connect the electrical lead to the sending unit. Refill the radiator with coolant. Connect the battery and start the generator to make sure that the temperature gage reads correctly and that there are no leaks around the sending unit.

High engine temperature switch

Replacing it is also very much like replacing the low oil pressure switch. Disconnect the battery and electrical lead. Drain the coolant below the level of the switch and unscrew it from the engine block.

To install a new temperature switch, screw it into the engine block and connect the electrical lead to the engine block. Refill the radiator, connect the negative side battery, and start the generator to make sure that there are no leaks around the switch.

Being able to replace cooling systems components is essential to the operation of your engines. This can help you meet mission requirements. Always refer to the appropriate technical order before you start any maintenance and use the step-by-step procedures throughout the job. Take the time to answer the following questions before you move to the next lesson, starting aids.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

422. Servicing an engine's cooling system

1. A 60 percent ethylene glycol to 40 percent water mixture raises the boiling point to what temperture?

2. Why are coolant additives necessary?

3. What does scale in a cooling system cause?

4. When is the hydrometer most accurate and easiest to read?

423. Replacing components

1. Once you have the fan and guards out of the way, what is the first step in removing the water pump?

2. What does removing the radiator cap before you drain the coolant do for you?

3. For what do you inspect hoses?

4. What are two ways tension is applied to belts?

4–3. Engine Starting Aids and Troubleshooting

Some engines are hard to start. This is especially true during the winter months. Diesel engines use heat from the compression to ignite the fuel, cold weather hampers this process. Increase the heat inside the engine or use a fuel that burns more easily than diesel to increase the starting efficiency of the engine.

424. Winter starting

To prevent damage to the engine during cold weather, use a starting aid to warm the engine before using the equipment. Let's look at some of these engine starting aids in this lesson and explain how they work.

Coolant heaters

There are two types of coolant heaters—circulating and immersion. Circulating coolant heaters (fig. 4–12) are usually mounted externally to the frame of the engine. Cold coolant leaves the bottom of the engine block and enters the heater tank, where a heating element warms the heater. Percolation moves the warm coolant back into the engine block. Circulating heaters are available with or without thermostatic control. The main advantage of circulating coolant heaters is that they warm the engine in a very short period of time. Most circulating coolant heaters are electric, but some are propane fired.

Inspect these heaters by looking at the engine temperature with the engine off. The engine should be warm enough to allow the engine to start. Also, look at the heater fittings for leaks and corrosion and check the clamps and the mounting brackets for tightness. Make sure the hoses are pliable and in good condition. Look at the electrical connections for signs of corrosion and overheating.

To replace an external heater, de-energize the power to the heater, and tag the switch or breaker. Drain the coolant from the radiator into a clean container so you can reuse it. Remove the heater by disconnecting the electrical leads, loosening the hose clamps, and removing the mounting bolts. Inspect the heater hoses very carefully. The heater produces high heat that can cause these hoses to deteriorate very quickly. If there is any doubt as to whether a hose is good, replace it. Install the new heater by bolting it to the bracket, then connecting the hoses and electrical leads. Fill the radiator with coolant and turn the power back on. If your engine is not equipped with shut off valves for the heater, now would be a good time to install them. This prevents you from having to drain the radiator the next time you have to replace the heater.

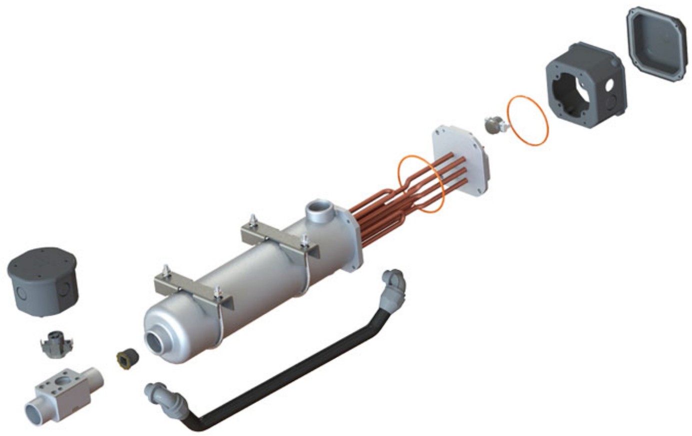


Figure 4–12. Circulating coolant heater.

Immersion coolant heaters (fig. 4–13) are installed internally in the engine block in place of a freeze plug. Large engines and V-type blocks usually require the use of two immersion heaters. Immersion coolant heaters do not circulate the coolant. Heat can move through the cylinder's wall only by convection, so warm-up time is increased when compared to external coolant heaters.

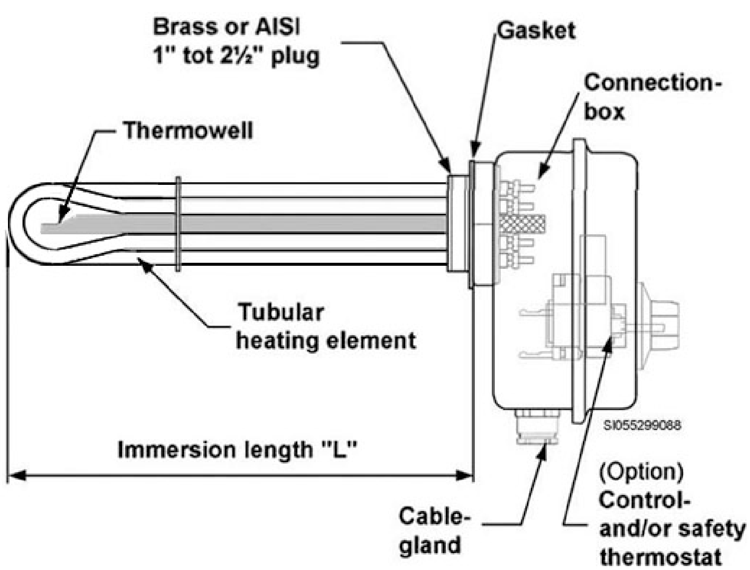


Figure 4–13. Immersion heater.

Inspect these heaters by looking at the engine temperature with the engine off. The engine should be warm enough to allow the engine to start. Also look at where the heater mounts into the engine for leaks and corrosion. Look at the electrical connections for signs of corrosion and overheating.

Replacing internal heaters is similar to external heaters. First, de-energize the power source and tag the switch or breaker. Next, disconnect the electrical wiring and drain the coolant below the heater level. Loosen the heater mounting bolts and remove the heater from the engine. Install the new heater into the engine and tighten it into place. Do *not* turn the power on to the heater until the engine is full of coolant because doing so could burn the heater up causing it not to work. Connect the electrical connections and fill the engine with coolant. Once everything is back together, operate the engine until it reaches operating temperature to make sure that there are no leaks around the heater. Return the following day to check whether the heater is operating properly.

Glow plugs

Glow plugs thread into the individual cylinders or intake manifolds and uses battery current to produce heat. Operating temperatures reach as high as 1,500˚F in seconds. Once the engine is running, the glow plugs turn off. Do not confuse glow plugs with spark plugs used in gasoline engines. They are not the same in either function or operation. It is important that you do *not* use starting fluid on engines that are equipped with glow plugs. Using starting fluid on engines with glow plugs can cause an explosion that can damage the engine and cause injury to you.

Glow plugs may be wired in parallel or series and have a fairly high current draw. They offer a method of warming the engine without the need for an AC hookup or alternate fuel fired heat source.

Ether

The two most common ways ether is packaged are aerosol cans and pressurized cylinders. Use of spray cans of ether is discouraged, as such devices can be dangerous. The only method of safely using ether is with a closed dispensing system. Starting aid systems of this type normally consist of a cylinder of pressurized ether, a metering valve, tubing, and an atomizer installed in the intake manifold. The valve trips only once during each starting attempt, to prevent a build-up of ether in the intake manifold that could lead to an explosion or hydraulic lock.

Diesel engines can also be fitted with another one-shot starting device consisting of a holder and needle. A capsule containing ether inserts into the device. The needle pierces the capsule, releasing the pre-measured dose of ether into the intake manifold. Regardless of the system used, introduce starting fluid into the intake manifold while the engine is cranking very sparingly.

These systems are essential to the starting and operation of your engines. You must ensure these systems operate to meet mission requirements.

425. Troubleshooting

When things go wrong with equipment it is important to know how to fix it. Using the troubleshooting process will help you to diagnose and repair fault with the cooling system.

Troubleshooting abnormal engine operating temperatures

While the engine is operating, you may encounter abnormal engine operating temperatures. If this happens, use the following procedures to troubleshoot the cooling system.

Above-normal operating temperatures

If the engine is operating above its recommended operating range, check for insufficient heat transfer. Clean the cooling system with an approved cleaner and thoroughly flush it to remove scale deposits, then follow the below procedures:

- Adjust loose fan belts to their proper tension to prevent slippage.
- Check for improper size radiator or inadequate shrouding.

- Adjust, repair, or replace inoperative temperature-controlled fans.
- Check the coolant level, and fill the system to its proper level if low.
- Inspect for collapsed or disintegrated hoses, replace if faulty.
- If the thermostat is inoperative, remove, inspect, and test it. Replace the thermostat if you find it to be faulty.
- Check the water pump for loose or damaged impeller.

In addition, clean the exterior of the radiator core to open plugged passages, permitting normal airflow. Also, you should check the flow of water through the radiator. A clogged radiator will cause an inadequate supply of water on the suction side of the pump. Clean the radiator core. Also, check for leaks on the suction side of the water pump, and replace any defective parts.

Remove the radiator cap and operate the engine, checking for combustion gases in the cooling system. If you find combustion gases, remove and inspect the cylinder head for cracks. In addition, replace head gaskets if combustion gases are entering the cooling system.

Below-normal operating temperatures

If the engine is operating below its recommended operating temperature, check to ensure the thermostat is closing. If the thermostat is not closing, remove, inspect, and test the defective thermostat, then check the thermostat seal. If the thermostat is defective, remove and replace it.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

424. Winter starting

1. What are the two most common types of coolant heaters?

2. How do immersion coolant heaters spread heat throughout the engine?

3. Why is it important that you do *not* use starting fluid on engines that are equipped with glow plugs?

4. What is the only safe method of using ether?

425. Troubleshooting

1. What procedures are used when the operating temperatures are abnormally high?

2. What is the most likely cause for abnormal low operating temperatures?

Answers to Self-Test Questions

420

1. The thermostat opens allowing the hot coolant to move to the radiator.
2. (1) Straight hoses.
   (2) Wire-reinforced hose.
   (3) Flex hose.
3. (1) Tanks.
   (2) A core.
   (3) A pressure cap.
4. The pitch of the blade and the direction that the fan spins.
5. 60 percent ethylene glycol to 40 percent water.
6. Centrifugal or axial-flow type fan used.

421

1. This ensures there is always coolant in contact with all internal engine components at all times.
2. 10 to 15 psi.
3. From the fan, across the cooling fins, and out away from the engine.

422

1. Around 276°F.
2. To prevent liner pitting, corrosion and scale build-up on your cooling system components.
3. Hot spots within the engine and clogs the tubes in the radiator core.
4. When you take the reading with the coolant near the normal operating temperature.

423

1. Removing the coolant hoses.
2. Prevent any vacuum hindering the coolant from draining.
3. Leaks at the connections, tightness of the hose clamps, cracks, dry rot, and pliability.
4. (1) Spring loaded tensioning pulley.
   (2) A pulley with a jacking bolt.

424

1. (1) Circulating.
   (2) Immersion.
2. By convection, so warm-up time is increased when compared to external coolant heaters.
3. It can cause an explosion that can damage the engine and cause injury to you.
4. With a closed dispensing system.

425

1. (1) Adjust loose fan belts to their proper tension to prevent slippage.
   (2) Check for improper size radiator or inadequate shrouding.
   (3) Adjust, repair, or replace inoperative temperature-controlled fans.
   (4) Check the coolant level, and fill the system to its proper level if low.
   (5) Inspect for collapsed or disintegrated hoses, replace if faulty.
   (6) If the thermostat is inoperative, remove, inspect, and test it. Replace the thermostat if you find it to be faulty.
   (7) Check the water pump for loose or damaged impeller Inoperative thermostat, low coolant level and improperly sized or dirty radiator.
2. Faulty thermostat.

Complete the unit review exercises before going to the next unit.

Unit Review Exercises

Note to Student: Consider all choices carefully, select the *best* answer to each question, and *circle* the corresponding letter. When you have completed all unit review exercises, transfer your answers to the Field-Scoring Answer Sheet.

Do not return your answer sheet to the Air Force Career Development Academy (AFCDA).

65. (420) What type of situation causes the need to use a wire-reinforced hose in the cooling system to prevent the lower radiator hose collapse?
    a. Low pressure from the engine.
    b. Extreme heat from the radiator.
    c. High suction from the water pump.
    d. Excessive strain from the thermostat.

66. (420) Which component collects the heat from the coolant in a radiator to transfer it to the air?
    a. Fins.
    b. Tank.
    c. Radial fan.
    d. Fan shrouding.

67. (420) What does antifreeze change in water when you mix it with water lowering the freezing point?
    a. Specific gravity.
    b. Properties of the oil.
    c. Boiling point of the water.
    d. Cooling effects of the water.

68. (420) Identify what drives the fan on an air cooled engine either directly or through gears?
    a. Flywheel.
    b. Camshaft.
    c. Crankshaft.
    d. Valve train.

69. (421) Which portion of the engine does coolant enter the engine to *ensure* there is always coolant in contact with *all* internal engine components?
    a. Middle.
    b. Lower.
    c. Upper.
    d. Side.

70. (421) At what pressures do *most* cooling systems operate?
    a. 3 to 5 pounds square inch (psi).
    b. 10 to 15 psi.
    c. 20 to 25 psi.
    d. 40 to 50 psi

71. (421) What opens a valve on the radiator cap, thus allowing coolant to move from the expansion tank to the radiator?
    a. Vacuum.
    b. Pressure.
    c. Pneumatics.
    d. Temperature.

72. (422) How do you add antifreeze to an engine while it is operating?
    a. Mix it with a large amount of inhibitors.
    b. Add straight water directly into the radiator.
    c. Mix it thoroughly with a small amount of water.
    d. Add straight antifreeze directly into the radiator.

73. (423) You inspect the water pump impeller’s ceramic seal for
    a. leaks, vibrations, and cracks.
    b. soot pockets, corrosion, and chips.
    c. chips, cracks, and rough conditions.
    d. corrosion, vibrations, and deformities.

74. (423) When you are inspecting a radiator, what component *must* be straight and free of debris?
    a. Cap.
    b. Fins.
    c. Tank.
    d. Hoses.

75. (423) Identify the *most* common cause of leaks with hoses in a cooling system?
    a. Bent fins.
    b. Cracks at the tank.
    c. Defective cap gasket.
    d. Corroded hose connectors.

76. (423) What property of engine drive belts causes you to *always* replace belts as a set?
    a. Dry rot over time.
    b. Deteriorate over time.
    c. Stretch slightly over time.
    d. None, belts do not need to be replaced as a set.

77. (423) Which component causes the engine to overheat or run cooler than normal if it fails?
    a. Hoses.
    b. Radiator.
    c. Thermostat.
    d. Water pump.

78. (424) What coolant heater has the *main* advantage of warming the engine in a very short period of time?
    a. Blanket.
    b. Immersion.
    c. Direct heat.
    d. Circulating.

79. (424) What do you do if you have any doubt as to whether a hose is good or not?
    a. Reuse it.
    b. Replace it.
    c. Ask for another opinion.
    d. Schedule it for replacement.

80. (424) Which coolant heater is installed internally in the engine block in place of a freeze plug?
    a. Blanket.
    b. Circulating.
    c. Direct heat.
    d. Immersion.

81. (424) Why do you *never* turn the power on to the heater until the engine is full of coolant?
    a. It boils the coolant.
    b. It could burn the heater up.
    c. It can cause a fire on the engine.
    d. There are no problems that occur.

82. (424) Identify the engine component where glow plugs are installed.
    a. Cylinder head.
    b. Intake manifolds.
    c. Air filter housing.
    d. Exhaust manifold.

83. (424) Identify the *only* safe method of using ether in an engine?
    a. Spray can.
    b. Liquid mixture.
    c. Open dispensing system.
    d. Closed dispensing system.

84. (425) What would cause an engine to run *below* normal operating temperatures?
    a. Thermostat is stuck closed.
    b. Thermostat stuck open.
    c. Radiator clogged.
    d. Broken fan belt.

85. (425) What would cause an engine to run *above* normal operating temperatures?
    a. Radiator is too large.
    b. Thermostat stuck open.
    c. Thermostat is inoperative.
    d. Rich fuel to air mixture.

Please read the unit menu for unit 5 and continue ➔

Student Notes

Unit 5. Intake and Exhaust Systems

5–1. Components and Theory of Operation **5–1**
426. Intake system components and theory of operation 5–1
427. Exhaust system components and theory of operation 5–3
5–2. Maintenance **5–5**
428. Servicing intake and exhaust systems 5–5
429. Replacing system components 5–7

ENGINES REQUIRE THREE THINGS to operate—fuel, air, and an ignition source. The intakes and exhaust system provide the fresh air to the engine and removes all of the burned gases from the combustion chamber. Without these systems, your engine would not operate because it would be missing one of the three components.

5–1. Components and Theory of Operation

You need to understand the theory of operation of the intake and exhaust system to be able to perform maintenance and troubleshoot problems. Understanding what each component does and how they fit into the system is the key to understanding this operation. This section explores the components and theories of operation to provide you with the necessary knowledge to maintain engine systems.

426. Intake system components and theory of operation

The intake system starts at the inlet air filter and ends in the combustion chamber of the engine. The design of the intake system provides the engine with clean air within the proper temperature range. Air is drawn into the intake system and filtered to remove any debris. This clean air then moves into the blower or turbocharger and intercooler, if so equipped. The air then moves through the piping to the intake manifold. The intake manifold then directs the air into the cylinders as the intake valves open.

The air intake systems or engines you are likely to see are generally made up of an intake air silencer, air filter or cleaner, turbocharger, and the necessary connecting pipes. We refer to engines without a turbocharger or blower as naturally aspirated engines. Once we mount a turbocharger or blower on an engine, we refer to it as a supercharged engine. Supercharging forces air into the cylinders to promote better combustion and produce more power. The air intake system's functions are as follows:

- Cool the air after it leaves the turbocharged two- and four-stroke engines.
- Furnish an adequate supply of clean air required for combustion.
- Furnish additional air for scavenging.
- Silence air noises.

Air filters

Air filter contain dry elements include screens, mesh, crimped metal, fiber, felt, spun glass, cloth, or paper. Technology has improved these types of filters dramatically. They retain contaminates from the air by trapping the particles in the filter material. You must keep these types of filters clean because the amount of air flow decreases as the amount of particles embedded into the filter material increases. These dry element filters have become the filter of choice for many engine manufacturers.

Air piping system

The air piping system connects engine air intake system components together. This allows air to flow through the system into the combustion chamber. The piping system could be as small as a few inches long or an intricate piping system to accommodate an externally mounted air filter system. The complexity of the air intake system determines just how much piping your engine has. You'll find piping constructed of rigid metal, flexible metal, and rubber. The flexible qualities accommodate engine expansion, contraction, and vibrations.

Intake manifold

The air intake manifold collects the intake air and distributes it into the appropriate cylinders for combustion. The manifold can consist of a single component or multiple pieces that make up the manifold. This usually depends on the size of the engine with smaller ones more likely to have a single piece making up the manifold and larger engines using a multiple piece manifold.

Air box

Two stroke engines have an air box, which serves the same purpose as the intake manifold of four-stroke engines. The list below provides characteristics of an airbox.

- The air box is part of the cylinder block and operates at engine temperatures.
- Cylinder liners containing ports extend through the air box.
- Blowers pressurize the air in the air box.

This pressurized air enters the cylinder through ports in the cylinder once the piston moves below the ports to open them.

A small amount of condensed moisture, lubricating oil, fuel oil, and foreign material gets into the air box. This is why the air box has drains. Air boxes usually contain four drains, one air box in each corner. They drain any accumulated liquid from the box. During engine operation, air continually blows out of each drain. You can feel the air discharging from the drain tube. This circulation of air keeps the box drained of liquids and reduces the formation of carbon on the air-box floor walls.

Superchargers

The purpose of supercharging is to force as much air into the engine combustion chamber as possible. This allows the engine to burn more fuel thereby increasing the amount of power the engine produces. Supercharging uses air at a pressure above the atmospheric pressure. This increase of air in the cylinder not only increases the power output but also increases efficiency, helps overcome high altitudes, and allows smaller engines to perform the jobs for larger naturally aspirated engines.

Turbochargers

A turbocharger (fig. 5–1) is a centrifugal blower driven by the exhaust gases. This allows the turbocharger to provide pressurized intake air without using any power created by the engine. The exhaust gases contain considerable amounts of energy that the turbocharger taps into. This energy is otherwise wasted as the exhaust gases vent to the atmosphere.

Turbochargers consist of a turbine housing, turbine wheel, compressor wheel, and common shaft. These components all fit into a housing that is essential to the operation of the turbocharger, which is decribed in the following list.

- The turbocharger fits into both the intake and exhaust systems.
- The turbine housing keeps these systems separate.
- Exhaust gases leave the cylinder and move through the exhaust manifold to the turbine side of the turbocharger.
- The gases enter the housing from the side hitting the turbine wheel. This causes it to rotate as the exhaust gases move to the exhaust outlet in the center of the housing.
- The exhaust gases then move to the exhaust pipe.

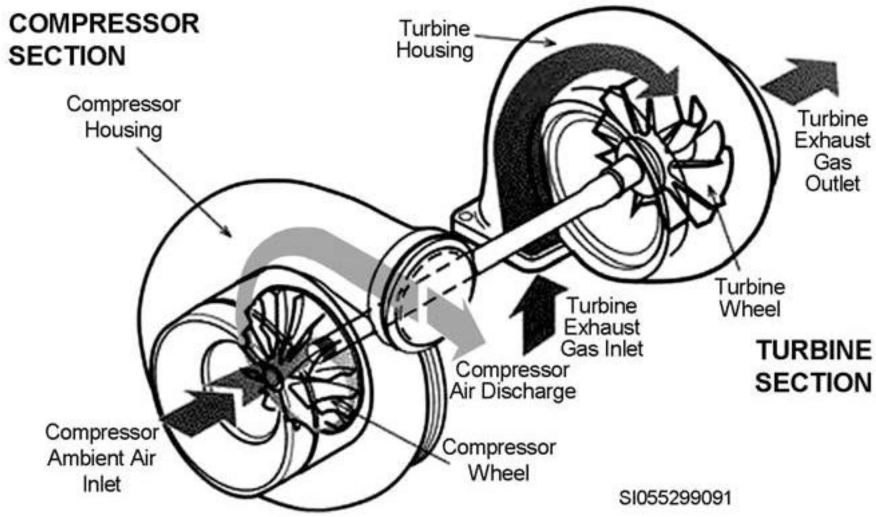


Figure 5–1. Turbocharger.

The rotating turbine wheel causes the shaft to rotate which causes the compressor wheel to rotate. This rotation of the compressor draws air into the center of the intake housing. The compressor wheel takes the air and throws it outward. The shape of the housing and the air movement outward causes the air to rotate under pressure within the housing. This rotation moves the air toward the intake outlet and moves the air, under pressure, into the intake manifold.

Turbochargers rotate at high speeds from 10,000 to over 100,000 rpm. The pressure of the exhaust gases determine the amount of speed at which the turbocharger rotates. The higher the pressure of the exhaust gases causes higher speeds of the turbocharger, which causes higher amounts of air to be moved into the intake system. This enables more air to be packed into the cylinder, allowing for more power to be made from the same engine. One problem associated with turbocharged engines is that the increase of intake air does not coincide with the increases in engine speed. This increase of intake air waits for the engine to increase the speed, burn the fuel creating more exhaust gases, thus more pressure on the exhaust system. This increase in pressure then causes an increase in turbocharger speed, drawing more air into the engine. This process often takes several seconds. We refer to this difference in time as turbocharger lag.

Intercoolers

Intercoolers cool the air after it leaves the turbocharger and before it enters the air intake manifold. Intake air passes through the intercooler and transfers heat to cooling tubes, similar to an engine radiator. This increases the density of the intake air and permits greater efficiency from the engine. When the turbocharger increases the air pressure to 10 psi, the temperature of the air rises at least 100°F. Cooling the air and increasing the density allows more oxygen to reach the combustion chamber. This increases the engine’s efficiency over the use of a turbocharger alone.

427. Exhaust system components and theory of operation

Once the intake air enters the cylinder, it mixes with the fuel and ignites. The burning of the fuel during combustion produces toxic gases. The engine must safely expel these gases in some manner. That is where the exhaust system fits into the picture.

The exhaust system must provide airtight piping to move exhaust gases safely to the atmosphere. Since the exhaust gases are highly toxic, we cannot tolerate leaks in the system because leaks can cause carbon monoxide poising which can lead to death. The exhaust must also silence the extremely loud noises created by combustion. The exhaust system typically consists of the exhaust manifold, turbocharger, exhaust silencer, and piping to direct the toxic gases to the atmosphere, which will be covered in this lesson.

Exhaust manifolds

The exhaust manifold collects the burned gases from the engine and directs them to the rest of the exhaust system. In doing this, gases from each cylinder enter individual exhaust headers. From each header the gases flow through a tube to a common manifold or to a discharge point at the turbocharger or exhaust piping. The exhaust gas temperatures can range up to 1,200°F or more. Because of this, you may find a heat shield incorporated around the manifold.

Diesel engines are equipped with a cast-iron or steel exhaust manifold. Engine designers often build these as one piece or in sections, depending on the size and style of the engines. The style of cylinder heads often determines which type of manifold the designers choose. Sectioned exhaust manifolds use slip joints, also referred to as tapered joints, to connect the sections of the manifold. This construction allows for the expansion and contraction between the three cylinder heads as heat increases and decreases.

Exhaust silencer

The silencer, or muffler as we often refer to it, consists of a series of perforated baffles within a cylindrical container. Silencers use heavy-gauge metal construction and should give many years of trouble-free service. An expansion joint absorbs any expansion or contraction of the generator set relative to the building structure. As the exhaust gases pass through the silencer, the baffles create a slight pressure. The baffles also absorb much of the acoustical energy in the exhaust gases. The absorption and smoothing effect reduces noise levels leaving the silencer.

Exhaust piping

The exhaust system contains piping that connects components together and directs the exhaust gases to a safe release to the atmosphere. You may find this piping connected using welds or clamps.

Theory of operation

Understanding the way these components fit together to form a system is important to the maintenance you must perform. The operation of these systems is vital to the proper operation of your engine.

Intake system

Air is drawn into the intake system and filtered to remove any debris. This clean air then moves into the blower or turbocharger and intercooler, if so equipped. The air then moves through the piping to the intake manifold. The intake manifold then directs the air into the cylinders as the intake valves open.

Exhaust system

Once the combustion chamber burns the fuel and the exhaust valve opens, burned gases rush out of the cylinder. The exhaust manifold collects these gases and directs them to piping. The gases then go to the turbocharger turbine, if so equipped. From there they move through more piping heading to the silencer. As these gases reach the silencer, they run into some pressure, which slows the gases down some. The gases move through the baffles in the silencer leaving much of the acoustical energy with each turn. Once the gases leave the silencer, more piping directs it outside to disperse into the atmosphere.

The intake system provides the engine with the sufficient amount of air for combustion. This air must also be clean. Blowers and turbochargers increase the efficiency of engines by supercharging them, which increases the amount of air in the cylinder for combustion. The exhaust system then removes the burned gases from the combustion chamber and safely disperses them into the atmosphere. These gases contain energy that sometimes drives the turbocharger.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

426. Intake system components and theory of operation

1. What do the air box's four drains remove from the air box?

2. What is the purpose of supercharging?

3. What components make up a turbochargers?

4. Turbochargers rotate at what speeds?

427. Exhaust system components and theory of operation

1. What collects burned gases and directs them to the rest of the exhaust system?

2. What other term is used when talking about a silencer?

3. Which side of a turbocharger do exhaust gases pass?

5–2. Maintenance

Now that you understand the components of the intake and exhaust system and how they operate, you are ready to look at the maintenance you must perform. The maintenance you accomplish keeps your engine intake and exhaust systems in top operating condition. You can break this maintenance into two categories—servicing and component replacement.

428. Servicing intake and exhaust systems

As you already read, the intake system gets clean air into the engine for combustion, and the exhaust system collects the burned gases created by the combustion and disperses it into the atmosphere. Servicing these systems at proper intervals extends the life of the generator and makes sure that it operates at peak efficiency.

Servicing the intake system consists of visual inspections of all intake components and replacement of the filters. Look for cracks, signs of leaks, and other damage. Look for anything out of the ordinary as you perform the inspection. If damage is found, replace the filters as necessary**.** In this lesson, we discuss the area in fullfiling those responsibilities.

Inspections

Servicing the exhaust system consists of visual inspections of all of the components on the exhaust system. Look for cracks and leaks throughout the system. You can identify leaks by black markings on the surface near the leak. You may not be able to visually see a crack, but you might notice a black streak. This carbon buildup occurs at leaks.

If the engine is equipped with a turbocharger, be sure to check it for unordinary vibrations. You use a rod to do this by placing the rod against the turbocharger housing while the engine is running. Do *not* use your hand or finger because you may incur severe burns. Some turbochargers have a rod welded to them that you can use to test for vibrations. If anything is out of the ordinary, immediately shut down the engine and further investigate after the engine cools down.

Air intake system

Inspecting the air intake system makes sure that your engine operates correctly. Problems with the intake system can cause increased fuel consumption, decreased power output, or an engine that will not operate at all. You can find many of the items that cause these things to occur before they become major issues. Take time to perform these inspections thoroughly to keep your engine operating at peak efficiency.

Air filters

The air filters are the most commonly replaced items in the air intake system. Thoroughly inspect the filters before every operation to make sure they are in good condition. Look for rips or tears in the filter elements and damage to the frame. Some filters use a rubber gasket built into the filter. Make sure these gaskets are in good condition to prevent air from bypassing the filter element because of a bad seal. Look at the clamping device to make sure it is secure. Look at the service indicator while the engine is operating. This determines if the filter element is allowing enough air through it or if it is clogged up.

Intake manifold

The intake manifold is subject to cracking and warping. The gaskets located between the manifold and the cylinder head are subject to leaks. Leaks often create a whistling sound. Look for any signs of corrosion and eliminate it as necessary. Check the manifold bolts or nuts periodically and make sure they are tight. Be sure to tighten and torque the manifold bolts or nuts following the technical order or the manufacturer’s instructions.

Intercoolers

Intercoolers cool the air after it leaves the turbocharger. This increases the density of the air allowing more oxygen in the same amount of space. If there are problems with the intercooler, the engine will not operate as efficiently or with the same power. Intercoolers vary in their appearance from manufacturer to manufacturer. Some resemble a football with hoses attached while others you can mistake for a radiator. This means there are slight variances in the inspection criteria. Start by making sure that the housing mounts securely to the frame. Inspect the hose connections for security, cracks, dry rot, and damage. Look at any welded joints for signs of cracks or damage. Look for any signs of leakage from the intercooler and identifies and eliminates any corrosion from the intercooler.

Exhaust system components

Inspecting the exhaust system is critical to the proper operation of your engine. Even more important, problems with the exhaust system can become deadly. You need to identify potential problems before they occur. This is where inspection of the exhaust system becomes very important. It could save your life and the lives of your co-workers.

Exhaust manifolds

Expansion and contraction, high operating temperatures, and vibration of the exhaust manifold cause nuts and bolts to work loose and gaskets to shrink and deteriorate with continued use. As a result, the manifold is subject to cracking and developing leaks at gaskets and expansion joints. Timely and effective preventive maintenance minimizes these troubles. Check for evidence of leaks at these gaskets and connections. You can see such leaks because of the carbon-colored discoloration of parts or surfaces adjacent to the leak.

Expansion joint

An expansion joint connects the exhaust manifold to the exhaust piping. It absorbs the vibrations of the engine allowing secure mounting of the exhaust piping to the facility. By properly inspecting an expansion joint you can find defects before they become severe. Cracks or distortion may cause leaks that can fill a room with carbon monoxide. This becomes extremely dangerous for personnel working in the area. Visually check the expansion joint for cracks, corrosion, leaks, and other damage. Check the connections and hardware for security. Start the engine and check for evidence of exhaust leaks in flex pipe. You can often see this as dust or smoke blowing from the joint during startup.

Exhaust silencer

Inspect the exhaust silencer components for erosion of metal parts and clogging. Contamination in the fuel oil is a major factor in erosion. Excessive sulfur and moisture in the fuel causes rapid erosion of the silencer, as well as other exhaust system parts. The erosion weakens the metal parts causing them to crack or break.

If the silencer clogs up, it creates excessive back pressure against the engine. Consequently, the engine is unable to scavenge its exhaust gases. This condition results in a loss of power from the engine. Operating the engine under light loads, by using bad fuel, and by baffles breaking loose inside the silencer can cause clogging. You can avoid this problem by using the proper fuel and operating the unit with a sufficient load to obtain good combustion.

Taking the time to properly service the intake and exhaust system provides problem free operation for a long time. The inspections you perform during preventive maintenance are the key to this. You must also take the time to change the filters and tighten the mounting bolts throughout the system. Next, we discuss how to perform maintenance when servicing the system is not enough.

429. Replacing system components

No matter how well you maintain a piece of equipment, mechanical failures occur. Often it is nobody’s fault, parts just wear out. Other times, components are defective and break. You must understand how to deal with scenarios that require corrective actions quickly. In this lesson, we provide you the tools to know how the system works so to allow you to efficiently accomplish your maintenance in the minimum amount of time.

Replacing a turbocharger

As you recall, turbochargers, (fig. 5–2) are centrifugal air pumps driven by exhaust gases as they depart the engine. When you are doing maintenance on the turbocharger, remember that it gets extremely hot and can cause severe burns. Be sure to let the turbocharger cool completely before you begin your work. To replace the turbocharger, disable the engine from starting. The following list provides you the steps to accomplish the disassembly.

- Disconnect the oil hose assembly from the turbocharger oil inlet and remove the oil drain tube assembly from the turbocharger casing.
- Remove the hose clamps and elbow from the turbocharger air inlet. You may find these bolted into place on some engines.

- Remove the V-band clamp and turbine exhaust connection from the turbocharger exhaust outlet.
- Unbolt the turbocharger intake air outlet from the intercooler housing.
- Unbolt the turbocharger exhaust inlet from the exhaust manifold.
- Remove and discard all of the gaskets.
- Remove the turbocharger assembly from the engine.

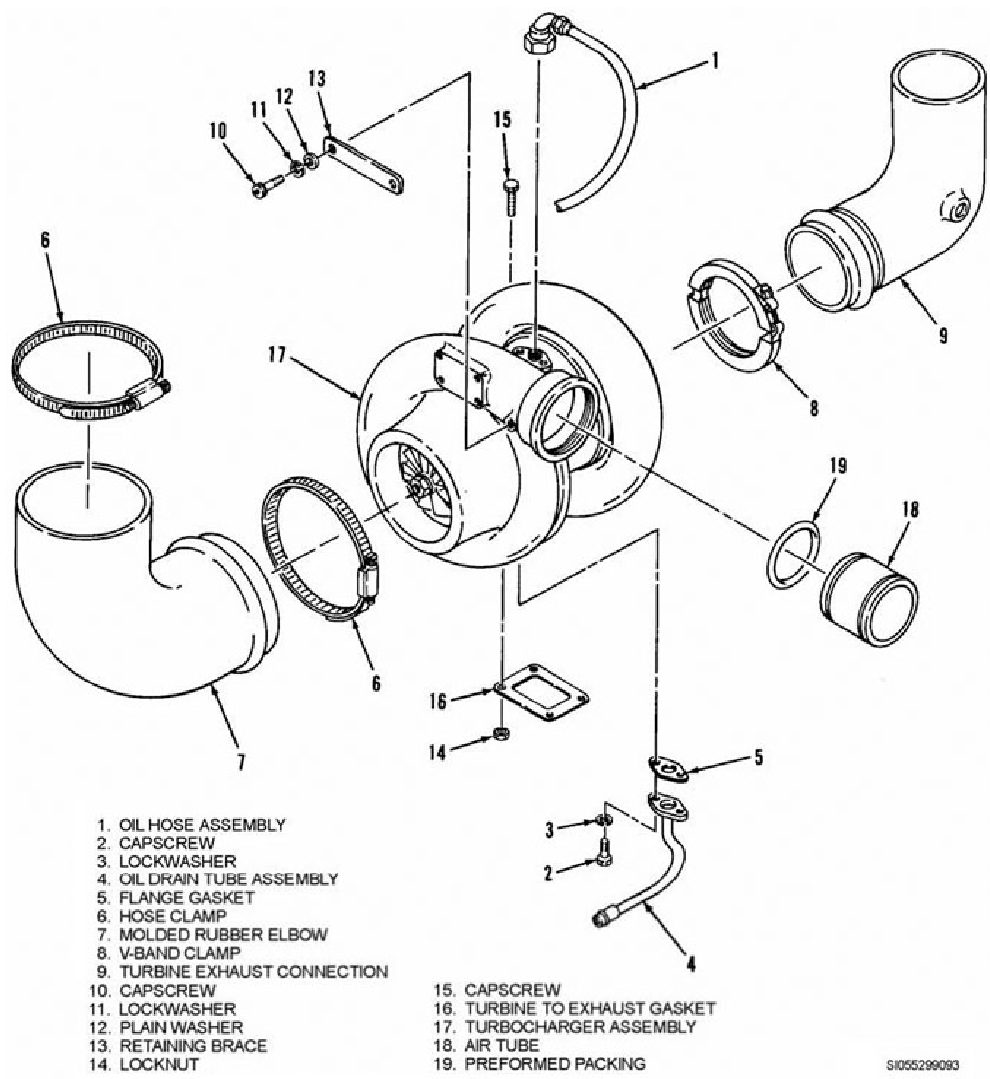


Figure 5–2. Turbocharger.

To reinstall the turbocharger, lubricate the pre-formed packing with clean engine lubricating oil and install it on the air tube (fig. 5–4, callout 18). Install the air tube in the intercooler housing. Coat the turbine to the exhaust gasket with a high temperature anti-seize compound and position the gasket on the exhaust manifold flange. Use a nonflammable paste form of anti-seize compound if possible. Install the air outlet of the turbocharger assembly on the air tube and position the exhaust inlet on the exhaust manifold outlet. Push the turbocharger assembly onto the air tube until the exhaust manifold flange is in proper alignment with the turbocharger exhaust inlet. Make sure the turbine to exhaust gasket is in alignment. Install the capscrews and locknuts, but don’t tighten them at this time. Make sure the inlet and exhaust connections are aligned properly and the oil drain hole points downward. Tighten the V-band clamp nut to the appropriate torque. Install the retaining braces. Install the oil drain tube assembly using a new flange gasket. Install the turbine exhaust connection and V-band clamp. Using a small funnel, pour two to three ounces of clean lubricating oil through the oil inlet opening of the turbocharger housing. Turn the compressor wheel slowly by hand while adding oil to distribute oil around the bearings. Install the oil hose assembly on the turbocharger inlet. Install the elbow and secure it with hose clamps. Start the engine and observe the turbocharger for proper operation.

Replacing an intercooler

To replace the intercooler, disable the engine by disconnecting the negative side of the battery. Drain the cooling system below the level of the intercooler. Remove the turbocharger and any other accessories secured to the intercooler. Remove the capscrews and lockwashers that secure the coolant outlet pipes to the outlet connections. Remove the hexagon head screws and washers that secure the coolant inlet connections. Unbolt and remove the intercooler assembly mounting plate. Most intercoolers are rather heavy. It takes at least two persons to remove a intercooler from the engine.

To reinstall the intercooler, lift it into place and bolt it down. Remember to use two people to prevent injuring yourself. Connect the coolant inlet and outlet connections and secure them. Install the turbocharger and connect any other accessories that you had to take off. Fill the cooling system and operate the engine to see if there are any leaks. Be sure that you use new gaskets and tighten everything to the proper torque specification.

Replace intake manifold

Several things determine just how involved it is to replace the intake manifold. You must answer questions, such as, “Does your engine have a turbocharger, intercooler, or blower?” before you get into the precise steps of removing the intake manifold. Obviously, the more of these items that you have, the more work you have to do. Once you get all of the other major components out of the way, the intake manifold is rather easy.

Let’s say your engine has a turbocharger and intercooler. First, as always, disable the engine by disconnecting the negative side of the battery. Remove the turbo and intercooler as we discussed earlier. Look at your manifold and determine if there are any other items that you need to remove before you can get to the manifold. About the only thing left to do is unbolt the manifold and remove it. Leave a bolt at each end of the manifold until last. This keeps it balanced until you are ready to lift it.

Be sure to support the manifold as you remove the final two bolts and lift the manifold off the engine. Larger manifolds require two people to lift them to prevent injury. Remove all of the old gasket material to prepare the manifold and head assembly for the installation of the manifold.

To reinstall the intake manifold, install new gaskets, lift the manifold into place, and start all of the bolts. It may help you to fabricate guide studs out to align the manifold to the head. Tighten them in the proper sequence and to the proper torque specification as described in the technical order or manufacturer manual. Install all of the components that you took off to remove the manifold.

Replacing the air cleaner

Air filters, (fig. 5–3) provide the engine with clean air necessary for combustion. Maintaining these filters is essential to the proper operation of the engine. Dirty air cleaners and filters can limit the amount of air allowed to flow to the engine. Replacing air filters at regular intervals makes sure that the engine operates at its peak capability. To replace the air filter, hold the elements and loosen the wing nuts on the retainer bar. Pull down slightly on the retainer bar and pivot the bar clockwise. Carefully remove filter elements and clean the air filter frame. Position the new filter elements in frame, making sure you position the arrow indicating airflow properly. It should point in the direction of the air flow. Pivot the retainer bar into place and slightly push it up then tighten the wing nuts finger tight.

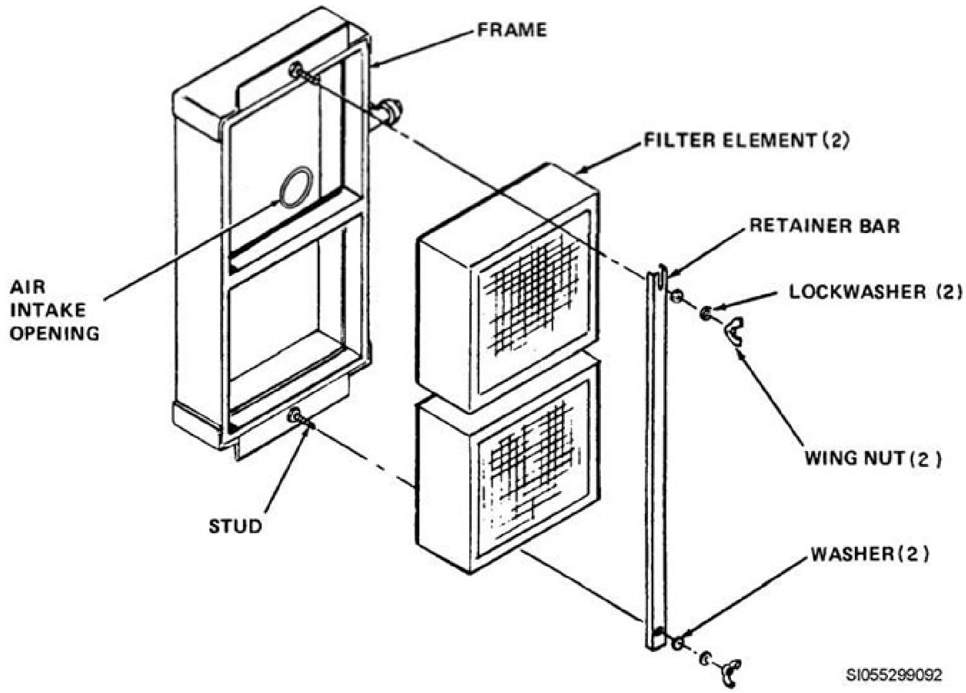


Figure 5–3. Air filters.

Replacing the exhaust manifold

Working on an exhaust system that has not properly cooled can cause third degree burns. You must use extreme caution when you do maintenance to the exhaust system.

Replacing the exhaust manifold (fig. 5–4) is very similar to replacing the intake manifold. You need to remove additional components before you can get to the manifold. The big questions for the exhaust system are, "Does this engine have a turbocharger?" and, "Is the exhaust system properly secured to support the weight after I disconnect the manifold?" If the answer to the second question is "No," you need to make arrangements to correct this. The weight that you apply to the exhaust manifold causes excessive stress and premature failure.

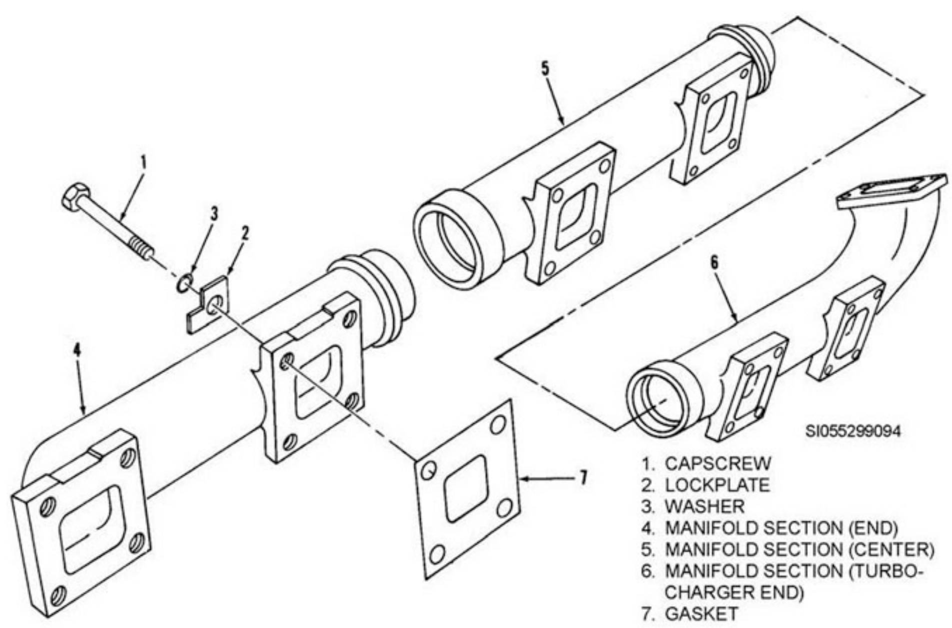


Figure 5–4. Exhaust manifold.

Start by removing and supporting all of the components connected to the manifold. Unbolt and lift the manifold from the head assembly. Remove the old gaskets and discard them.

To reinstall the exhaust manifold, install new gaskets, lift the manifold into place, and start all of the bolts. Tighten the bolts in the sequence and to the torque specifications that the technical order or manufacturer's manual specifies. Install all of the components you removed during the disassembly.

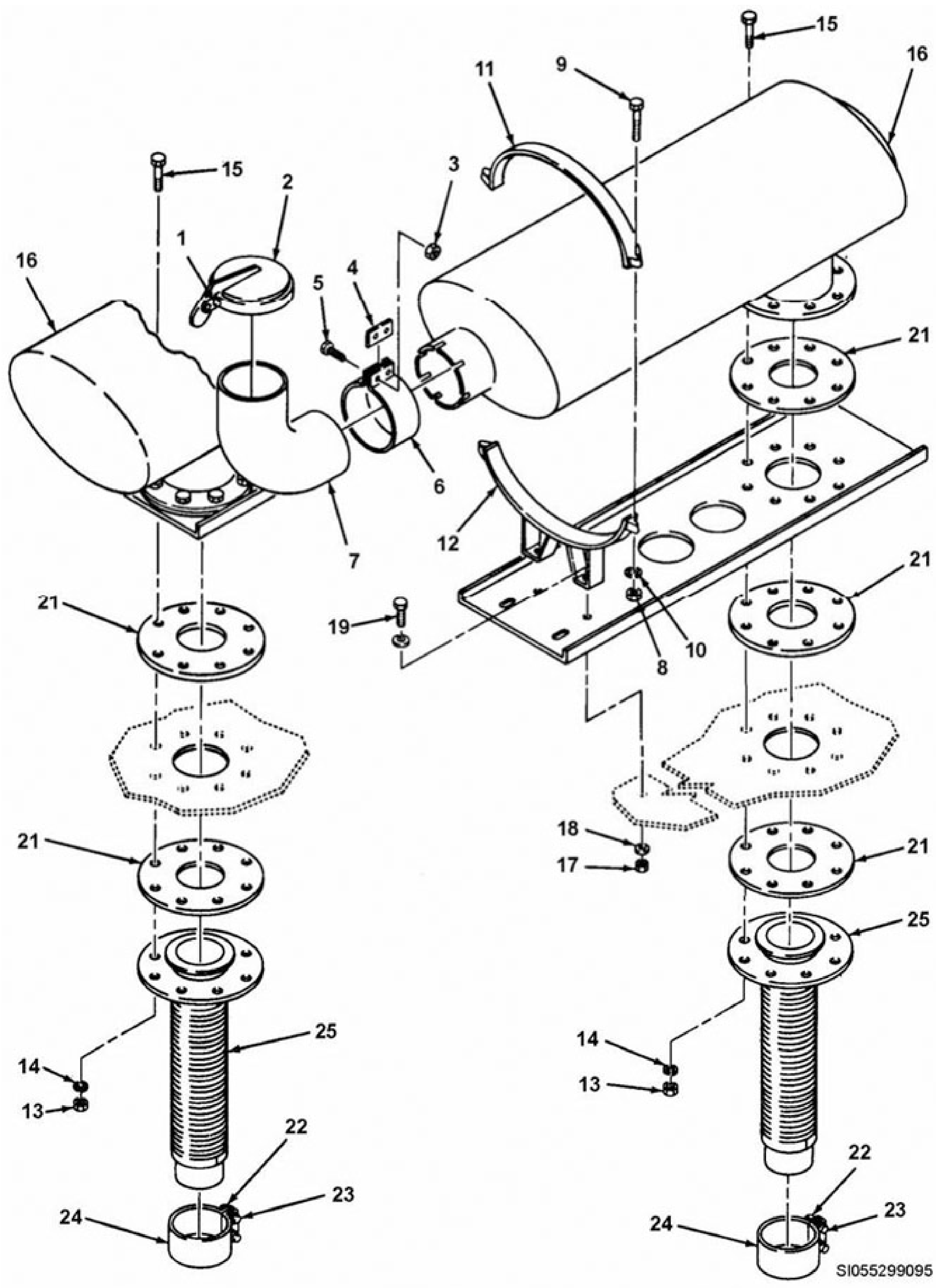
Replacing the exhaust

The exhaust system, (fig. 5–5) takes the burned gases from engine combustion to the atmosphere in a safe and quiet manner. The gases contain carbon monoxide that is deadly. It is essential to disperse these gases in a way that poses no threat to life. The exhaust system also quiets the engine noise that prevents damage to hearing. The exhaust system, like the exhaust manifold, gets very hot and can cause severe burns. Use extreme caution when you are working with it. Allow it to completely cool before you start maintenance.

To replace the exhaust system, you need to ask yourself more questions. "Is the exhaust system welded or bolted together?" "Will I need a hoist or forklift to support the muffler because of its weight?" These are things that you need to plan for before you start the work. Start by disabling the engine from starting off by removing the negative side of the battery. Next, remove the expansion joint by unbolting it from the exhaust manifold or turbocharger, if the engine is so equipped. You typically find the top of the expansion joint bolted to an elbow. Unbolt it and remove the expansion joint. Next, support the muffler and unbolt it or break the welds. Disassemble the muffler support system and remove the muffler. Remove any remaining exhaust piping.

To reinstall the exhaust system, piece the system back together, starting with the muffler. Be sure to properly align the muffler so that the expansion joint is directly over the connection point. Supporting the entire weight of the muffler is necessary to prevent overstressing the expansion joint and causing premature failure. Install new gaskets between each of the components that you bolt together. If you need to weld the system, make sure that there are no fuel vapors that could cause an explosion. Make sure to install the rain cap over the end of the piping to prevent water from entering the system. Start the engine and look for leaks, which you commonly find during startup because they show a puff of smoke or dust.

The key to being able to perform maintenance like you have just read about is have a full understanding of how the system works. This knowledge allows you to see the big picture of what you are doing. This big picture allows you to better understand why the steps in the instructions of the technical order fall in the order they do. Having the understanding of what you are working on allows you to complete that task much more quickly than someone that doesn't know the equipment. This could be the difference in meeting mission requirements or failing.



1. NUT
2. WEATHER CAP
3. FLANGE NUT
4. SPACER
5. FLANGED CAPSCREW
6. CLAMP
7. ELBOW
8. NUT
9. BOLT
10. WASHER
11. TOP MUFFLER BAND
12. BOTTOM MUFFLER BAND
13. NUT
14. LOCKWASHER
15. HEXAGON HEAD SCREW
16. MUFFLER
17. NUT
18. LOCKWASHER
19. HEXAGON HEAD SCREW
20. EXHAUST STIFFENER CHANNEL
21. EXHAUST GASKET
22. NUT
23. HEXAGON HEAD SCREW
24. CLAMP
25. EXHAUST FLEX PIPE

Figure 5–5. Exhaust system.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

428. Servicing intake and exhaust systems

1. How do you test the turbocharger for vibration?

2. What do you look for when looking at welded joints on an intercooler?

3. Where do you check for evidence of leaks on an exhaust system?

429. Replacing system components

1. What do you use to coat the turbine to the exhaust gasket when you install a new one?

2. How do you tighten the bolts when you are replacing an exhaust manifold?

3. Why is supporting the entire weight of the muffler necessary?

Answers to Self-Test Questions

426

1. (1) Condensed moisture.
   (2) Llubricating oil.
   (3) Fuel oil.
   (4) Foreign material gets into the air box.
2. Force as much air into the engine combustion chamber as possible.
3. Turbine housing, turbine wheel, compressor wheel, and common shaft.
4. From 10,000 to over 100,000 rpm.

427

1. Exhaust manifold.
2. Muffler.
3. Turbine side.

428

1. By placing the rod against the turbocharger housing while the engine is running.
2. Cracks or damage.
3. At the gaskets and connections.

429

1. A high temperature anti-seize compound and position the gasket on the exhaust manifold flange.
2. In the sequence and to the torque specifications that the TO or manufacturer's manual specifies.
3. To prevent overstressing the expansion joint and causing premature failure.

Complete the unit review exercises before going to the next unit.

Unit Review Exercises

Note to Student: Consider all choices carefully, select the *best* answer to each question, and *circle* the corresponding letter. When you have completed all unit review exercises, transfer your answers to the Field-Scoring Answer Sheet.

Do not return your answer sheet to the Air Force Career Development Academy (AFCDA).

86. (426) Which component do two stroke engines have that serves the same purpose as the intake manifold of four-stroke engines?
    a. Blower.
    b. Air box.
    c. Intercooler.
    d. Intake ports.

87. (426) At what speeds do turbochargers normally rotate?
    a. 5,000 to over 50,000 revolutions per minute (rpm).
    b. 10,000 to over 100,000 rpm.
    c. 25,000 to over 250,000 rpm.
    d. 50,000 to over 500,000 rpm.

88. (426) Identify the component that *increases* the density of the intake air and permits greater efficiency from the engine?
    a. Blower.
    b. Intercooler.
    c. Turbocharger.
    d. Intake manifold.

89. (427) The exhaust system component that consists of a series of perforated baffles within a cylindrical container is called
    a. silencer.
    b. turbocharger.
    c. expansion joint.
    d. exhaust manifold.

90. (427) How is exhaust piping connected?
    a. High temperature tape.
    b. Low temperature tape.
    c. Self-tapping screws.
    d. Welds or clamps.

91. (427) Which intake component directs air into the cylinders?
    a. Blower.
    b. Intercooler.
    c. Intake manifold.
    d. Turbocharger.

92. (427) Which part of a turbocharger do exhaust gases travel?
    a. Turbine.
    b. Bearings.
    c. Exhaust.
    d. Compressor.

93. (428) Which system has leaks that often create a whistling sound?
    a. Intake.
    b. Exhaust.
    c. Cooling.
    d. Lubrication.

94. (428) Which area is *not* part of inspecting an intercooler?
    a. Coolant level.
    b. Corrosion.
    c. Leaks.
    d. Cracks.

95. (428) In which component might you see leaks because of the carbon-colored discoloration of parts or surfaces adjacent to the leak?
    a. Blower.
    b. Intercooler.
    c. Intake manifold.
    d. Exhaust manifold.

96. (428) What is a *major* factor in erosion in the exhaust silencer?
    a. Acidity in the oil.
    b. Condensation in the air.
    c. Corrosive in the coolant.
    d. Contamination in the fuel oil.

97. (429) With what do you coat the exhaust gasket to the turbine before you position it on the exhaust manifold flange?
    a. Thin layer of grease.
    b. Lock tight compound.
    c. Abundant covering of diesel fuel.
    d. High temperature anti-seize compound.

98. (429) How much coolant *must* you drain from the cooling system to replace the intercooler?
    a. Completely.
    b. Below the level of the radiator.
    c. Below the level of the intercooler.
    d. Above the level of the turbocharger.

99. (429) How can you determine correct torque specification can be found when replacing an intake manifold?
    a. Ask your boss.
    b. Look it up on the internet.
    c. All intake manifold are torqued to 20 ft. lbs.
    d. Technical Order (TO) or manufacturers' manual.

100. (429) What can happen if you work on an exhaust system and it has *not* been allowed to cool?
    a. You can receive third degree burns.
    b. The exhaust component may crack.
    c. When torqued the bolts will back out.
    d. The mounting nuts and bolts will not be able to be removed.

Glossary

Abbreviations and Acronyms

AC	alternating current
API	American Petroleum Institute
BDC	bottom dead center
DC	direct current
DCA	diesel coolant additive
ECM	engine control module
ECU	electronic control unit
ELC	extended life coolant
MEP	mobile electric power
MPU	magnetic pickup
PSI	pounds per square inch
PT	pressure time
RPM	revolutions per minute
SAE	Society of Automotive Engineers
SOAP	Spectrometric Oil Analysis Program
TDC	top dead center
TO	technical order

Student Notes

Student Notes

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