Diesel Engine Fundamentals

Course No: M04-002
Credit: 4 PDH

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REFERENCES

- Benson & Whitehouse, <u>Internal Combustion Engines</u>, Pergamon.

- Cheremisinoff, N. P., <u>Fluid Flow, Pumps, Pipes and Channels</u>, Ann Arbor Science.

- Scheel, <u>Gas and Air Compression Machinery</u>, McGraw/Hill.

- Skrotzki and Vopat, <u>Steam and Gas Turbines</u>, McGraw/Hill.

- Stinson, Karl W., <u>Diesel Engineering Handbook</u>, Diesel Publications Incorporated.

DIESEL ENGINES

One of the most common prime movers is the diesel engine. Before gaining an understanding of how the engine operates a basic understanding of the engine's components must be gained. This chapter reviews the major components of a generic diesel engine.

EO 1.1   **DEFINE the following diesel engine terms:**

     a.   **Compression ratio**
     b.   **Bore**
     c.   **Stroke**
     d.   **Combustion chamber**

EO 1.2   **Given a drawing of a diesel engine, IDENTIFY the following:**

     a.   **Piston/rod**   **e.**   **Intake ports or valve(s)**
     b.   **Cylinder**   **f.**   **Exhaust ports or valve(s)**
     c.   **Blower**   **g.**   **Fuel injector**
     d.   **Crankshaft**

Introduction

Most DOE facilities require some type of prime mover to supply mechanical power for pumping, electrical power generation, operation of heavy equipment, and to act as a backup electrical generator for emergency use during the loss of the normal power source. Although several types of prime movers are available (gasoline engines, steam and gas turbines), the diesel engine is the most commonly used. Diesel engines provide a self-reliant energy source that is available in sizes from a few horsepower to 10,000 hp. Figure 1 provides an illustration of a common skid-mounted, diesel-driven generator. Relatively speaking, diesel engines are small, inexpensive, powerful, fuel efficient, and extremely reliable if maintained properly.

Because of the widespread use of diesel engines at DOE facilities, a basic understanding of the operation of a diesel engine will help ensure they are operated and maintained properly. Due to the large variety of sizes, brands, and types of engines in service, this module is intended to provide the fundamentals and theory of operation of a diesel engine. Specific information on a particular engine should be obtained from the vendor's manual.
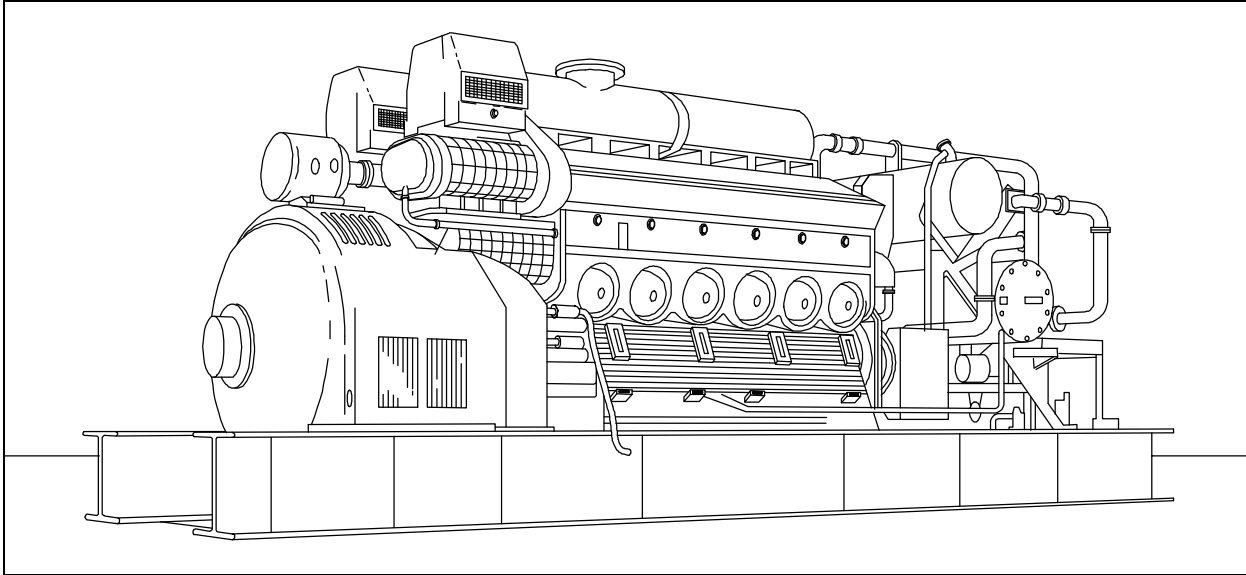
Figure 1 Example of a Large Skid-Mounted, Diesel-Driven Generator

History

The modern diesel engine came about as the result of the internal combustion principles first proposed by Sadi Carnot in the early 19th century. Dr. Rudolf Diesel applied Sadi Carnot's principles into a patented cycle or method of combustion that has become known as the "diesel" cycle. His patented engine operated when the heat generated during the compression of the air fuel charge caused ignition of the mixture, which then expanded at a constant pressure during the full power stroke of the engine.

Dr. Diesel's first engine ran on coal dust and used a compression pressure of 1500 psi to increase its theoretical efficiency. Also, his first engine did not have provisions for any type of cooling system. Consequently, between the extreme pressure and the lack of cooling, the engine exploded and almost killed its inventor. After recovering from his injuries, Diesel tried again using oil as the fuel, adding a cooling water jacket around the cylinder, and lowering the compression pressure to approximately 550 psi. This combination eventually proved successful. Production rights to the engine were sold to Adolphus Bush, who built the first diesel engines for commercial use, installing them in his St. Louis brewery to drive various pumps.

Diesel Engines

A diesel engine is similar to the gasoline engine used in most cars. Both engines are internal combustion engines, meaning they burn the fuel-air mixture within the cylinders. Both are reciprocating engines, being driven by pistons moving laterally in two directions. The majority of their parts are similar. Although a diesel engine and gasoline engine operate with similar components, a diesel engine, when compared to a gasoline engine of equal horsepower, is heavier due to stronger, heavier materials used to withstand the greater dynamic forces from the higher combustion pressures present in the diesel engine.

The greater combustion pressure is the result of the higher compression ratio used by diesel engines. The *compression ratio* is a measure of how much the engine compresses the gasses in the engine's cylinder. In a gasoline engine the compression ratio (which controls the compression temperature) is limited by the air-fuel mixture entering the cylinders. The lower ignition temperature of gasoline will cause it to ignite (burn) at a compression ratio of less than 10:1. The average car has a 7:1 compression ratio. In a diesel engine, compression ratios ranging from 14:1 to as high as 24:1 are commonly used. The higher compression ratios are possible because only air is compressed, and then the fuel is injected. This is one of the factors that allows the diesel engine to be so efficient. Compression ratio will be discussed in greater detail later in this module.

Another difference between a gasoline engine and a diesel engine is the manner in which engine speed is controlled. In any engine, speed (or power) is a direct function of the amount of fuel burned in the cylinders. Gasoline engines are self-speed-limiting, due to the method the engine uses to control the amount of air entering the engine. Engine speed is indirectly controlled by the butterfly valve in the carburetor. The butterfly valve in a carburetor limits the amount of air entering the engine. In a carburetor, the rate of air flow dictates the amount of gasoline that will be mixed with the air. Limiting the amount of air entering the engine limits the amount of fuel entering the engine, and, therefore, limits the speed of the engine. By limiting the amount of air entering the engine, adding more fuel does not increase engine speed beyond the point where the fuel burns 100% of the available air (oxygen).

Diesel engines are not self-speed-limiting because the air (oxygen) entering the engine is always the maximum amount. Therefore, the engine speed is limited solely by the amount of fuel injected into the engine cylinders. Therefore, the engine always has sufficient oxygen to burn and the engine will attempt to accelerate to meet the new fuel injection rate. Because of this, a manual fuel control is not possible because these engines, in an unloaded condition, can accelerate at a rate of more than 2000 revolutions per second. Diesel engines require a speed limiter, commonly called the governor, to control the amount of fuel being injected into the engine.

Unlike a gasoline engine, a diesel engine does not require an ignition system because in a diesel engine the fuel is injected into the cylinder as the piston comes to the top of its compression stroke. When fuel is injected, it vaporizes and ignites due to the heat created by the compression of the air in the cylinder.

Major Components of a Diesel Engine

To understand how a diesel engine operates, an understanding of the major components and how they work together is necessary. Figure 2 is an example of a medium-sized, four-stroke, supercharged, diesel engine with inlet ports and exhaust valves. Figure 3 provides a cross section of a similarly sized V-type diesel engine.
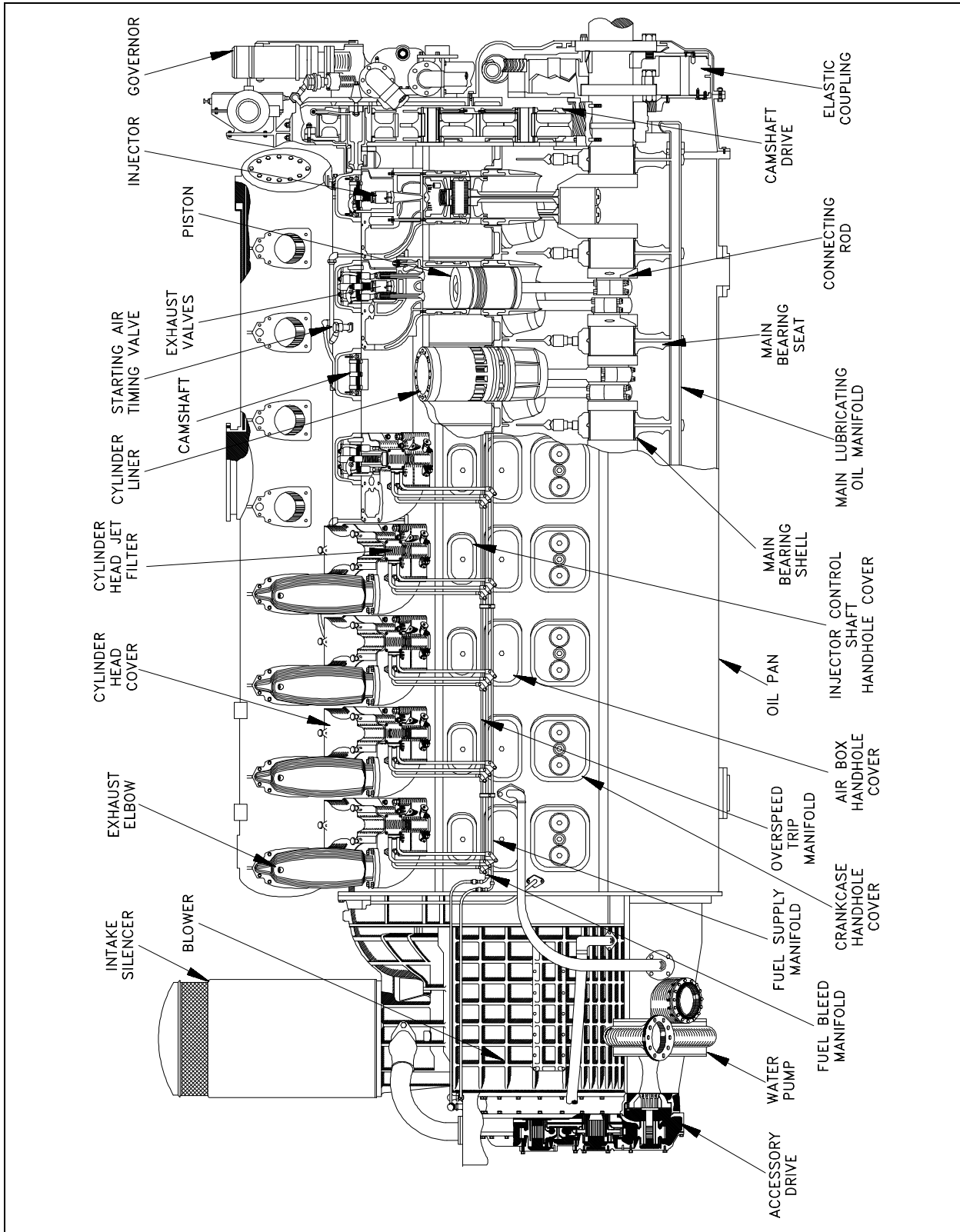
Figure 2 Cutaway of a GM V-16 Four-Stroke Supercharged Diesel Engine
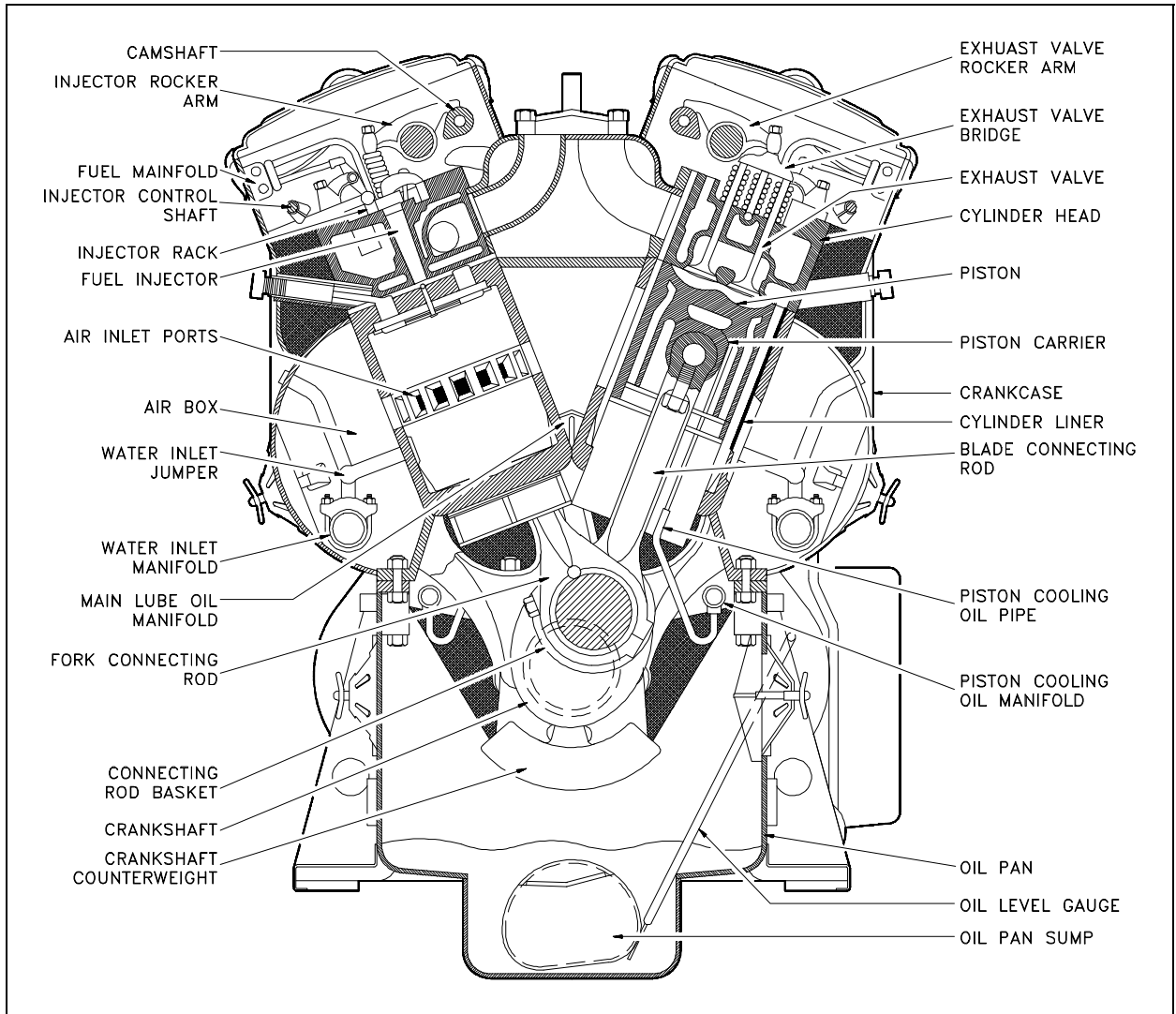
Figure 3 Cross Section of a V-type Four Stroke Diesel Engine

The Cylinder Block

The cylinder block, as shown in Figure 4, is generally a single unit made from cast iron. In a liquid-cooled diesel, the block also provides the structure and rigid frame for the engine's cylinders, water coolant and oil passages, and support for the crankshaft and camshaft bearings.
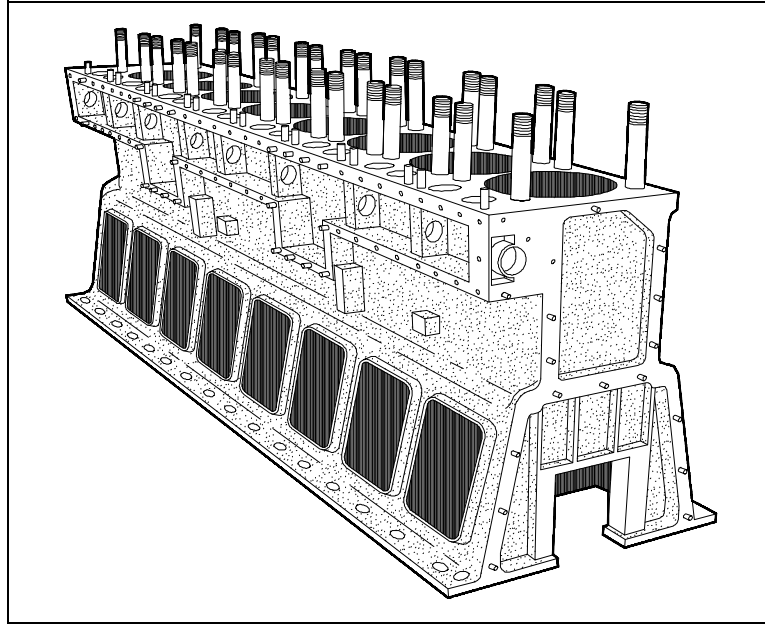

Figure 4 The Cylinder Block

Crankcase and Oil Pan

The *crankcase* is usually located on the bottom of the cylinder block. The crankcase is defined as the area around the crankshaft and crankshaft bearings. This area encloses the rotating crankshaft and crankshaft counter weights and directs returning oil into the oil pan. The oil pan is located at the bottom of the crankcase as shown in Figure 2 and Figure 3. The *oil pan* collects and stores the engine's supply of lubricating oil. Large diesel engines may have the oil pan divided into several separate pans.

Cylinder Sleeve or Bore

Diesel engines use one of two types of cylinders. In one type, each cylinder is simply machined or bored into the block casting, making the block and cylinders an integral part. In the second type, a machined steel sleeve is pressed into the block casting to form the cylinder. Figure 2 and Figure 3 provide examples of sleeved diesel engines. With either method, the *cylinder sleeve* or *bore* provides the engine with the cylindrical structure needed to confine the combustion gasses and to act as a guide for the engine's pistons.

In engines using sleeves, there are two types of sleeves, wet and dry. A dry sleeve is surrounded by the metal of the block and does not come in direct contact with the engine's coolant (water). A wet sleeve comes in direct contact with the engine's coolant. Figure 5 provides an example of a wet sleeve. The volume enclosed by the sleeve or bore is called the combustion chamber and is the space where the fuel is burned.

In either type of cylinder, sleeved or bored, the diameter of the cylinder is called the bore of the engine and is stated in inches. For example, the bore of a 350 cubic inch Chevrolet gasoline engine is 4 inches.
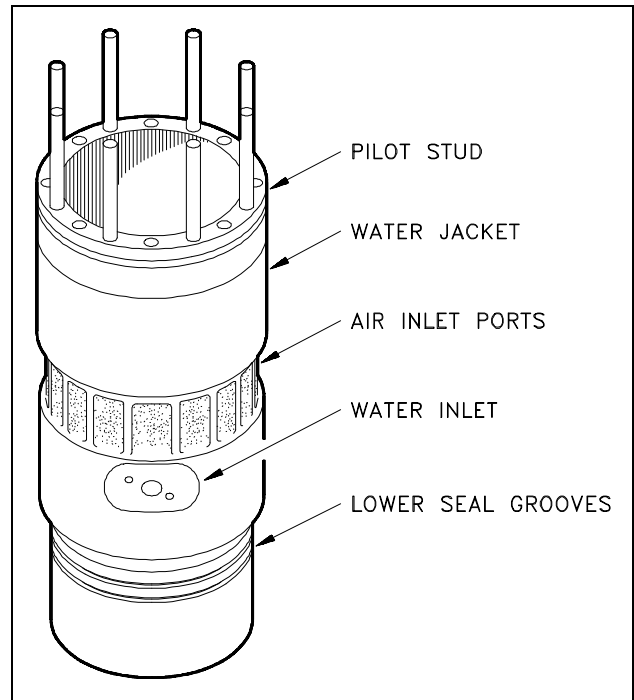
Most diesel engines are multi-cylinder engines and typically have their cylinders arranged in one of two

Figure 5 Diesel Engine Wet Cylinder Sleeve

ways, an in-line or a "V", although other combinations exits. In an in-line engine, as the name indicates, all the cylinders are in a row. In a "V" type engine the cylinders are arranged in two rows of cylinders set at an angle to each other that align to a common crankshaft. Each group of cylinders making up one side of the "V" is referred to as a bank of cylinders.

Piston and Piston Rings

The *piston* transforms the energy of the expanding gasses into mechanical energy. The piston rides in the cylinder liner or sleeve as shown in Figure 2 and Figure 3. Pistons are commonly made of aluminum or cast iron alloys.

To prevent the combustion gasses from bypassing the piston and to keep friction to a minimum, each piston has several metal rings around it, as illustrated by Figure 6.
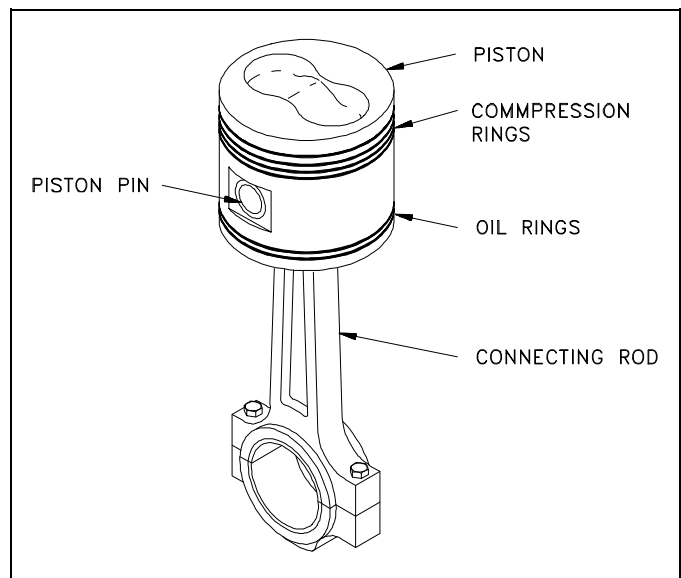
Figure 6 Piston and Piston Rod

These rings function as the seal between the piston and the cylinder wall and also act to reduce friction by minimizing the contact area between the piston and the cylinder wall. The rings are usually made of cast iron and coated with chrome or molybdenum. Most diesel engine pistons have several rings, usually 2 to 5, with each ring performing a distinct function. The top ring(s) acts primarily as the pressure seal. The intermediate ring(s) acts as a wiper ring to remove and control the amount of oil film on the cylinder walls. The bottom ring(s) is an oiler ring and ensures that a supply of lubricating oil is evenly deposited on the cylinder walls.

Connecting Rod

The *connecting rod* connects the piston to the crankshaft. See Figure 2 and Figure 3 for the location of the connecting rods in an engine. The rods are made from drop-forged, heat-treated steel to provide the required strength. Each end of the rod is bored, with the smaller top bore connecting to the piston pin (wrist pin) in the piston as shown in Figure 6. The large bore end of the rod is split in half and bolted to allow the rod to be attached to the crankshaft. Some diesel engine connecting rods are drilled down the center to allow oil to travel up from the crankshaft and into the piston pin and piston for lubrication.

A variation found in V-type engines that affects the connecting rods is to position the cylinders in the left and right banks directly opposite each other instead of staggered (most common configuration). This arrangement requires that the connecting rods of two opposing cylinders share the same main journal bearing on the crankshaft. To allow this configuration, one of the connecting rods must be split or forked around the other.

Crankshaft

The *crankshaft* transforms the linear motion of the pistons into a rotational motion that is transmited to the load. Crankshafts are made of forged steel. The forged crankshaft is machined to produce the crankshaft bearing and connecting rod bearing surfaces. The rod bearings are eccentric, or offset, from the center of the crankshaft as illustrated in Figure 7. This offset converts the reciprocating (up and down) motion of the piston into the rotary motion of the crankshaft. The amount of offset determines the stroke (distance the piston travels) of the engine (discussed later).

The crankshaft does not ride directly on the cast iron block crankshaft supports, but rides on special bearing material as shown in Figure 7. The connecting rods also have bearings inserted between the crankshaft and the connecting rods. The bearing material is a soft alloy of metals that provides a replaceable wear surface and prevents galling between two similar metals (i.e., crankshaft and connecting rod). Each bearing is split into halves to allow assembly of the engine. The crankshaft is drilled with oil passages that allow the engine to feed oil to each of the crankshaft bearings and connection rod bearings and up into the connecting rod itself.

The crankshaft has large weights, called counter weights, that balance the weight of the connecting rods. These weights ensure an even (balance) force during the rotation of the moving parts.
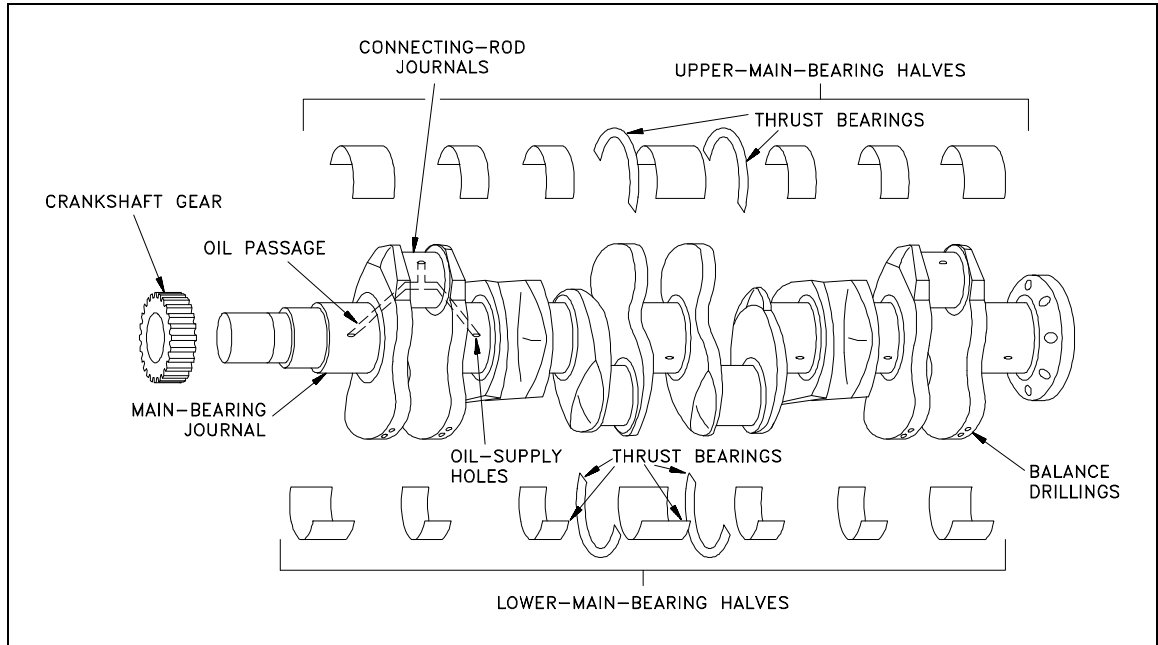
Figure 7 Diesel Engine Crankshaft and Bearings

Flywheel

The *flywheel* is located on one end of the crankshaft and serves three purposes. First, through its inertia, it reduces vibration by smoothing out the power stroke as each cylinder fires. Second, it is the mounting surface used to bolt the engine up to its load. Third, on some diesels, the flywheel has gear teeth around its perimeter that allow the starting motors to engage and crank the diesel.

Cylinder Heads and Valves

A diesel engine's *cylinder heads* perform several functions. First, they provide the top seal for the cylinder bore or sleeve. Second, they provide the structure holding exhaust valves (and intake valves where applicable), the fuel injector, and necessary linkages. A diesel engine's heads are manufactured in one of two ways. In one method, each cylinder has its own head casting, which is bolted to the block. This method is used primarily on the larger diesel engines. In the second method, which is used on smaller engines, the engine's head is cast as one piece (multi-cylinder head).

Diesel engines have two methods of admitting and exhausting gasses from the cylinder. They can use either ports or valves or a combination of both. *Ports* are slots in the cylinder walls located in the lower 1/3 of the bore. See Figure 2 and Figure 3 for examples of intake ports, and note their relative location with respect to the rest of the

engine. When the piston travels below the level of the ports, the ports are "opened" and fresh air or exhaust gasses are able to enter or leave, depending on the type of port.

The ports are then "closed" when the piston travels back above the level of the ports. *Valves* (refer to figure 8) are mechanically opened and closed to admit or exhaust the gasses as needed. The valves are located in the head casting of the engine. The point at which the valve seals against the head is called the *valve seat*. Most medium-sized diesels have either intake ports or exhaust valves or both intake and exhaust valves.

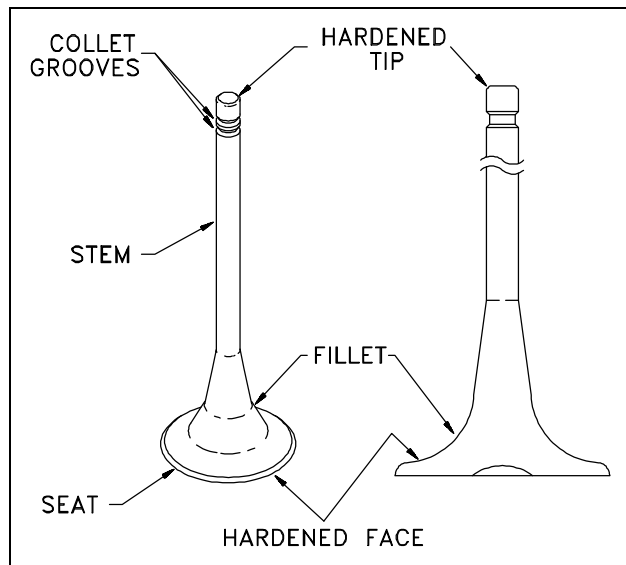## Timing Gears, Camshaft, and Valve Mechanism

Figure 8 Diesel Engine Valve

In order for a diesel engine to operate, all of its components must perform their functions at very precise intervals in relation to the motion of the piston. To accomplish this, a component called a *camshaft* is used. Figure 9 illustrates a camshaft and camshaft drive gear. Figure 2 and Figure 3 illustrate the location of a camshaft in a large overhead cam diesel engine.

A camshaft is a long bar with egg-shaped eccentric lobes, one lobe for each valve and fuel injector (discussed later). Each lobe has a follower as shown on Figure 10. As the camshaft is rotated, the follower is forced up and down as it follows the profile of the cam lobe. The followers are connected to the engine's valves and fuel injectors through various types of linkages called *pushrods* and *rocker arms*. The
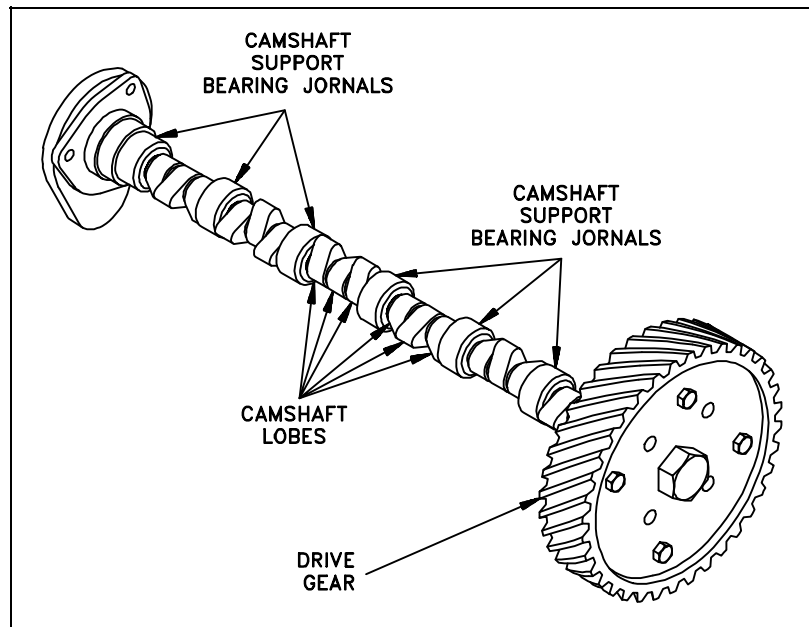
Figure 9 Diesel Engine Camshaft and Drive Gear

pushrods and rocker arms transfer the reciprocating motion generated by the camshaft lobes to the valves and injectors, opening and closing them as needed. The valves are maintained closed by springs.

As the valve is opened by the camshaft, it compresses the valve spring. The energy stored in the valve spring is then used to close the valve as the camshaft lobe rotates out from under the follower. Because an engine experiences fairly large changes in temperature (e.g., ambient to a normal running temperature of about 190°F), its components must be designed to allow for thermal expansion. Therefore, the valves, valve pushrods, and rocker arms must have some method of allowing for the expansion. This is accomplished by the use of valve lash. *Valve lash* is the term given to the "slop" or "give" in the valve train before the cam actually starts to open the valve.

The camshaft is driven by the engine's crankshaft through a series of gears called idler gears and timing gears. The gears allow the rotation of the camshaft to correspond or be in time with, the rotation of the crankshaft and thereby allows the valve opening, valve closing, and injection of fuel to be timed to occur at precise intervals in the piston's travel. To increase the flexibility in timing the valve opening, valve closing, and injection of fuel, and to increase power or to reduce cost, an engine may have one or more camshafts. Typically,
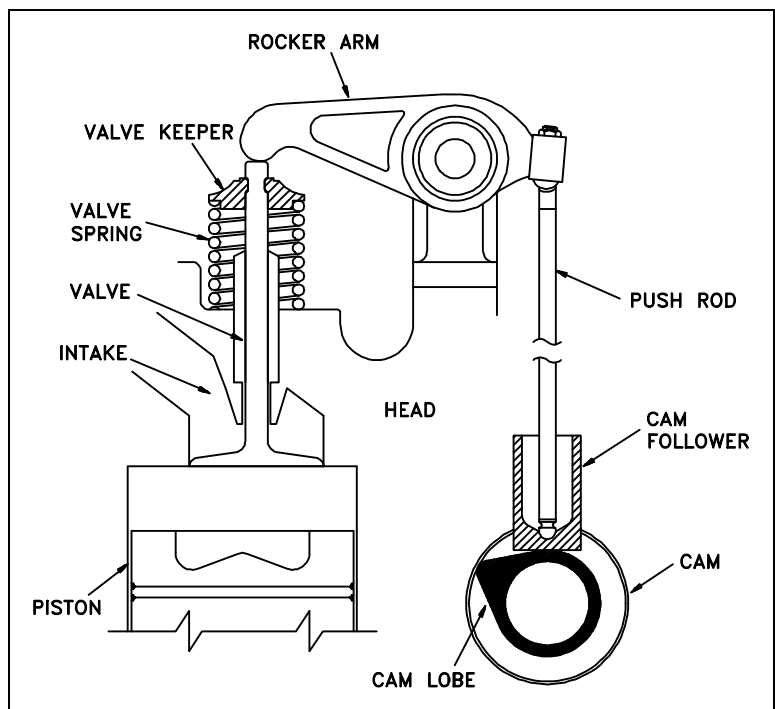

Figure 10 Diesel Engine Valve Train

in a medium to large V-type engine, each bank will have one or more camshafts per head. In the larger engines, the intake valves, exhaust valves, and fuel injectors may share a common camshaft or have independent camshafts.

Depending on the type and make of the engine, the location of the camshaft or shafts varies. The camshaft(s) in an in-line engine is usually found either in the head of the engine or in the top of the block running down one side of the cylinder bank. Figure 10 provides an example of an engine with the camshaft located on the side of the engine. Figure 3 provides an example of an overhead cam arrangement as on a V-type engine. On small or mid-sized V-type engines, the camshaft is usually located in the block at the

center of the "V" between the two banks of cylinders. In larger or multi-camshafted V-type engines, the camshafts are usually located in the heads.

Blower

The diesel engine's *blower* is part of the air intake system and serves to compress the incoming fresh air for delivery to the cylinders for combustion. The location of the blower is shown on Figure 2. The blower can be part of either a turbocharged or supercharged air intake system. Additional information on these two types of blowers is provided later in this module.

Diesel Engine Support Systems

A diesel engine requires five supporting systems in order to operate: cooling, lubrication, fuel injection, air intake, and exhaust. Depending on the size, power, and application of the diesel, these systems vary in size and complexity.

Engine Cooling

Nearly all diesel engines rely on a liquid cooling system to transfer waste heat out of the block and internals as shown in Figure 11. The cooling system consists of a closed loop similar to that of a car engine and contains the following major components: water pump, radiator or heat exchanger, water jacket (which consists of coolant passages in the block and heads), and a thermostat.
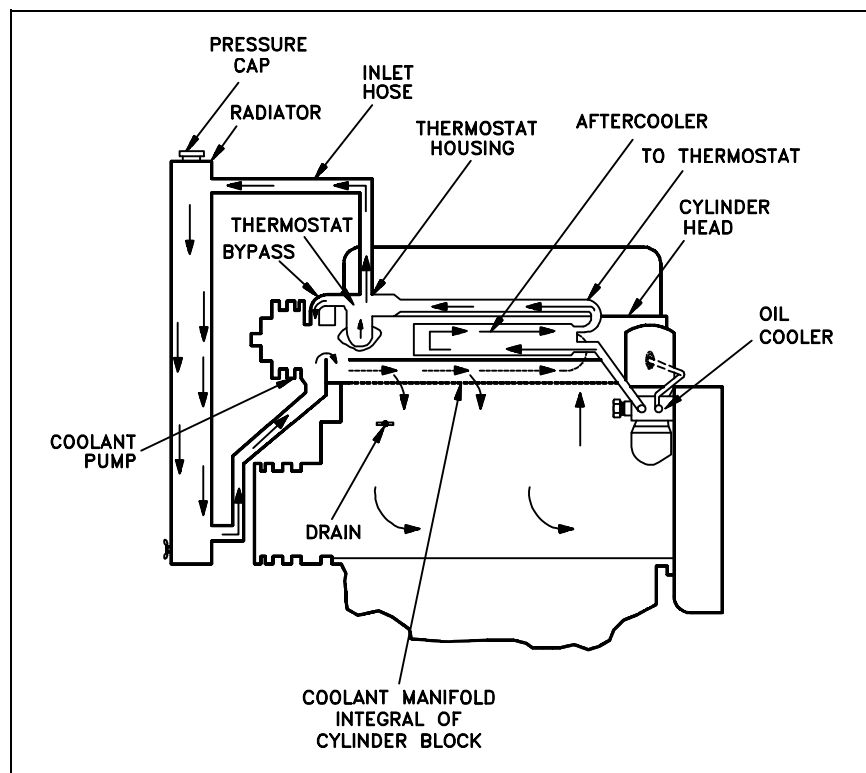

Figure 11 Diesel Engine Cooling System

Engine Lubrication

An internal combustion engine would not run for even a few minutes if the moving parts were allowed to make metal-to-metal contact. The heat generated due to the tremendous amounts of friction would melt the metals, leading to the destruction of the engine. To prevent this, all moving parts ride on a thin film of oil that is pumped between all the moving parts of the engine.

Once between the moving parts, the oil serves two purposes. One purpose is to lubricate the bearing surfaces. The other purpose is to cool the bearings by absorbing the friction-generated heat. The flow of oil to the moving parts is accomplished by the engine's internal lubricating system.
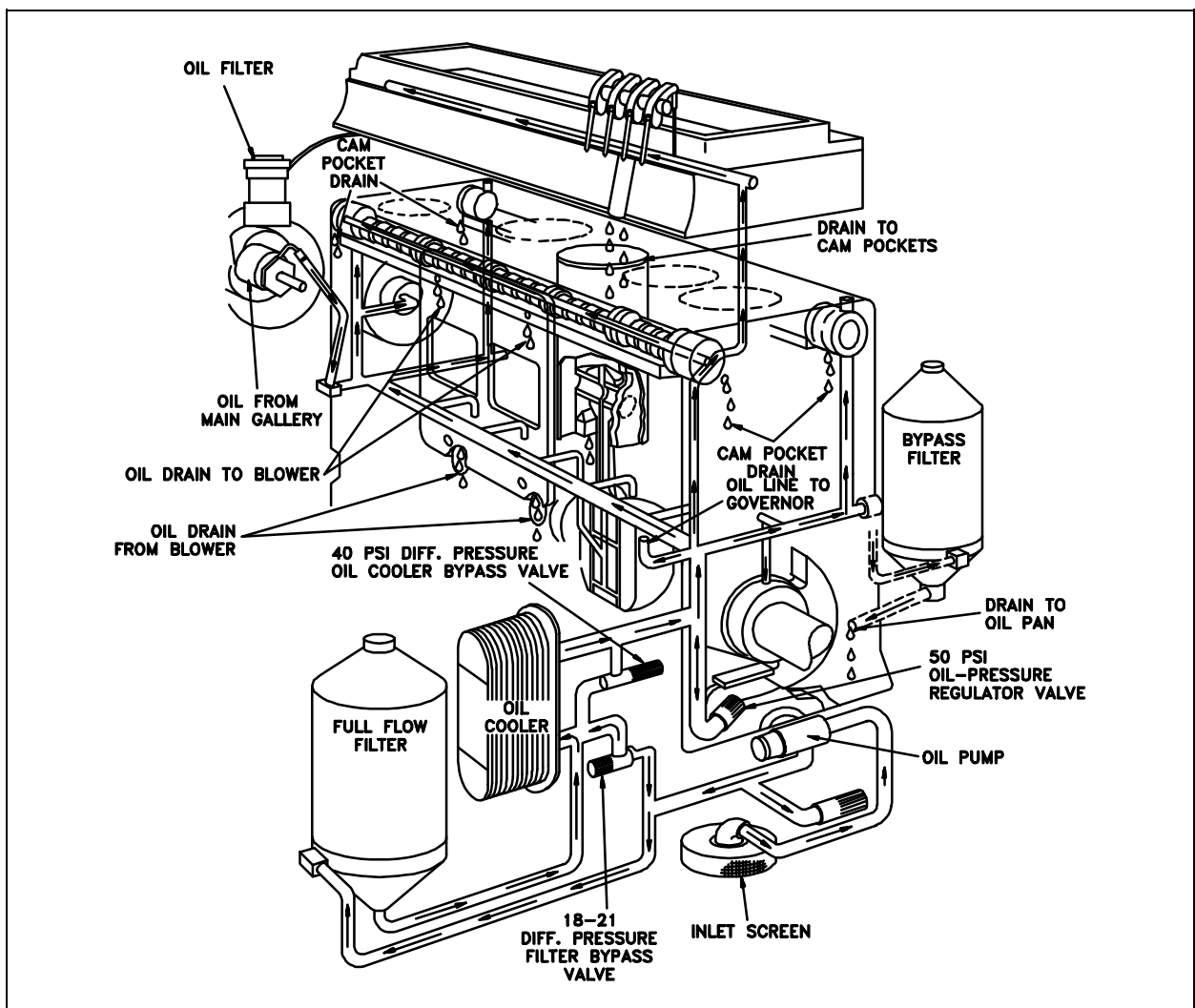
Figure 12 Diesel Engine Internal Lubrication System

Oil is accumulated and stored in the engine's oil pan where one or more oil pumps take a suction and pump the oil through one or more oil filters as shown in Figure 12. The filters clean the oil and remove any metal that the oil has picked up due to wear. The cleaned oil then flows up into the engine's oil galleries. A pressure relief valve(s) maintains oil pressure in the galleries and returns oil to the oil pan upon high pressure. The oil galleries distribute the oil to all the bearing surfaces in the engine.

Once the oil has cooled and lubricated the bearing surfaces, it flows out of the bearing and gravity-flows back into the oil pan. In medium to large diesel engines, the oil is also cooled before being distributed into the block. This is accomplished by either an internal or external oil cooler. The lubrication system also supplies oil to the engine's governor, which is discussed later in this module.

Fuel System

All diesel engines require a method to store and deliver fuel to the engine. Because diesel engines rely on injectors which are precision components with extremely tight tolerances and very small injection hole(s), the fuel delivered to the engine must be extremely clean and free of contaminants.

The fuel system must, therefore, not only deliver the fuel but also ensure its cleanliness. This is usually accomplished through a series of in-line filters. Commonly, the fuel will be filtered once outside the engine and then the fuel will pass through at least one more filter internal to the engine, usually located in the fuel line at each fuel injector.

In a diesel engine, the fuel system is much more complex than the fuel system on a simple gasoline engine because the fuel serves two purposes. One purpose is
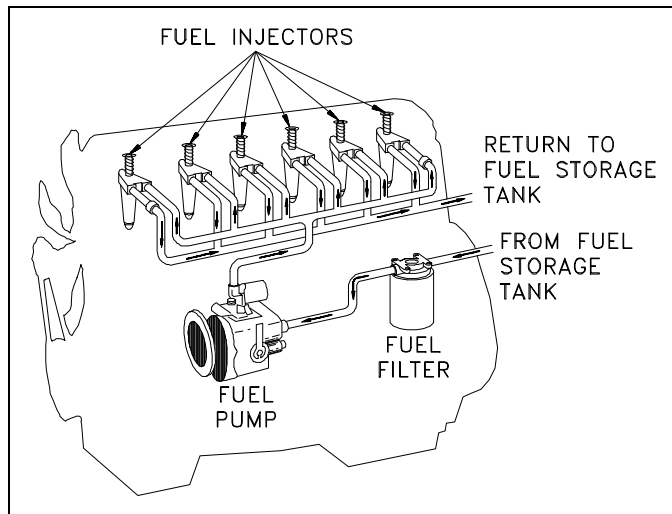
Figure 13 Diesel Engine Fuel Flowpath

obviously to supply the fuel to run the engine; the other is to act as a coolant to the injectors. To meet this second purpose, diesel fuel is kept continuously flowing through the engine's fuel system at a flow rate much higher than required to simply run the engine, an example of a fuel flowpath is shown in Figure 13. The excess fuel is routed back to the fuel pump or the fuel storage tank depending on the application.

Air Intake System

Because a diesel engine requires close tolerances to achieve its compression ratio, and because most diesel engines are either turbocharged or supercharged, the air entering the engine must be clean, free of debris, and as cool as possible. Turbocharging and supercharging are discussed in more detail later in this chapter. Also, to improve a turbocharged or supercharged engine's efficiency, the compressed air must be cooled after being compressed. The air intake system is designed to perform these tasks.

Air intake systems vary greatly from vendor to vendor but are usually one of two types, wet or dry. In a wet filter intake system, as shown in Figure 14, the air is sucked or bubbled through a housing that holds a bath of oil such that the dirt in the air is removed by the oil in the filter. The air then flows through a screen-type material to ensure any entrained oil is removed from the air. In a dry filter system, paper, cloth, or a metal screen material is used to catch and trap dirt before it enters the engine (similar to the type used in automobile engines).

In addition to cleaning the air, the intake system is usually designed to intake fresh air from as far away from the engine as practicable, usually just outside of the engine's building or enclosure. This provides the engine with a supply of air that has not been heated by the engine's own waste heat.
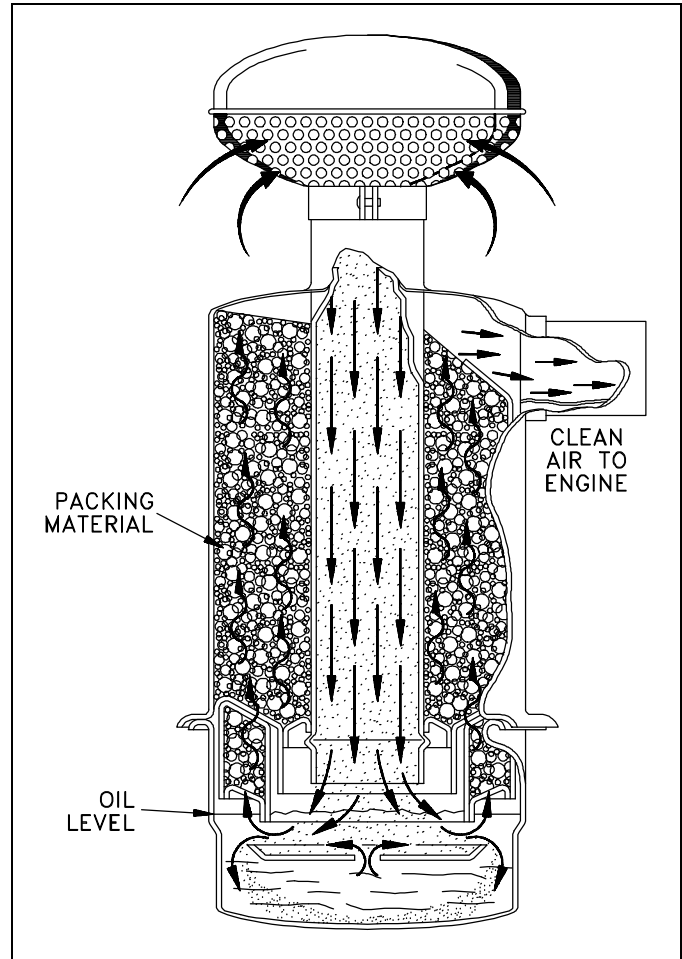

Figure 14 Oil Bath Air Filter

The reason for ensuring that an engine's air supply is as cool as possible is that cool air is more dense than hot air. This means that, per unit volume, cool air has more oxygen than hot air. Thus, cool air provides more oxygen per cylinder charge than less dense, hot air. More oxygen means a more efficient fuel burn and more power.

After being filtered, the air is routed by the intake system into the engine's intake manifold or air box. The manifold or air box is the component that directs the fresh air to each of the engine's intake valves or ports.   If the engine is turbocharged or supercharged, the fresh air will be compressed with a blower and possibly cooled before entering the intake manifold or air box. The intake system also serves to reduce the air flow noise.

Turbocharging

Turbocharging an engine occurs when the engine's own exhaust gasses are forced through a turbine (impeller), which rotates and is connected to a second impeller located in the fresh air intake system. The impeller in the fresh air intake system compresses the fresh air. The compressed air serves two functions. First, it increases the engine's available power by increasing the maximum amount of air (oxygen) that is forced into each cylinder. This allows more fuel to be injected and more power to be produced by the engine. The second function is to increase intake pressure. This improves the scavenging of the exhaust gasses out of the cylinder. Turbocharging is commonly found on high power four-stroke engines. It can also be used on two-stroke engines where the increase in intake pressure generated by the turbocharger is required to force the fresh air charge into the cylinder and help force the exhaust gasses out of the cylinder to enable the engine to run.

Supercharging

Supercharging an engine performs the same function as turbocharging an engine. The difference is the source of power used to drive the device that compresses the incoming fresh air. In a supercharged engine, the air is commonly compressed in a device called a blower. The blower is driven through gears directly from the engines crankshaft. The most common type of blower uses two rotating rotors to compress the air.   Supercharging is more commonly found on two-stroke engines where the higher pressures that a supercharger is capable of generating are needed.

Exhaust System

The exhaust system of a diesel engine performs three functions. First, the exhaust system routes the spent combustion gasses away from the engine, where they are diluted by the atmosphere. This keeps the area around the engine habitable. Second, the exhaust system confines and routes the gasses to the turbocharger, if used. Third, the exhaust system allows mufflers to be used to reduce the engine noise.

Operational Terminology

Before a detailed operation of a diesel engine can be explained, several terms must be defined.

Bore and Stroke

Bore and stroke are terms used to define the size of an engine. As previously stated, *bore* refers to the diameter of the engine's cylinder, and *stroke* refers to the distance the piston travels from the top of the cylinder to the bottom. The highest point of travel by the piston is called *top dead center* (TDC), and the lowest point of travel is called *bottom dead center* (BDC). There are 180° of travel between TDC and BDC, or one stroke.

Engine Displacement

Engine displacement is one of the terms used to compare one engine to another. *Displacement* refers to the total volume displaced by all the pistons during one stroke. The displacement is usually given in cubic inches or liters. To calculate the displacement of an engine, the volume of one cylinder must be determined (volume of a cylinder = $(\pi r^2)h$ where h = the stroke). The volume of one cylinder is multiplied by the number of cylinders to obtain the total engine displacement.

Degree of Crankshaft Rotation

All events that occur in an engine are related to the location of the piston. Because the piston is connected to the crankshaft, any location of the piston corresponds directly to a specific number of degrees of crankshaft rotation.

Location of the crank can then be stated as XX degrees before or XX degrees after top or bottom dead center.

Firing Order

Firing order refers to the order in which each of the cylinders in a multicylinder engine fires (power stroke). For example, a four cylinder engine's firing order could be 1-4-3-2. This means that the number 1 cylinder fires, then the number 4 cylinder fires, then the number 3 cylinder fires, and so on. Engines are designed so that the power strokes are as uniform as possible, that is, as the crankshaft rotates a certain number of degrees, one of the cylinders will go through a power stroke. This reduces vibration and allows the power generated by the engine to be applied to the load in a smoother fashion than if they were all to fire at once or in odd multiples.

Compression Ratio and Clearance Volume

Clearance volume is the volume remaining in the cylinder when the piston is at TDC. Because of the irregular shape of the combustion chamber (volume in the head) the clearance volume is calculated empirically by filling the chamber with a measured amount of fluid while the piston is at TDC. This volume is then added to the displacement volume in the cylinder to obtain the cylinders total volume.

An engine's *compression ratio* is determined by taking the volume of the cylinder with piston at TDC (highest point of travel) and dividing the volume of the cylinder when the piston is at BDC (lowest point of travel), as shown in Figure 15. This can be calculated by using the following formula:

$$\text{Compression Ratio} = \frac{\text{displacement volume} + \text{clearance volume}}{\text{clearance volume}}$$
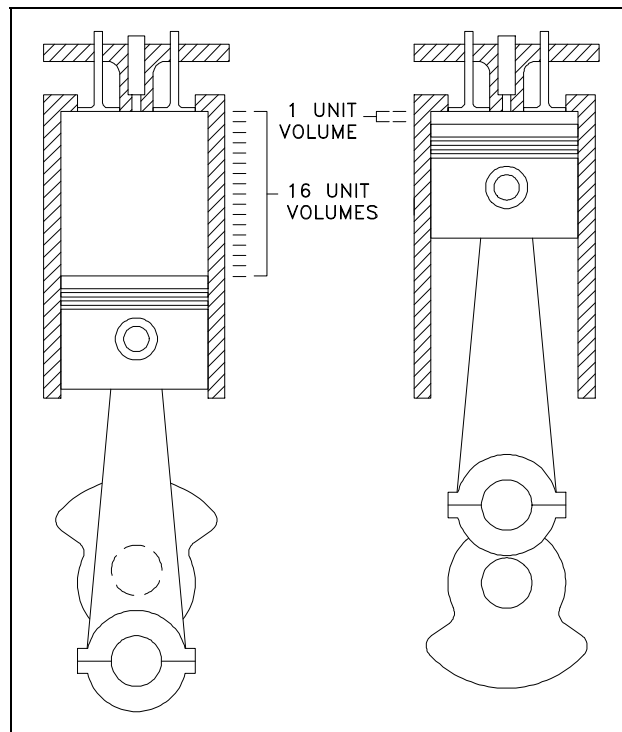

Figure 15 Compression Ratio

Horsepower

Power is the amount of work done per unit time or the rate of doing work. For a diesel engine, power is rated in units of horsepower. *Indicated horsepower* is the power transmitted to the pistons by the gas in the cylinders and is mathematically calculated.

Brake horsepower refers to the amount of usable power delivered by the engine to the crankshaft. Indicated horsepower can be as much as 15% higher than brake horsepower. The difference is due to internal engine friction, combustion inefficiencies, and parasitic losses, for example, oil pump, blower, water pump, etc.

The ratio of an engine's brake horsepower and its indicated horsepower is called the *mechanical efficiency* of the engine. The mechanical efficiency of a four-cycle diesel is about 82 to 90 percent. This is slightly lower than the efficiency of the two-cycle diesel engine. The lower mechanical efficiency is due to the additional friction losses and power needed to drive the piston through the extra 2 strokes.

Engines are rated not only in horsepower but also by the torque they produce. *Torque* is a measure of the engine's ability to apply the power it is generating. Torque is commonly given in units of lb-ft.

Summary

The important information in this chapter is summarized below.

Diesel Engines Summary

- The compression ratio is the volume of the cylinder with piston at TDC divided by the volume of the cylinder with piston at BDC.

- Bore is the diameter of the cylinder.

- Stroke is the distance the piston travels from TDC to BDC, and is determined by the eccentricity of the crankshaft.

- The combustion chamber is the volume of space where the fuel air mixture is burned in an engine. This is in the cylinder of the engine.

- The following components were discussed and identified on a drawing.

  a. Piston and rod
  b. Cylinder
  c. Blower
  d. Crankshaft
  e. Intake ports or valve(s)
  f. Exhaust ports or valve(s)
  g. Fuel injector

FUNDAMENTALS OF THE DIESEL CYCLE

Diesel engines operate under the principle of the internal combustion engine. There are two basic types of diesel engines, two-cycle and four-cycle. An understanding of how each cycle operates is required to understand how to correctly operate and maintain a diesel engine.

EO 1.3   **EXPLAIN how a diesel engine converts the chemical energy stored in the diesel fuel into mechanical energy.**

EO 1.4   **EXPLAIN how the ignition process occurs in a diesel engine.**

EO 1.5   **EXPLAIN the operation of a 4-cycle diesel engine, including when the following events occur during a cycle:**

      a.   **Intake**
      b.   **Exhaust**
      c.   **Fuel injection**
      d.   **Compression**
      e.   **Power**

EO 1.6   **EXPLAIN the operation of a 2-cycle diesel engine, including when the following events occur during a cycle:**

      a.   **Intake**
      b.   **Exhaust**
      c.   **Fuel injection**
      d.   **Compression**
      e.   **Power**

The Basic Diesel Cycles

A diesel engine is a type of heat engine that uses the internal combustion process to convert the energy stored in the chemical bonds of the fuel into useful mechanical energy. This occurs in two steps. First, the fuel reacts chemically (burns) and releases energy in the form of heat. Second the heat causes the gasses trapped in the cylinder to expand, and the expanding gases, being confined by the cylinder, must move the piston to expand. The reciprocating motion of the piston is then converted into rotational motion by the crankshaft.

To convert the chemical energy of the fuel into useful mechanical energy all internal combustion engines must go through four events: intake, compression, power, and exhaust. How these events are timed and how they occur differentiates the various types of engines.

All diesel engines fall into one of two categories, two-stroke or four-stroke cycle engines. The word cycle refers to any operation or series of events that repeats itself. In the case of a four-stroke cycle engine, the engine requires four strokes of the piston (intake, compression, power, and exhaust) to complete one full cycle. Therefore, it requires two rotations of the crankshaft, or 720° of crankshaft rotation (360° x 2) to complete one cycle. In a two-stroke cycle engine the events (intake, compression, power, and exhaust) occur in only one rotation of the crankshaft, or 360°.

Timing

In the following discussion of the diesel cycle it is important to keep in mind the time frame in which each of the actions is required to occur. Time is required to move exhaust gas out of the cylinder and fresh air in to the cylinders, to compress the air, to inject fuel, and to burn the fuel. If a four-stroke diesel engine is running at a constant 2100 revolutions per minute (rpm), the crankshaft would be rotating at 35 revolutions, or 12,600 degrees, per second. One stroke is completed in about 0.01429 seconds.

The Four-Stoke Cycle

In a four-stroke engine the camshaft is geared so that it rotates at half the speed of the crankshaft (1:2). This means that the crankshaft must make two complete revolutions before the camshaft will complete one revolution. The following section will describe a four-stroke, normally aspirated, diesel engine having both intake and exhaust valves with a 3.5-inch bore and 4-inch stroke with a 16:1 compression ratio, as it passes through one complete cycle. We will start on the intake stroke. All the timing marks given are generic and will vary from engine to engine. Refer to Figures 10, 16, and 17 during the following discussion.

Figure 16 Scavenging and Intake

Intake

As the piston moves upward and approaches 28° before top dead center (BTDC), as measured by crankshaft rotation, the camshaft lobe starts to lift the cam follower. This causes the pushrod to move upward and pivots the rocker arm on the rocker arm shaft. As the valve lash is taken up, the rocker arm pushes the intake valve downward and the valve starts to open. The intake stroke now starts while the exhaust valve is still open. The flow of the exhaust gasses will have created a low
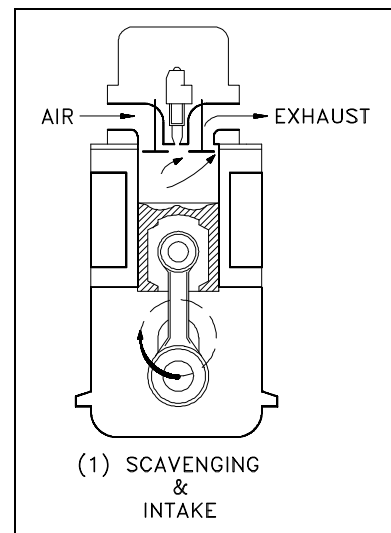
pressure condition within the cylinder and will help pull in the fresh air charge as shown in Figure 16.

The piston continues its upward travel through top dead center (TDC) while fresh air enters and exhaust gasses leave. At about 12° after top dead center (ATDC), the camshaft exhaust lobe rotates so that the exhaust valve will start to close. The valve is fully closed at 23° ATDC. This is accomplished through the valve spring, which was compressed when the valve was opened, forcing the rocker arm and cam follower back against the cam lobe as it rotates. The time frame during which both the intake and exhaust valves are open is called valve overlap (51° of overlap in this example) and is necessary to allow the fresh air to help scavenge (remove) the spent exhaust gasses and cool the cylinder. In most engines, 30 to 50 times cylinder volume is scavenged through the cylinder during overlap. This excess cool air also provides the necessary cooling effect on the engine parts.

As the piston passes TDC and begins to travel down the cylinder bore, the movement of the piston creates a suction and continues to draw fresh air into the cylinder.

Compression

At 35° after bottom dead center (ABDC), the intake valve starts to close. At 43° ABDC (or 137° BTDC), the intake valve is on its seat and is fully closed. At this point the air charge is at normal pressure (14.7 psia) and ambient air temperature (~80°F), as illustrated in Figure 17.

At about 70° BTDC, the piston has traveled about 2.125 inches, or about half of its stroke, thus reducing the volume in the cylinder by half. The temperature has now doubled to ~160°F and pressure is ~34 psia.

At about 43° BTDC the piston has traveled upward 3.062 inches of its stroke and the volume is once again halved. Consequently, the temperature again doubles to about 320°F and pressure is ~85 psia. When the piston has traveled to 3.530 inches of its stroke the volume is again

Figure 17 Compression

halved and temperature reaches ~640°F and pressure 277 psia. When the piston has traveled to 3.757 inches of its stroke, or the volume is again halved, the temperature climbs to 1280°F and pressure reaches 742 psia. With a piston area of 9.616 in^2 the pressure in the cylinder is exerting a force of approximately 7135 lb. or 3-1/2 tons of force.
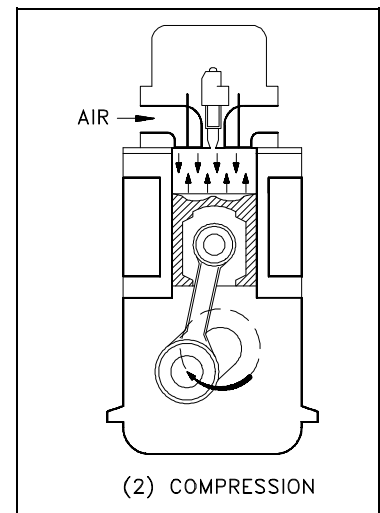
The above numbers are ideal and provide a good example of what is occurring in an engine during compression. In an actual engine, pressures reach only about 690 psia. This is due primarily to the heat loss to the surrounding engine parts.

Fuel Injection

Fuel in a liquid state is injected into the cylinder at a precise time and rate to ensure that the combustion pressure is forced on the piston neither too early nor too late, as shown in Figure 18. The fuel enters the cylinder where the heated compressed air is present; however, it will only burn when it is in a vaporized state (attained through the addition of heat to cause vaporization) and intimately mixed with a supply of oxygen. The first minute droplets of fuel enter the combustion chamber and are quickly vaporized. The vaporization of the fuel causes the air surrounding the fuel to cool and it requires time for the air to reheat sufficiently to ignite the vaporized fuel. But once ignition has started, the additional heat from combustion helps to further

Figure 18 Fuel Injection

vaporize the new fuel entering the chamber, as long as oxygen is present. Fuel injection starts at 28° BTDC and ends at 3° ATDC; therefore, fuel is injected for a duration of 31°.
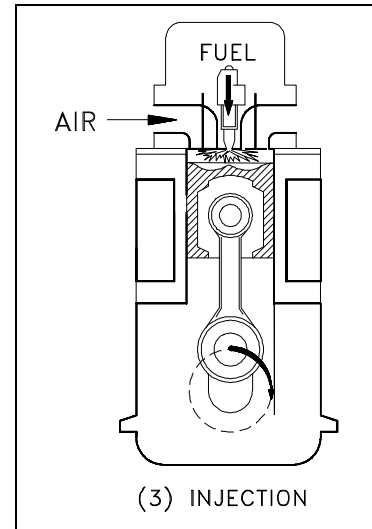
Power

Both valves are closed, and the fresh air charge has been compressed. The fuel has been injected and is starting to burn. After the piston passes TDC, heat is rapidly released by the ignition of the fuel, causing a rise in cylinder pressure. Combustion temperatures are around 2336°F. This rise in pressure forces the piston downward and increases the force on the crankshaft for the power stroke as illustrated in Figure 19.

The energy generated by the combustion process is not all harnessed. In a two stroke diesel engine, only about 38% of the generated power is harnessed to do work, about 30% is wasted in the form of heat rejected to the cooling system, and about 32% in the form of heat is rejected out the exhaust. In comparison, the four-stroke diesel engine has a thermal distribution of 42% converted
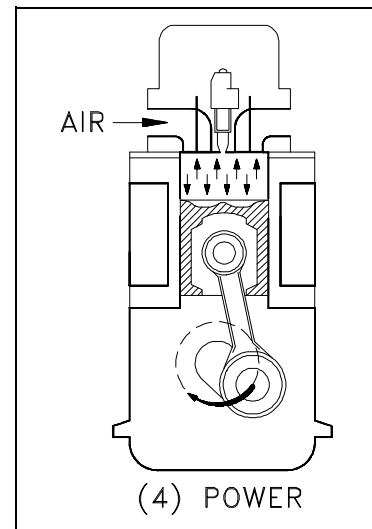

Figure 19 Power

to useful work, 28% heat rejected to the cooling system, and 30% heat rejected out the exhaust.

Exhaust

As the piston approaches 48° BBDC, the cam of the exhaust lobe starts to force the follower upward, causing the exhaust valve to lift off its seat. As shown in Figure 20, the exhaust gasses start to flow out the exhaust valve due to cylinder pressure and into the exhaust manifold. After passing BDC, the piston moves upward and accelerates to its maximum speed at 63° BTDC. From this point on the piston is decelerating. As the piston speed slows down, the velocity of the gasses flowing out of the cylinder creates a pressure slightly lower than atmospheric pressure. At 28° BTDC, the intake valve opens and the cycle starts again.
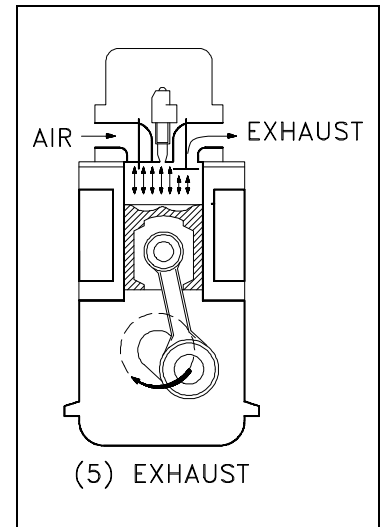

Figure 20 Exhaust

The Two-Stroke Cycle

Like the four-stroke engine, the two-stroke engine must go through the same four events: intake, compression, power, and exhaust. But a two-stroke engine requires only two strokes of the piston to complete one full cycle. Therefore, it requires only one rotation of the crankshaft to complete a cycle. This means several events must occur during each stroke for all four events to be completed in two strokes, as opposed to the four-stroke engine where each stroke basically contains one event.

In a two-stroke engine the camshaft is geared so that it rotates at the same speed as the crankshaft (1:1). The following section will describe a two-stroke, supercharged, diesel engine having intake ports and exhaust valves with a 3.5-inch bore and 4-inch stroke with a 16:1 compression ratio, as it passes through one complete cycle. We will start on the exhaust stroke. All the timing marks given are generic and will vary from engine to engine.

Exhaust and Intake

At 82° ATDC, with the piston near the end of its power stroke, the exhaust cam begins to lift the exhaust valves follower. The valve lash is taken up, and 9° later (91° ATDC), the rocker arm forces the exhaust valve off its seat. The exhaust gasses start to escape into the exhaust manifold, as shown in Figure 21. Cylinder pressure starts to decrease.

After the piston travels three-quarters of its (down) stroke, or 132° ATDC of crankshaft rotation, the piston starts to uncover the inlet ports. As the exhaust valve is still open, the uncovering of the inlet ports lets the compressed fresh air enter the cylinder and helps cool the cylinder and scavenge the cylinder of the remaining exhaust gasses (Figure 22). Commonly, intake and exhaust occur over approximately 96° of crankshaft rotation.

At 43° ABDC, the camshaft starts to close the exhaust valve. At 53° ABDC (117° BTDC), the camshaft has rotated sufficiently to allow the spring pressure to close the exhaust valve. Also, as the piston travels past 48°ABDC (5° after the exhaust valve starts closing), the intake ports are closed off by the piston.
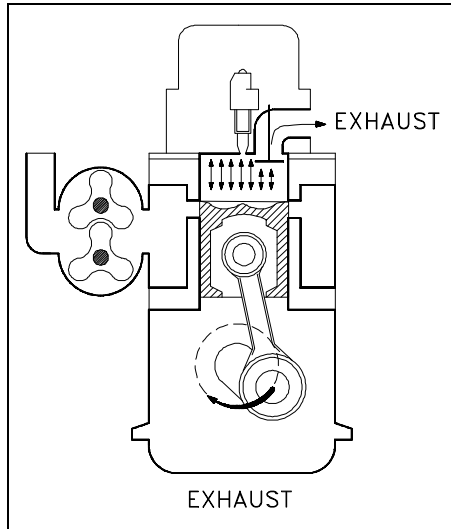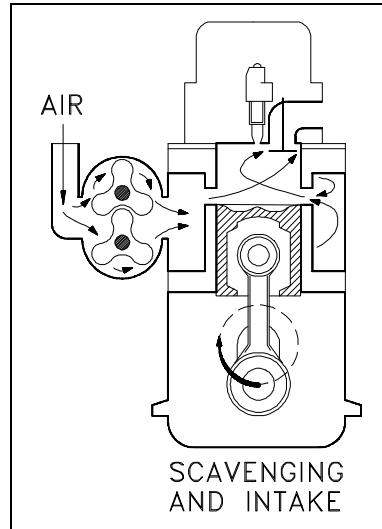

Figure 21 2-Stroke Exhaust   Figure 22 2-Stroke Intake

Compression

After the exhaust valve is on its seat (53° ATDC), the temperature and pressure begin to rise in nearly the same fashion as in the four-stroke engine. Figure 23 illustrates the compression in a 2-stroke engine. At 23° BTDC the injector cam begins to lift the injector follower and pushrod. Fuel injection continues until 6° BTDC (17 total degrees of injection), as illustrated in Figure 24.
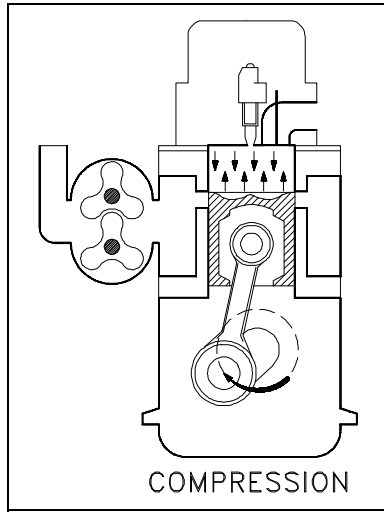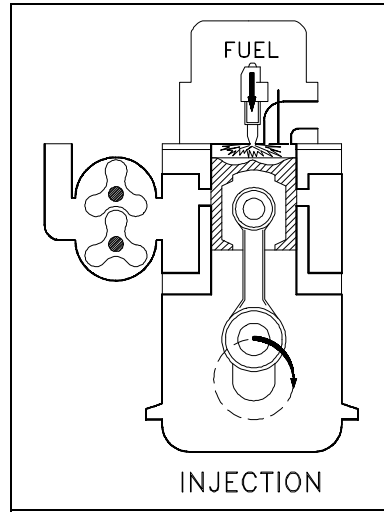
Figure 23 2-Stroke Compression

Figure 24 2-Stroke Fuel Injection

Power

The power stroke starts after the piston passes TDC. Figure 25 illustrates the power stroke which continues until the piston reaches 91° ATDC, at which point the exhaust valves start to open and a new cycle begins.
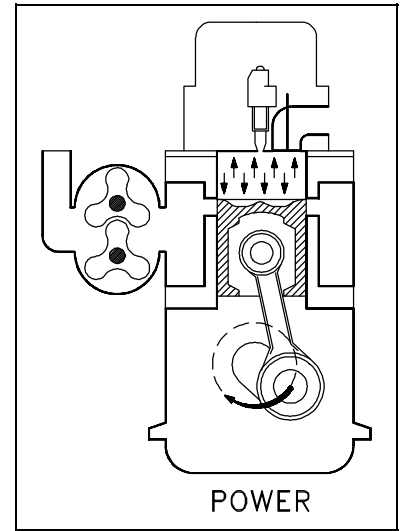

Figure 25 2-Stroke Power

Summary

The important information in this chapter is summarized below.

Fundamentals of the Diesel Cycle Summary

• Ignition occurs in a diesel by injecting fuel into the air charge which has been heated by compression to a temperature greater than the ignition point of the fuel.

• A diesel engine converts the energy stored in the fuel's chemical bonds into mechanical energy by burning the fuel. The chemical reaction of burning the fuel liberates heat, which causes the gasses to expand, forcing the piston to rotate the crankshaft.

• A four-stroke engine requires two rotations of the crankshaft to complete one cycle. The event occur as follows:

> Intake - the piston passes TDC, the intake valve(s) open and the fresh air is admitted into the cylinder, the exhaust valve is still open for a few degrees to allow scavenging to occur.

> Compression - after the piston passes BDC the intake valve closes and the piston travels up to TDC (completion of the first crankshaft rotation).

> Fuel injection - As the piston nears TDC on the compression stroke, the fuel is injected by the injectors and the fuel starts to burn, further heating the gasses in the cylinder.

> Power - the piston passes TDC and the expanding gasses force the piston down, rotating the crankshaft.

> Exhaust - as the piston passes BDC the exhaust valves open and the exhaust gasses start to flow out of the cylinder. This continues as the piston travels up to TDC, pumping the spent gasses out of the cylinder. At TDC the second crankshaft rotation is complete.

Fundamentals of the Diesel Cycle Summary (Cont.)

- A two-stroke engine requires one rotation of the crankshaft to complete one cycle. The events occur as follows:

    Intake - the piston is near BDC and exhaust is in progress. The intake valve or ports open and the fresh air is forced in. The exhaust valves or ports are closed and intake continues.

    Compression - after both the exhaust and intake valves or ports are closed, the piston travels up towards TDC. The fresh air is heated by the compression.

    Fuel injection - near TDC the fuel is injected by the injectors and the fuel starts to burn, further heating the gasses in the cylinder.

    Power - the piston passes TDC and the expanding gasses force the piston down, rotating the crankshaft.

    Exhaust - as the piston approaches BDC the exhaust valves or ports open and the exhaust gasses start to flow out of the cylinder.

DIESEL ENGINE SPEED, FUEL CONTROLS, AND PROTECTION

Understanding how diesel engines are controlled and the types of protective instrumentation available is important for a complete understanding of the operation of a diesel engine.

EO 1.7   **DESCRIBE how the mechanical-hydraulic governor on a diesel engine controls engine speed.**

EO 1.8   **LIST five protective alarms usually found on mid-sized and larger diesel engines.**

Engine Control

The control of a diesel engine is accomplished through several components: the camshaft, the fuel injector, and the governor. The camshaft provides the timing needed to properly inject the fuel, the fuel injector provides the component that meters and injects the fuel, and the governor regulates the amount of fuel that the injector is to inject. Together, these three major components ensure that the engine runs at the desired speed.

Fuel Injectors

Each cylinder has a fuel injector designed to meter and inject fuel into the cylinder at the proper instant. To accomplish this function, the injectors are actuated by the engine's camshaft. The camshaft provides the timing and pumping action used by the injector to inject the fuel. The injectors meter the amount of fuel injected into the cylinder on each stroke. The amount of fuel to be injected by each injector is set by a mechanical linkage called the fuel rack. The fuel rack position is controlled by the engine's governor. The governor determines the amount of fuel required to maintain the desired engine speed and adjusts the amount to be injected by adjusting the position of the fuel rack.

Each injector operates in the following manner. As illustrated in Figure 26, fuel under pressure enters the injector through the injector's filter cap and filter element. From the filter element the fuel travels down into the supply chamber (that area between the plunger bushing and the spill deflector). The plunger operates up and down in the bushing, the bore of which is open to the fuel supply in the supply chamber by two funnel-shaped ports in the plunger bushing.
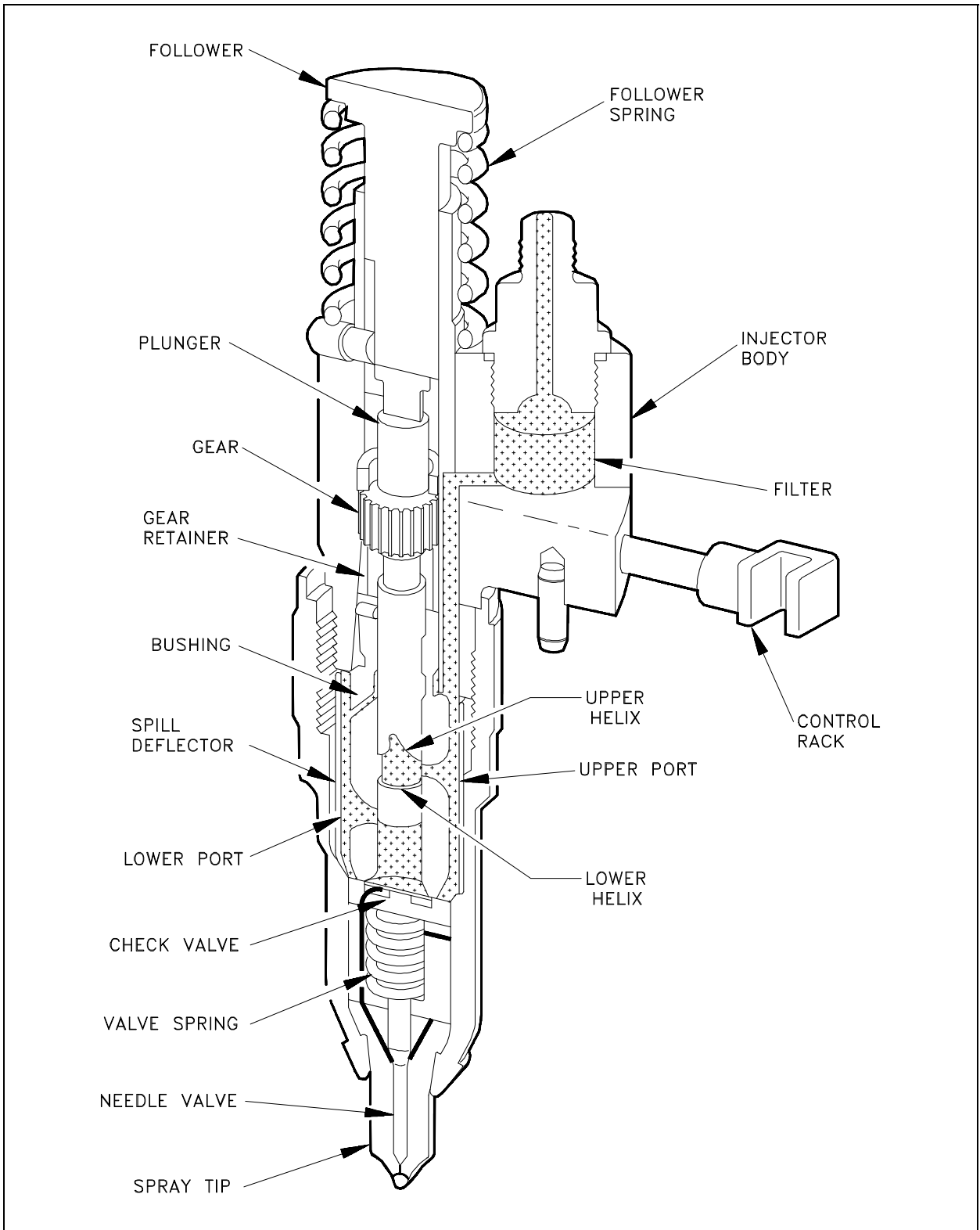
Figure 26 Fuel Injector Cutaway

The motion of the injector rocker arm (not shown) is transmitted to the plunger by the injector follower which bears against the follower spring. As the plunger moves downward under pressure of the injector rocker arm, a portion of the fuel trapped under the plunger is displaced into the supply chamber through the lower port until the port is closed off by the lower end of the plunger. The fuel trapped below the plunger is then forced up through the central bore of the plunger and back out the upper port until the upper port is closed off by the downward motion of the plunger. With the upper and lower ports both closed off, the remaining fuel under the plunger is subjected to an increase in pressure by the downward motion of the plunger.

When sufficient pressure has built up, the injector valve is lifted off its seat and the fuel is forced through small orifices in the spray tip and atomized into the combustion chamber. A check valve, mounted in the spray tip, prevents air in the combustion chamber from flowing back into the fuel injector. The plunger is then returned back to its original position by the injector follower spring.

On the return upward movement of the plunger, the high pressure cylinder within the bushing is again filled with fresh fuel oil through the ports. The constant circulation of fresh, cool fuel through the injector renews the fuel supply in the chamber and helps cool the injector. The fuel flow also effectively removes all traces of air that might otherwise accumulate in the system.

The fuel injector outlet opening, through which the excess fuel returns to the fuel return manifold and then back to the fuel tank, is adjacent to the inlet opening and contains a filter element exactly the same as the one on the fuel inlet side.

In addition to the reciprocating motion of the plunger, the plunger can be rotated during operation around its axis by the gear which meshes with the fuel rack. For metering the fuel, an upper helix and a lower helix are machined in the lower part of the plunger. The relation of the helices to the two ports in the injector bushing changes with the rotation of the plunger.

Changing the position of the helices, by rotating the plunger, retards or advances the closing of the ports and the beginning and ending of the injection period. At the same time, it increases or decreases the amount of fuel injected into the cylinder. Figure 27 illustrates the various plunger positions from NO LOAD to FULL LOAD. With the control rack pulled all the way (no injection), the upper port is not closed by the helix until after the lower port is uncovered. Consequently, with the rack in this position, all of the fuel is forced back into the supply chamber and no injection of fuel takes place. With the control rack pushed all the way in (full injection), the upper port is closed shortly after the lower port has been covered, thus producing a maximum effective stroke and maximum fuel injection. From this no-injection position to the full-injection position (full rack movement), the contour of the upper helix advances the closing of the ports and the beginning of injection.
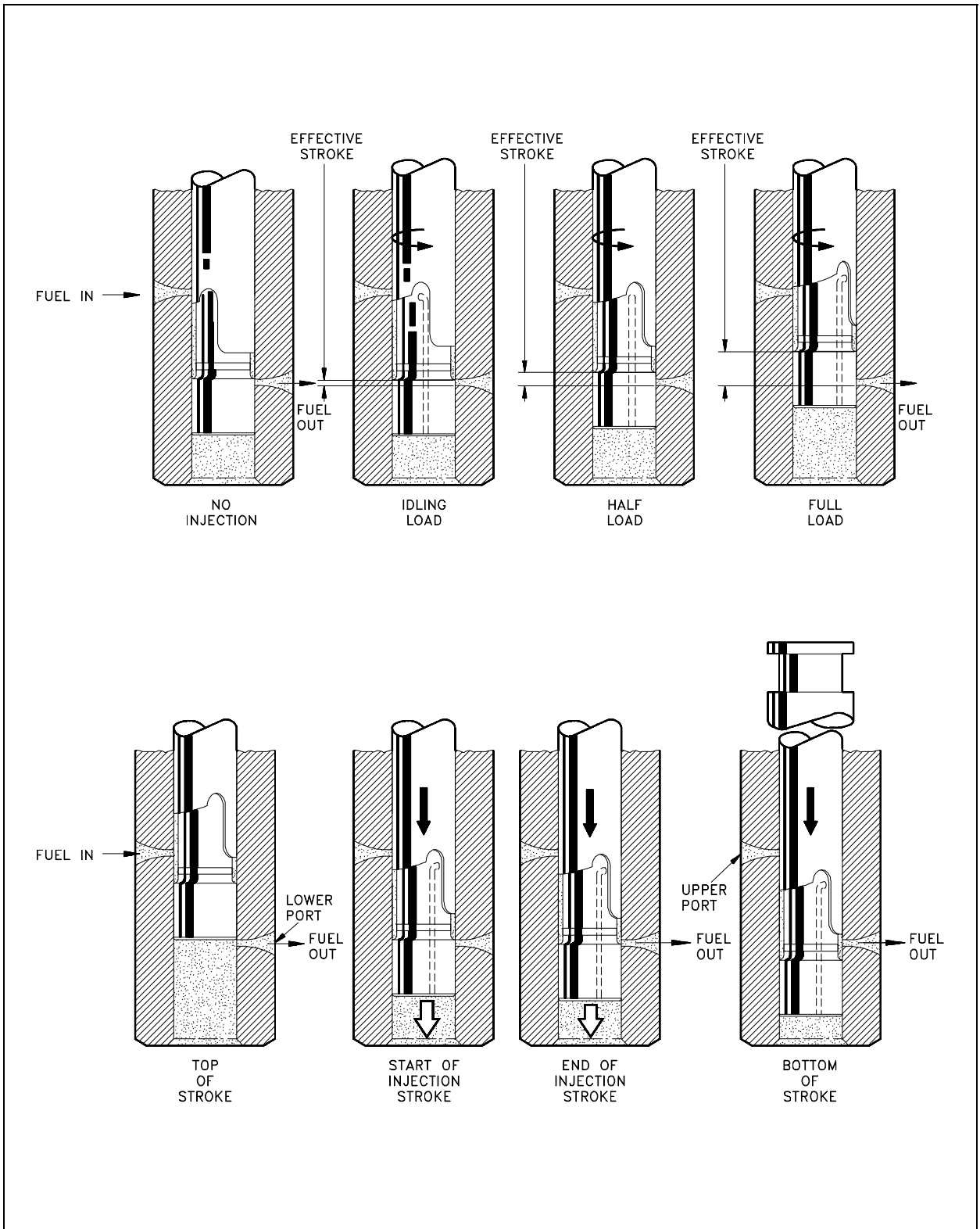
Figure 27 Fuel Injector Plunger

Governor

Diesel engine speed is controlled solely by the amount of fuel injected into the engine by the injectors. Because a diesel engine is not self-speed-limiting, it requires not only a means of changing engine speed (throttle control) but also a means of maintaining the desired speed. The governor provides the engine with the feedback mechanism to change speed as needed and to maintain a speed once reached.

A governor is essentially a speed-sensitive device, designed to maintain a constant engine speed regardless of load variation. Since all governors used on diesel engines control engine speed through the regulation of the quantity of fuel delivered to the cylinders, these governors may be classified as speed-regulating governors. As with the engines themselves there are many types and variations of governors. In this module, only the common mechanical-hydraulic type governor will be reviewed.

The major function of the governor is determined by the application of the engine. In an engine that is required to come up and run at only a single speed regardless of load, the governor is called a constant-speed type governor. If the engine is manually controlled, or controlled by an outside device with engine speed being controlled over a range, the governor is called a variable-speed type governor. If the engine governor is designed to keep the engine speed above a minimum and below a maximum, then the governor is a speed-limiting type. The last category of governor is the load limiting type. This type of governor limits fuel to ensure that the engine is not loaded above a specified limit. Note that many governors act to perform several of these functions simultaneously.

Operation of a Governor

The following is an explanation of the operation of a constant speed, hydraulically compensated governor using the Woodward brand governor as an example. The principles involved are common in any mechanical and hydraulic governor.

The Woodward speed governor operates the diesel engine fuel racks to ensure a constant engine speed is maintained at any load. The governor is a mechanical-hydraulic type governor and receives its supply of oil from the engine lubricating system. This means that a loss of lube oil pressure will cut off the supply of oil to the governor and cause the governor to shut down the engine. This provides the engine with a built-in shutdown device to protect the engine in the event of loss of lubricating oil pressure.

Simplified Operation of the Governor

The governor controls the fuel rack position through a combined action of the hydraulic piston and a set of mechanical flyweights, which are driven by the engine blower shaft. Figure 28 provides an illustration of a functional diagram of a mechanical-hydraulic governor. The position of the flyweights is determined by the speed of the engine. As the engine speeds up or down, the weights move in or out. The movement of the flyweights, due to a change in engine speed, moves a small piston (pilot valve) in the governor's hydraulic system. This motion adjusts flow of hydraulic fluid to a large hydraulic piston (servo-motor piston). The large hydraulic piston is linked to the fuel rack and its motion resets the fuel rack for increased/decreased fuel.
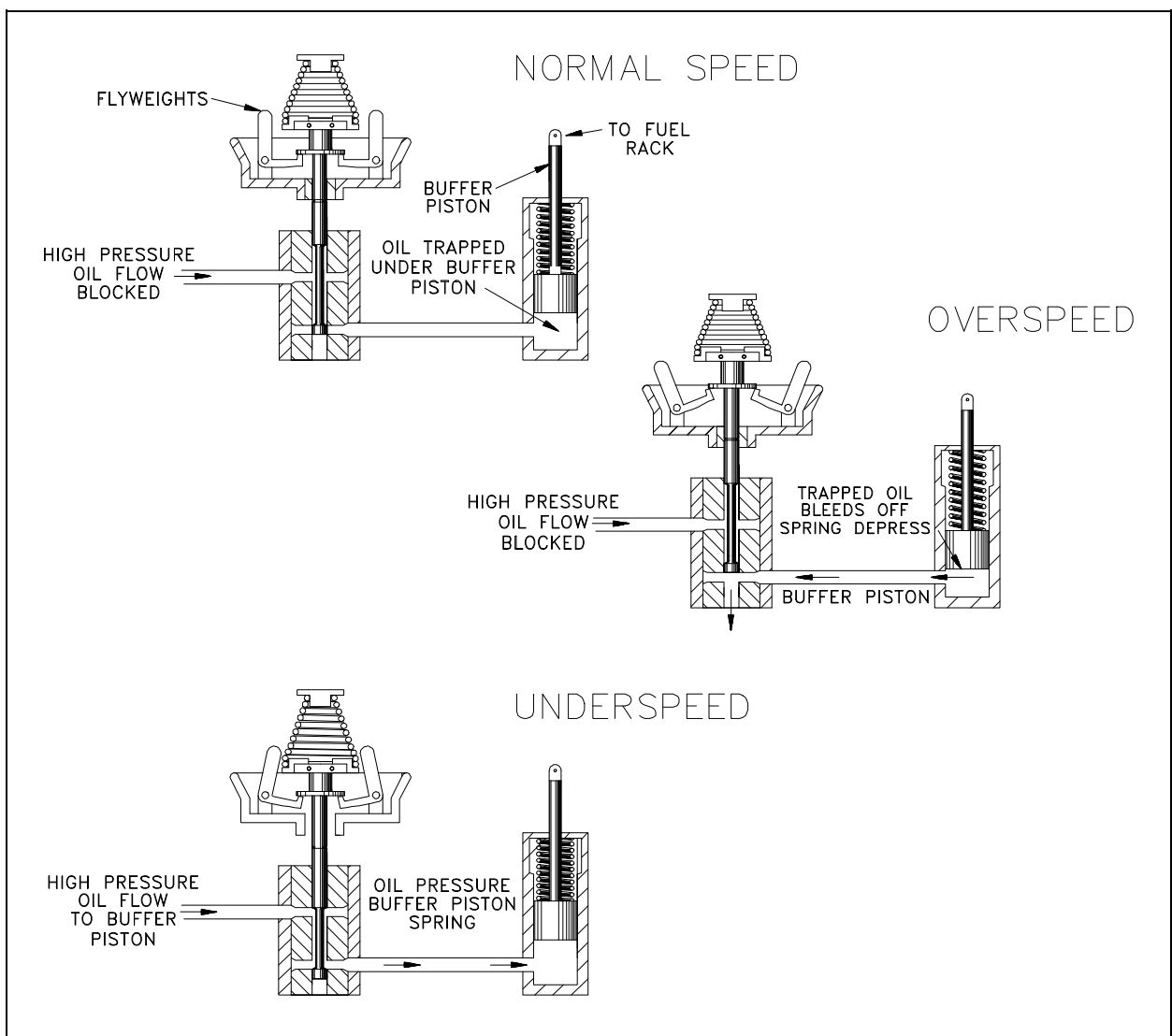
Figure 28 Simplified Mechanical-Hydraulic Governor

Detailed Operation of the Governor

With the engine operating, oil from the engine lubrication system is supplied to the governor pump gears, as illustrated in Figure 29. The pump gears raise the oil pressure to a value determined by the spring relief valve. The oil pressure is maintained in the annular space between the undercut portion of the pilot valve plunger and the bore in the pilot valve bushing. For any given speed setting, the spring speeder exerts a force that is opposed by the centrifugal force of the revolving flyweights. When the two forces are equal, the control land on the pilot valve plunger covers the lower ports in the pilot valve bushing.
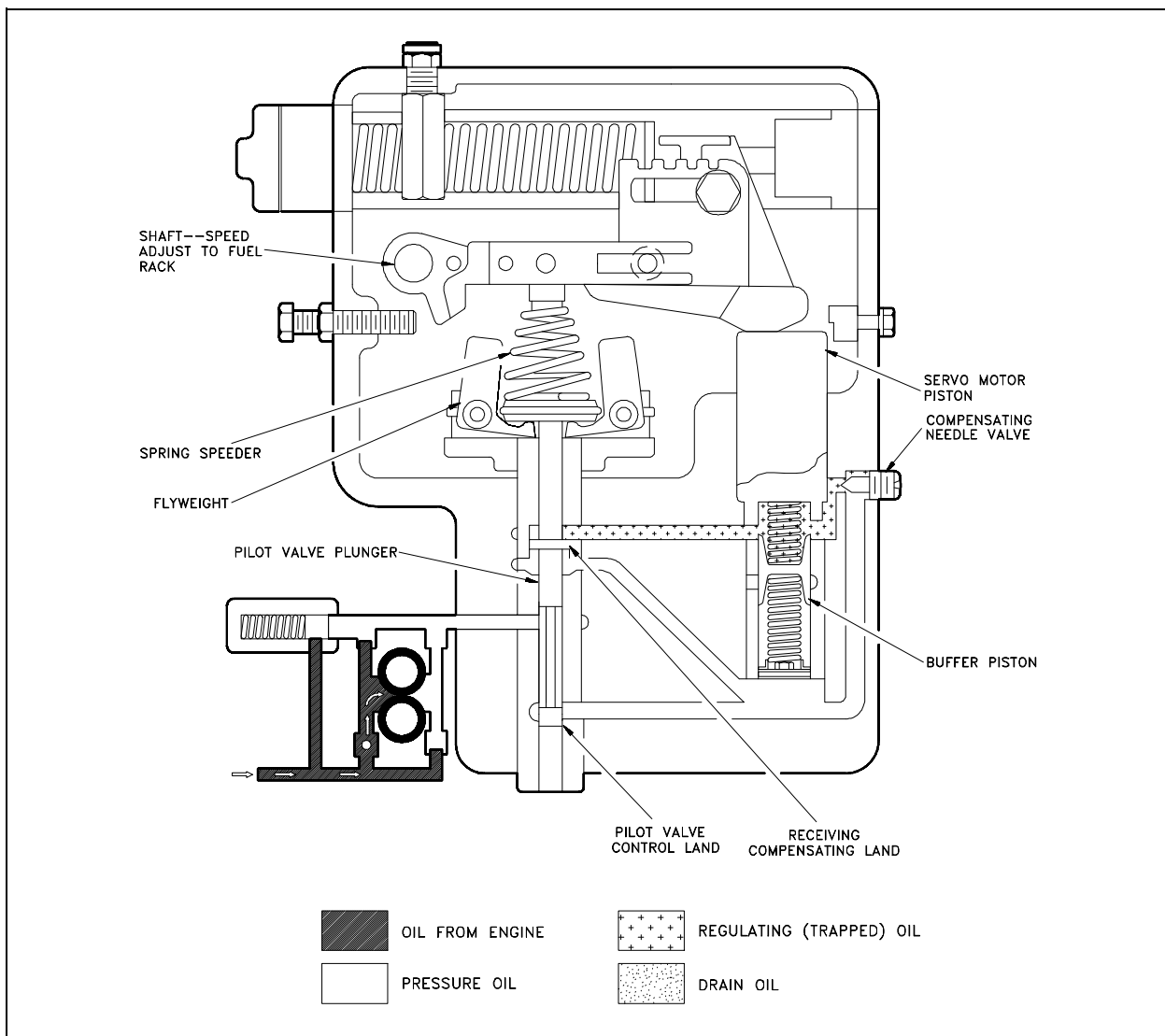

Figure 29 Cutaway of a Woodward Governor

Under these conditions, equal oil pressures are maintained on both sides of the buffer piston and tension on the two buffer springs is equal. Also, the oil pressure is equal on both sides of the receiving compensating land of the pilot valve plunger due to oil passing through the compensating needle valve. Thus, the hydraulic system is in balance, and the engine speed remains constant.

When the engine load increases, the engine starts to slow down in speed. The reduction in engine speed will be sensed by the governor flyweights. The flyweights are forced inward (by the spring), thus lowering the pilot valve plunger (again, due to the downward spring force). Oil under pressure will be admitted under the servo-motor piston (topside of the buffer piston) causing it to rise. This upward motion of the servo-motor piston will be transmitted through the terminal lever to the fuel racks, thus increasing the amount of fuel injected into the engine. The oil that forces the servo-motor piston upward also forces the buffer piston upward because the oil pressure on each side of the piston is unequal. This upward motion of the piston compresses the upper buffer spring and relieves the pressure on the lower buffer spring.

The oil cavities above and below the buffer piston are common to the receiving compensating land on the pilot valve plunger. Because the higher pressure is below the compensating land, the pilot valve plunger is forced upward, recentering the flyweights and causing the control land of the pilot valve to close off the regulating port. Thus, the upward movement of the servo-motor piston stops when it has moved far enough to make the necessary fuel correction.

Oil passing through the compensating needle valve slowly equalizes the pressures above and below the buffer piston, thus allowing the buffer piston to return to the center position, which in turn equalizes the pressure above and below the receiving compensating land. The pilot valve plunger then moves to its central position and the engine speed returns to its original setting because there is no longer any excessive outward force on the flyweights.

The action of the flyweights and the hydraulic feedback mechanism produces stable engine operation by permitting the governor to move instantaneously in response to the load change and to make the necessary fuel adjustment to maintain the initial engine speed.

Starting Circuits

Diesel engines have as many different types of starting circuits as there are types, sizes, and manufacturers of diesel engines. Commonly, they can be started by air motors, electric motors, hydraulic motors, and manually. The start circuit can be a simple manual start pushbutton, or a complex auto-start circuit. But in almost all cases the following events must occur for the starting engine to start.

1. The start signal is sent to the starting motor. The air, electric, or hydraulic motor, will engage the engine's flywheel.

2. The starting motor will crank the engine. The starting motor will spin the engine at a high enough rpm to allow the engine's compression to ignite the fuel and start the engine running.

3. The engine will then accelerate to idle speed. When the starter motor is overdriven by the running motor it will disengage the flywheel.

Because a diesel engine relies on compression heat to ignite the fuel, a cold engine can rob enough heat from the gasses that the compressed air falls below the ignition temperature of the fuel. To help overcome this condition, some engines (usually small to medium sized engines) have glowplugs. Glowplugs are located in the cylinder head of the combustion chamber and use electricity to heat up the electrode at the top of the glowplug. The heat added by the glowplug is sufficient to help ignite the fuel in the cold engine. Once the engine is running, the glowplugs are turned off and the heat of combustion is sufficient to heat the block and keep the engine running.

Larger engines usually heat the block and/or have powerful starting motors that are able to spin the engine long enough to allow the compression heat to fire the engine. Some large engines use air start manifolds that inject compressed air into the cylinders which rotates the engine during the start sequence.

Engine Protection

A diesel engine is designed with protection systems to alert the operators of abnormal conditions and to prevent the engine from destroying itself.

Overspeed device -   Because a diesel is not self-speed-limiting, a failure in the governor, injection system, or sudden loss of load could cause the diesel to overspeed. An overspeed condition is extremely dangerous because engine failure is usually catastrophic and can possibly cause the engine to fly apart.

An overspeed device, usually some type of mechanical flyweight, will act to cut off fuel to the engine and alarm at a certain preset rpm. This is usually accomplished by isolating the governor from its oil supply, causing it to travel to the no-fuel position, or it can override the governor and directly trip the fuel rack to the no-fuel position.

Water jacket -
Water-cooled engines can overheat if the cooling water system fails to remove waste heat. Removal of the waste heat prevents the engine from seizing due to excessive expansion of the components under a high temperature condition. The cooling water jacket is commonly where the sensor for the cooling water system is located.

The water jacket temperature sensors provide early warning of abnormal engine temperature, usually an alarm function only. The setpoint is set such that if the condition is corrected in a timely manner, significant engine damage will be avoided. But continued engine operation at the alarm temperature or higher temperatures will lead to engine damage.

Exhaust temperatures -
In a diesel engine, exhaust temperatures are very important and can provide a vast amount of information regarding the operation of the engine. High exhaust temperature can indicate an overloading of the engine or possible poor performance due to inadequate scavenging (the cooling effect) in the engine. Extended operation with high exhaust temperatures can result in damage to the exhaust valves, piston, and cylinders. The exhaust temperature usually provides only an alarm function.

Low lube oil pressure -
Low oil pressure or loss of oil pressure can destroy an engine in short order. Therefore, most medium to larger engines will stop upon low or loss of oil pressure. Loss of oil pressure can result in the engine seizing due to lack of lubrication. Engines with mechanical-hydraulic governors will also stop due to the lack of oil to the governor.

The oil pressure sensor usually stops the engine. The oil pressure sensors on larger engines usually have two low pressure setpoints. One setpoint provides early warning of abnormal oil pressure, an alarm function only. The second setpoint can be set to shutdown the engine before permanent damage is done.

High crankcase pressure -   High crankcase pressure is usually caused by excessive blow-by (gas pressure in the cylinder blowing by the piston rings and into the crankcase). The high pressure condition indicates the engine is in poor condition. The high crankcase pressure is usually used only as an alarm function.

Summary

The important information in this chapter is summarized below.

Diesel Engine Speed, Fuel Controls, and Protection Summary

- A mechanical-hydraulic governor controls engine speed by balancing engine speed (mechanical flyweights) against hydraulic pressure. As the engine speeds up or slows down, the weights move the hydraulic plunger in or out. This in turn actuates a hydraulic valve which controls the hydraulic pressure to the buffer piston. The buffer piston is connected to the fuel rack. Therefore, any motion of the buffer piston will control fuel to the cylinder by adjusting the position of the fuel rack, which regulates the amount of fuel in the injectors.

- Most mid-sized to large diesel engines have (as a minimum) the following protective alarms and trips.

   Engine overspeed alarm/trip
   High water jacket temperature alarm
   High exhaust temperature alarm
   Low lube oil pressure (alarm and/or trip)
   High crankcase pressure alarm