

**TRAINING  
COURSE 6**

**DIESEL ENGINES AND FUEL SYSTEMS**

**VOLUME 1**

## Course Program

### GENERAL

The purpose of this course is to introduce the characteristics of diesel fuel systems. This discussion will include a description of the principles, construction, and function of a diesel engine.

#### Lesson 1: FUNCTION AND CONSTRUCTION OF DIESEL FUEL SYSTEMS

TASK 1: Describe the characteristics of diesel fuel.

TASK 2: Describe the principles, construction, and function of diesel fuel systems.

TABLE OF CONTENTS

Section	Page
TITLE.....	i
TABLE OF CONTENTS.....	ii
Lesson 1: FUNCTION AND CONSTRUCTION OF DIESEL FUEL SYSTEMS.....	4
TASK 1: Describe the characteristics of diesel fuel .....	5
TASK 2: Describe the principles, construction, and function of diesel fuel systems .....	9
Practical Exercise 1 .....	62
Answers to Practical Exercise 1 .....	65

## FUNCTION AND CONSTRUCTION OF DIESEL FUEL SYSTEMS

TASK 1. Describe the characteristics of diesel fuel.

### CONDITIONS

Within a self-study environment and given the course text, without assistance.

### REFERENCES

No supplementary references are needed for this task.

#### 1. Introduction

The fuels used in modern high-speed diesel engines are derived from the heavier residues of the crude oil left over after the more volatile fuels, such as gasoline and kerosene, are removed during the refining process. The large, slow running diesel engines used in stationary or marine installations will burn almost any grade of heavy fuel oil. This contrasts with the smaller, high-speed diesel engines that require a fuel oil that is as light as kerosene.

Although diesel fuels are considered a residue of the refining process, their specification requirements are just as exacting as gasoline. In this lesson, the function and construction of diesel fuel systems will be discussed. The first task will describe the characteristics of diesel fuel; the second task will portray the principles, construction, and function of diesel fuel systems used in vehicles.

## 2. Characteristics of Diesel Fuels

a. *Cleanliness.* Probably the most necessary characteristic of diesel fuels is cleanliness. Any foreign material present in diesel fuel will certainly cause damage to the finely machined injector parts. Damage occurs in two ways:

(1) Particles of dirt cause scoring of the injector components.

(2) Moisture in the fuel will cause corrosion of the injector components.

Any damage to the fuel injectors will cause poor operation or render the engine inoperative. Controlling dirt and moisture content in diesel fuel is more difficult because it is heavier than gasoline. This causes foreign material to remain in suspension longer, so that sediment bowls do not work as well as with gasoline fuel systems.

b. *Viscosity.* The viscosity of a fluid is an indication of its resistance to flow. What this means is that a fluid with a high viscosity is heavier than a fluid with a low viscosity. The viscosity of diesel fuel must be low enough to flow freely at its lowest operational temperature, yet high enough to provide lubrication to the moving parts of the finely machined injectors. The fuel must also be sufficiently viscous so that leakage at the pump plungers and dribbling at the injectors will not occur. Viscosity also will determine the size of the fuel droplets which, in turn, govern the atomization and penetration qualities of the fuel injector spray.

c. *Ignition Quality.* The ignition quality of a fuel is its ability to ignite spontaneously under the conditions existing in the engine cylinder. The spontaneous-ignition point of a diesel fuel is a function of pressure, temperature, and time. Because it is difficult to reproduce the operating conditions of the fuel artificially outside the engine cylinder, a diesel engine operating under controlled conditions is used to determine the ignition quality of diesel fuel. The yardstick that is used to measure the ignition quality of a diesel fuel is the cetane number scale. The cetane number of a fuel is obtained by comparing it to the operation of a reference fuel. The reference fuel is a mixture of alpha-methyl-naphthalene, which has

virtually no spontaneous ignition qualities, and pure cetane, which has what are considered to be perfect spontaneous ignition qualities. The percentage of cetane is increased gradually in the reference fuel until the fuel matches the spontaneous ignition qualities of the fuel being tested. The cetane number then is established for the fuel being tested based on the percentage of cetane present in the reference mixture.

d. Diesel engines have a tendency to produce a knock that is particularly noticeable during times when the engine is under a light load. This knocking occurs due to a condition known as ignition delay or ignition lag. When the power stroke begins, the first molecules of fuel injected into the combustion chamber must first vaporize and superheat before ignition occurs. During this period, a quantity of unburned fuel builds up in the combustion chamber. When ignition occurs, the pressure increase causes the built-up fuel to ignite instantly. This causes a disproportionate increase in pressure, creating a distinct and audible knock. Increasing the compression ratio of a diesel engine will decrease ignition lag and the tendency to knock. This contrasts with a gasoline engine, whose tendency to knock will increase with an increase in compression ratio. Knocking in diesel engines is affected by factors other than compression ratio, such as the type of combustion chamber, airflow within the chamber, injector nozzle type, air and fuel temperature, and the cetane number of the fuel.

e. *Multifuel Engine Authorized Fuels.* Multifuel engines are four-stroke cycle diesel engines that will operate satisfactorily on a wide variety of fuels. The fuels are grouped accordingly:

(1) *Primary and Alternate I Fuels.* These fuels will operate the multifuel engine with no additives.

(2) *Alternate II Fuels.* These fuels generally require the addition of diesel fuel to operate the multifuel engine.

(3) *Emergency Fuels.* These fuels will operate the multifuel engine with the addition of diesel fuel; however, extended use of fuels from this group will cause eventual fouling of fuel injection

parts. It should be noted that there are no adjustments necessary to the engine when changing from one fuel to another.

f. *Fuel Density Compensator.* The multifuel engine operates on a variety of fuels, with a broad range of viscosities and heat values. These variations in the fuels affect engine output. Because it is unacceptable for the power output of the engine to vary with fuel changes, the multifuel engine is fitted with a device known as a fuel density compensator. The fuel density compensator is a device that serves to vary the quantity of fuel injected to the engine by regulating the full-load stop of the fuel pump. The characteristics of the fuels show that their heat values decrease almost inversely proportional to their viscosities. The fuel density compensator uses viscosity as the indicator for regulating fuel flow. Its operation is as follows:

(1) The fuel supply enters the compensator through the fuel pressure regulator, where the supply pressure is regulated to a constant 20 psi regardless of engine speed and load range.

(2) The pressure regulated fuel then passes through a series of two orifices. The two orifices, by offering greatly different resistances to flow, form a system that is sensitive to viscosity changes.

(a) The first orifice is annular, formed by the clearance between the servo piston and its cylinder. This orifice is sensitive to viscosity.

(b) The second orifice is formed by an adjustable needle valve and, unlike the first, is not viscosity sensitive.

(c) After the fuel passes through the two orifices, it leaves the compensator through an outlet port. From here, the fuel passes back to the pump.

(3) The higher the viscosity of the fuel, the more trouble it will have passing through the first orifice. Because of this, the fuel pressure under the servo piston will rise proportionally with viscosity. Because the second orifice is not viscosity sensitive, the pressure over the servo piston will remain fairly constant. This will

cause a pressure differential that increases proportionally with viscosity that, in turn, will cause the piston to seek a position in its bore that becomes higher as viscosity increases.

(4) The upward movement of the servo piston will move a wedge-shaped movable plate which will increase fuel delivery. A lower viscosity fuel will cause the piston to move downward causing the pump to decrease fuel delivery.

### 3. Conclusion

This task described the characteristics of diesel fuel. Having gained an understanding of diesel fuel, our attention in the next task will focus on the function and construction of diesel fuel systems.



## FUNCTION AND CONSTRUCTION OF DIESEL FUEL SYSTEMS

TASK 2. Describe the principles, construction, and function of diesel fuel systems.

### CONDITIONS

Within a self-study environment and given the subcourse text, without assistance.

### STANDARDS

Within one hour

### REFERENCES

No supplementary references are needed for this task.

#### 1. Introduction

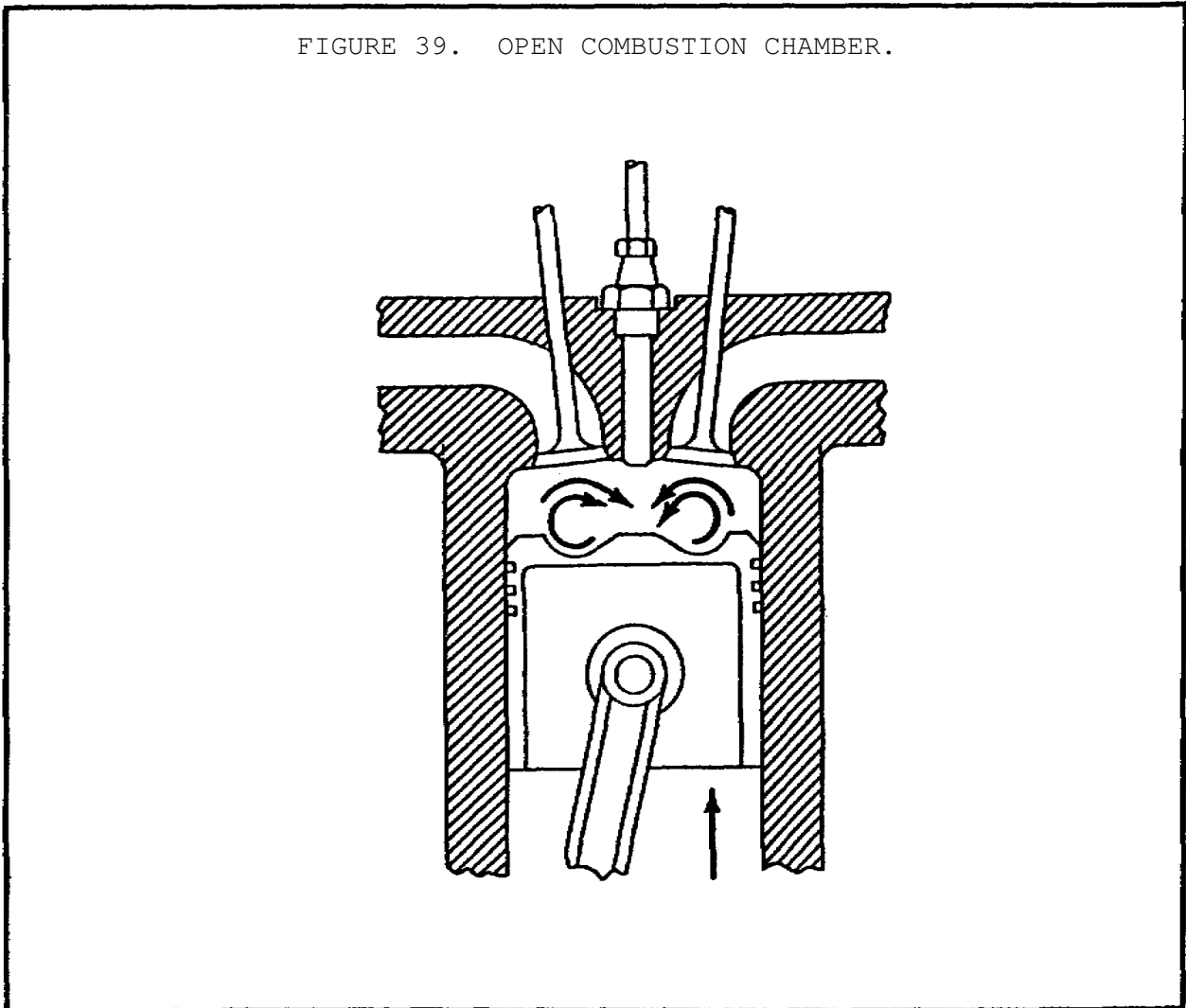
The fuel injected into the combustion chamber must be mixed thoroughly with the compressed air and distributed as evenly as possible throughout the chamber if the engine is to function at maximum efficiency and exhibit maximum driveability. The well-designed diesel engine uses a combustion chamber that is designed for the engine's intended usage.

This task illustrates the function of a diesel fuel system. It will describe the principles and construction for the following components of this system: injection systems, fuel supply pumps, governors, timing devices, and combustion chambers. The combustion chambers described in the following paragraphs are the most common, and cover virtually all of the designs used in current automotive practice.

## 2. Combustion Chamber Design

a. *Open Chamber* (figure 39). The open chamber is the simplest form of diesel chamber design. It is suitable only for slow-speed, four-stroke cycle engines, but is also used widely in two-stroke cycle diesel engines. In the open chamber, the fuel is injected directly into the space at the top of the cylinder. The combustion space, formed by the top of the piston and the cylinder head, usually is shaped to provide a swirling action of the air as the piston comes up on the compression stroke. There are no special pockets, cells, or passages to aid the mixing of the fuel and air. This type of chamber requires a higher injection pressure and a greater degree of fuel atomization than is required by other combustion chambers to obtain a comparable level of fuel mixing. This chamber design is very susceptible to ignition lag.

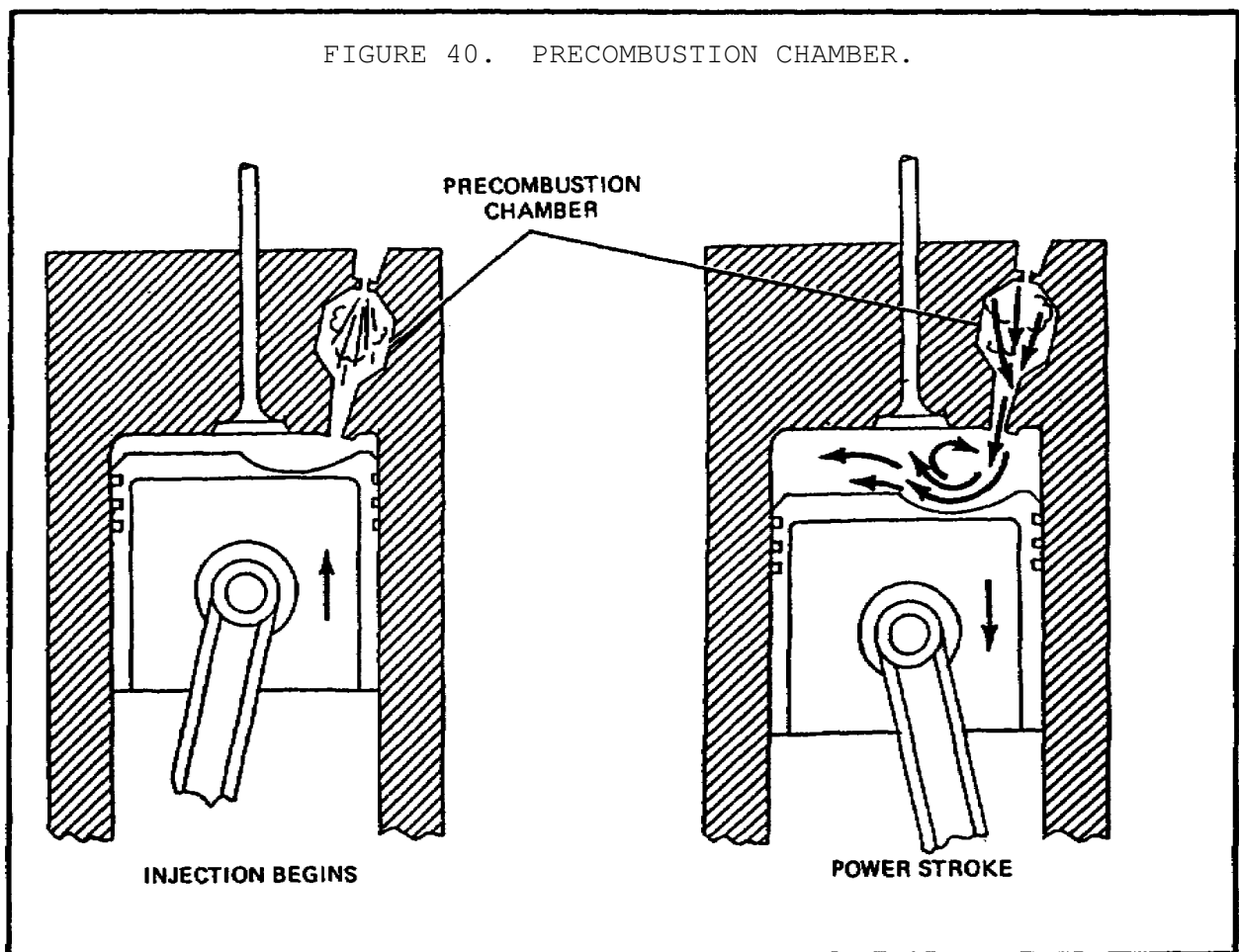
FIGURE 39. OPEN COMBUSTION CHAMBER.



b. *Precombustion Chamber* (figure 40). The precombustion chamber is an auxiliary chamber at the top of the cylinder. It is connected to the main combustion chamber by a restricted throat or passage. The precombustion chamber conditions the fuel for final combustion in the cylinder. A hollowed out portion of the piston top causes turbulence in the main combustion chamber as the fuel enters from the precombustion chamber to aid in mixing with air. The following steps occur during the combustion process:

(1) During the compression stroke of the engine, air is forced into the precompression chamber and, because the air is compressed, it is hot. At the beginning of injection, the precombustion chamber contains a definite volume of air.

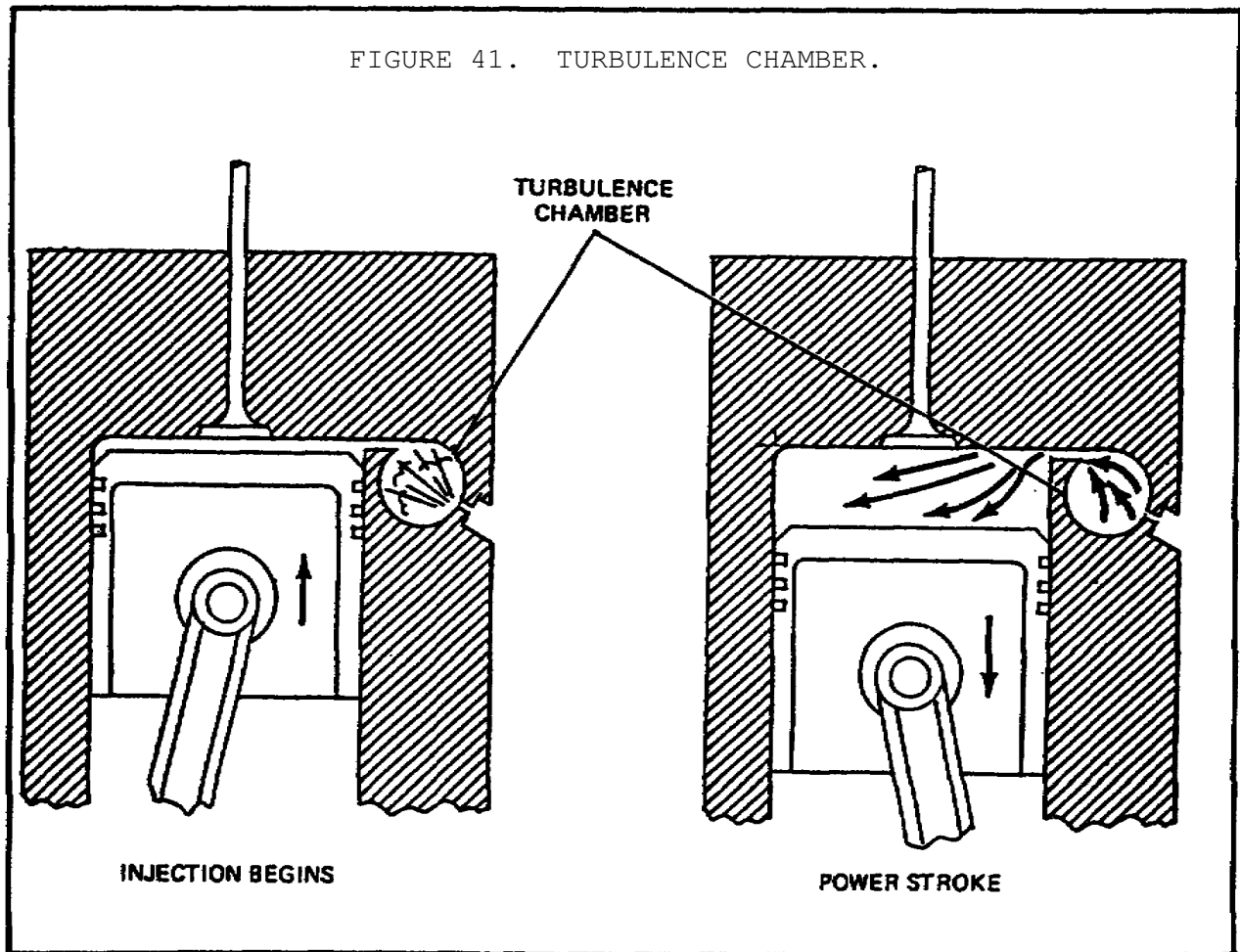
(2) As the injection begins, combustion starts in the precombustion chamber. The burning of the fuel, combined with the restricted passage to the main combustion chamber, creates a tremendous



amount of pressure in the precombustion chamber. The pressure and the initial combustion cause a superheated fuel charge to enter the main combustion chamber at a tremendous velocity.

(3) The entering mixture hits the hollowed out piston top, creating turbulence in the chamber to ensure complete mixing of the fuel charge with the air. This mixing ensures even and complete combustion. This chamber design will provide satisfactory performance with low fuel injector pressures and coarse spray patterns because a large amount of vaporization takes place in the combustion chamber. This chamber is also not very susceptible to ignition lag, making it more suitable for high speed applications.

c. *Turbulence Chamber* (figure 41). The turbulence chamber is similar in appearance to the precombustion chamber, but its function is different. There is very little clearance between the top of the piston and the head, so that a high



percentage of the air between the piston and the cylinder head is forced into the turbulence chamber during the compression stroke. The chamber usually is spherical, and the opening through which the air must pass becomes smaller as the piston reaches the top of the stroke, thereby increasing the velocity of the air in the chamber. This turbulence speed is approximately 50 times crankshaft speed. The fuel injection is timed to occur when the turbulence in the chamber is the greatest. This ensures a thorough mixing of the fuel and the air, with the result that the greater part of combustion takes place in the turbulence chamber itself. The pressure created by the expansion of the burning gases is the force that drives the piston downward on the power stroke.

d. *Spherical Combustion Chamber.* The spherical combustion chamber is designed principally for use in the multifuel engine. The chamber consists of a basic open-type chamber with a spherical-shaped relief in the top of the piston head. The chamber works in conjunction with a strategically positioned injector, and an intake port which produces a swirling effect on the intake air as it enters the chamber. Operation of the chamber is as follows:

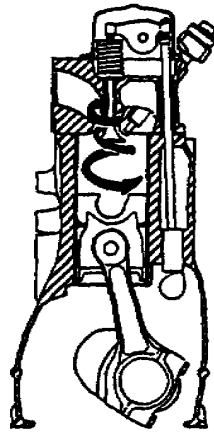
(1) As the air enters the combustion chamber, a swirl effect is introduced to it by the shape of the intake port (figure 42, view A, on the following page).

(2) During the compression stroke, the swirling motion of the air continues as the temperature in the chamber increases (figure 42, view B, on the following page).

(3) As the fuel is injected, approximately 95 percent of it is deposited on the head of the piston and the remainder mixes with the air in the spherical combustion chamber (figure 42, view C, on the following page).

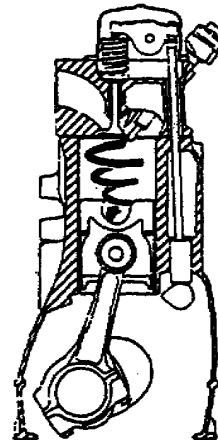
(4) As combustion begins, the main portion of the fuel is swept off of the piston head by the high velocity swirl that was created by the intake and the compression strokes. As the fuel is swept off of the head, it burns through the power stroke, maintaining even combustion and eliminating detonation (figure 42, view D and E, on the following page).

FIGURE 42. SPHERICAL CHAMBER.



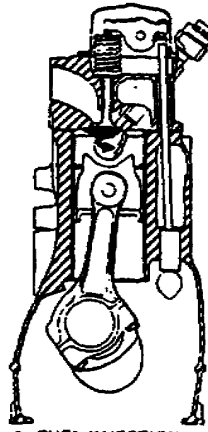
A. INTAKE STROKE

AIR INTAKE PASSAGE IS SHAPED TO PRODUCE AN AIR SWIRL IN CYLINDER DURING INTAKE STROKE OF PISTON.



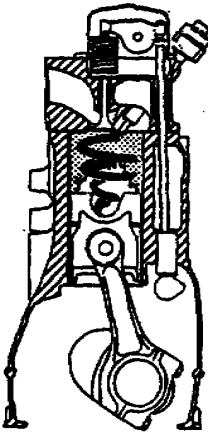
B. COMPRESSION STROKE

AIR SWIRL CONTINUES THROUGHOUT COMPRESSION STROKE.



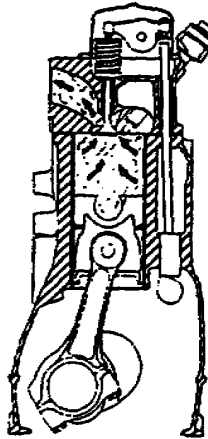
C. FUEL INJECTION

AIR SWIRL CONTINUES DURING FUEL INJECTION. 5% OF INJECTED FUEL MIXES DIRECTLY WITH AIR MOLECULES AND IGNITES IN SPHERICAL COMBUSTION CHAMBER.



D. POWER STROKE

AIR SWIRL CONTINUES TO REMOVE ONLY THE UPPER SURFACE OF DEPOSITED FUEL ON THE PISTONS IN SPHERICAL COMBUSTION CHAMBER THROUGHOUT THE POWER STROKE OF PISTON, MAINTAINING EVEN COMBUSTION.



E. EXHAUST STROKE

BURNED GASES THEN ARE EXHAUSTED ON THE EXHAUST STROKE OF PISTON TO COMPLETE THE CYCLE.

### 3. Injection Systems

#### a. *Fuel Injection Principles.*

(1) *Methods.* There are two methods of injecting fuel into a compression-ignition engine. One method is air injection. This method uses a blast of air to force a measured charge of fuel into the combustion chamber. The other method is solid injection, where direct mechanical pressure is placed on the fuel itself to force it into the combustion chamber. Only the solid injection system will be discussed in this task because air injection is virtually unused in automotive applications.

(2) *Fuel Atomization and Penetration.* The fuel spray entering the combustion chamber must conform to the chamber's shape so that the fuel particles will be well distributed and thoroughly mixed with the air. The shape of the spray is determined by the degree of atomization and penetration produced by the orifice through which the fuel enters the chamber. Atomization is the term used to indicate the size of the droplets into which the fuel is broken down. Penetration is the distance from the orifice that the fuel droplets attain at a given phase of the injection period. The dominant factors that control penetration are the length of the nozzle orifice, the diameter of the orifice outlet, the viscosity of the fuel, and the injection pressure of the fuel. Increasing the ratio of the length of the orifice to its diameter will increase penetration and decrease atomization. Decreasing this ratio will have an opposite effect. Because penetration and atomization are opposed mutually and both are important, a compromise is necessary if uniform fuel distribution is to be obtained. The amount of fuel pressure for injection is dependent on the pressure of the air in the combustion chamber, and the amount of turbulence in the combustion space.

(3) *Function of the Injection System.* It is impossible to cover the operation and construction of the many types of modern injection systems in this lesson. However, the operation of the more common systems will be discussed. If the three basic functions of diesel fuel injection are kept in mind while studying the operation of the systems, it will be easier to understand how they work. The three basic functions are:

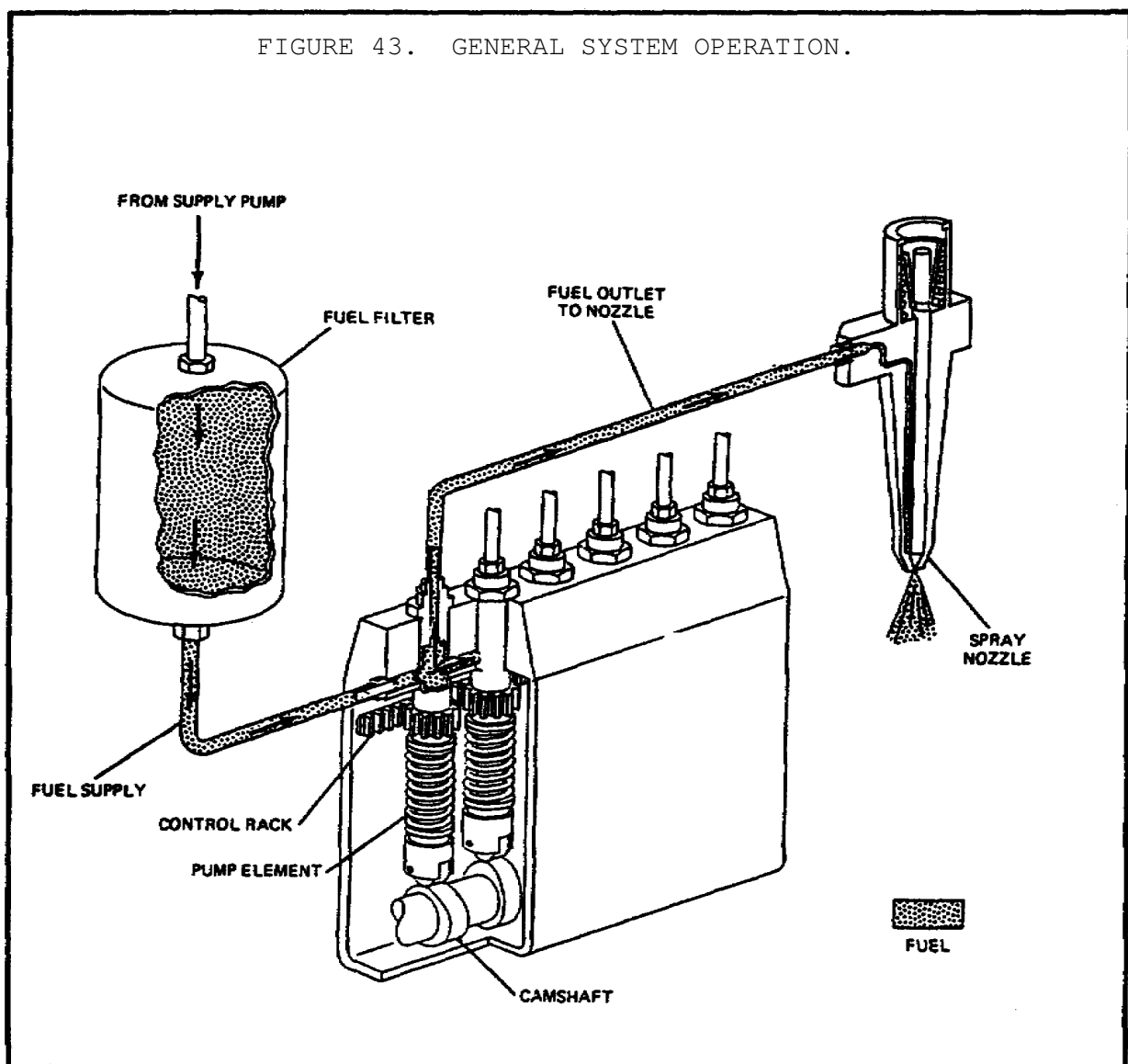
(a) To meter the fuel accurately.

(b) To distribute the fuel equally to all of the cylinders at a high enough pressure to ensure atomization.

(c) To control the start, rate, and duration of the injection.

b. *Multiple Unit Injection.*

(1) *General System Operation* (figure 43). The basic system consists of a fuel supply pump, fuel filter, multiple unit injection pump, and one injector for each cylinder. The operation of the system is as follows:





(a) The fuel supply pump and the fuel filter provide a low-pressure supply of fuel to the multiple unit injection pump. Pressure usually is regulated to approximately 15 psi.

(b) The multiple unit injection pump contains an individual injection pump for each engine cylinder. Fuel is delivered from the multiple unit injection pump to the injectors at each cylinder in a timed sequence and a regulated amount, based on accelerator pedal position and engine speed.

(c) The injectors receive fuel charges from their respective injection pumps and spray it into the combustion chambers in a spray pattern that is tailored to provide the best overall performance for their particular application.

(2) *The Multiple Unit Injection Pump.*

(a) The multiple unit injection pump contains an individual plunger-type injector pump for each cylinder. These pumps are arranged in a line so that they may be driven by a common camshaft. The lobes of the camshaft are arranged so that they operate the injection pumps in a sequence that coincides with the firing order of the engine. This camshaft is driven by the engine, through gears, at a speed of exactly one-half that of the crankshaft. This exact speed is maintained so that the injectors will each deliver their fuel charge at the beginning of their respective cylinder's power stroke. Power strokes occur during every other crankshaft revolution in a four-stroke cycle diesel engine.

(b) Excess fuel flows from the injection pump through the relief valve and back to the fuel tank. The relief valve usually is adjusted to open at approximately 15 psi.

(c) The pumps consist of a finely fitted plunger that is actuated by the camshaft against the force of the plunger spring. The bore that the plunger rides in has two passages machined into it. One of these passages is the delivery port, through which the pump is filled. The other passage is the spill port, through which excess fuel is discharged. When the plunger is fully in its return position, fuel flows into the pump cavity through the uncovered delivery port and out of the pump cavity through the uncovered spill port. The

pump cavity always is kept full as the fuel flows through. The plunger moves up in its bore as it is actuated by the camshaft, sealing the ports. The fuel that is trapped in the cavity is forced out of the pump and to its respective injector.

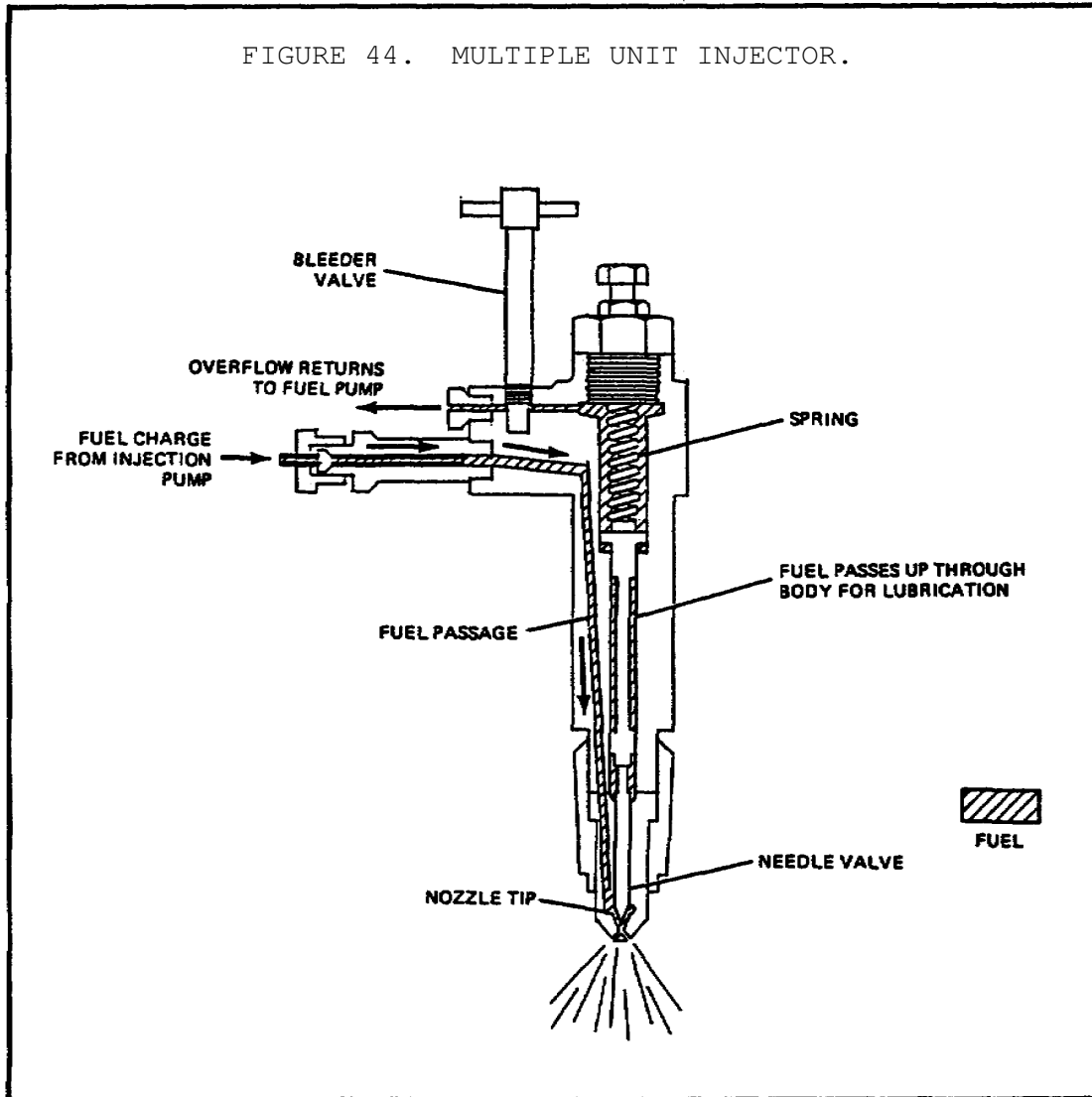
(d) The pump plunger has a rectangular slot cut into it that leads from the top face, down the side, and is finally connecting to a helical shaped cavity called the bypass helix. In operation, the slot will allow fuel to pass .to the bypass helix. As the bypass helix passes over the spill port, it will allow a portion of the fuel charge to bypass back to the fuel tank rather than be injected into the engine cylinder. The outer pump sleeve is made to rotate and has gear teeth around its outer diameter. A horizontal toothed rack meshes with these gear teeth to rotate the sleeve without any plunger rotation. By moving the rack back and forth, the outer pump sleeve is rotated, moving the delivery and spill ports in relation to the bypass helix on the pump plunger. This enables the volume of fuel injected to the cylinders to be varied by changing the effective length of the pump stroke (the length of the pump stroke that occurs before the spill port is uncovered by the bypass helix). The rack extends down the whole row of injection pumps so that they are all operated simultaneously. The end result is that the injection pumps can be moved from full to no-fuel delivery by moving the rack back and forth. Rack movement is controlled by a governor.

(e) When the plunger begins its pump stroke, it covers both ports. When this happens, the pressure exerted on the fuel causes the spring-loaded delivery valve to lift off of its seat, thereby permitting fuel to discharge into the tubing that leads to the spray nozzle. At the instant the bypass helix uncovers the spill port, the fuel begins to bypass. This causes the pressure in the pump cavity to drop.

High pressure in the delivery line combined with spring pressure causes the delivery valve to close. When the delivery valve closes, it prevents fuel from the line from draining back into the pump, which could cause the system to lose its prime. As the delivery valve seats, it also serves to reduce pressure in the delivery line. The delivery valve has an accurately lapped displacement piston incorporated into it to accomplish pressure relief.

The pressure is relieved in the line by the increase in volume as the delivery valve seats.

(3) *Fuel Injectors* (figure 44). For proper engine performance, the fuel must be injected into the combustion space in a definite spray pattern. This is accomplished by the fuel injector.



(a) The fuel enters the nozzle holder body through the high-pressure inlet. It then passes down to the pressure chamber above the valve seat.

(b) At the moment the pressure developed by the injection pump exceeds the force exerted by the

pressure adjusting spring, the nozzle valve will be lifted off of its seat resulting in the injection of fuel into the cylinder. The valve usually requires a fuel pressure of 1,000 to 40,000 psi to open, depending on the engine combustion chamber requirements.

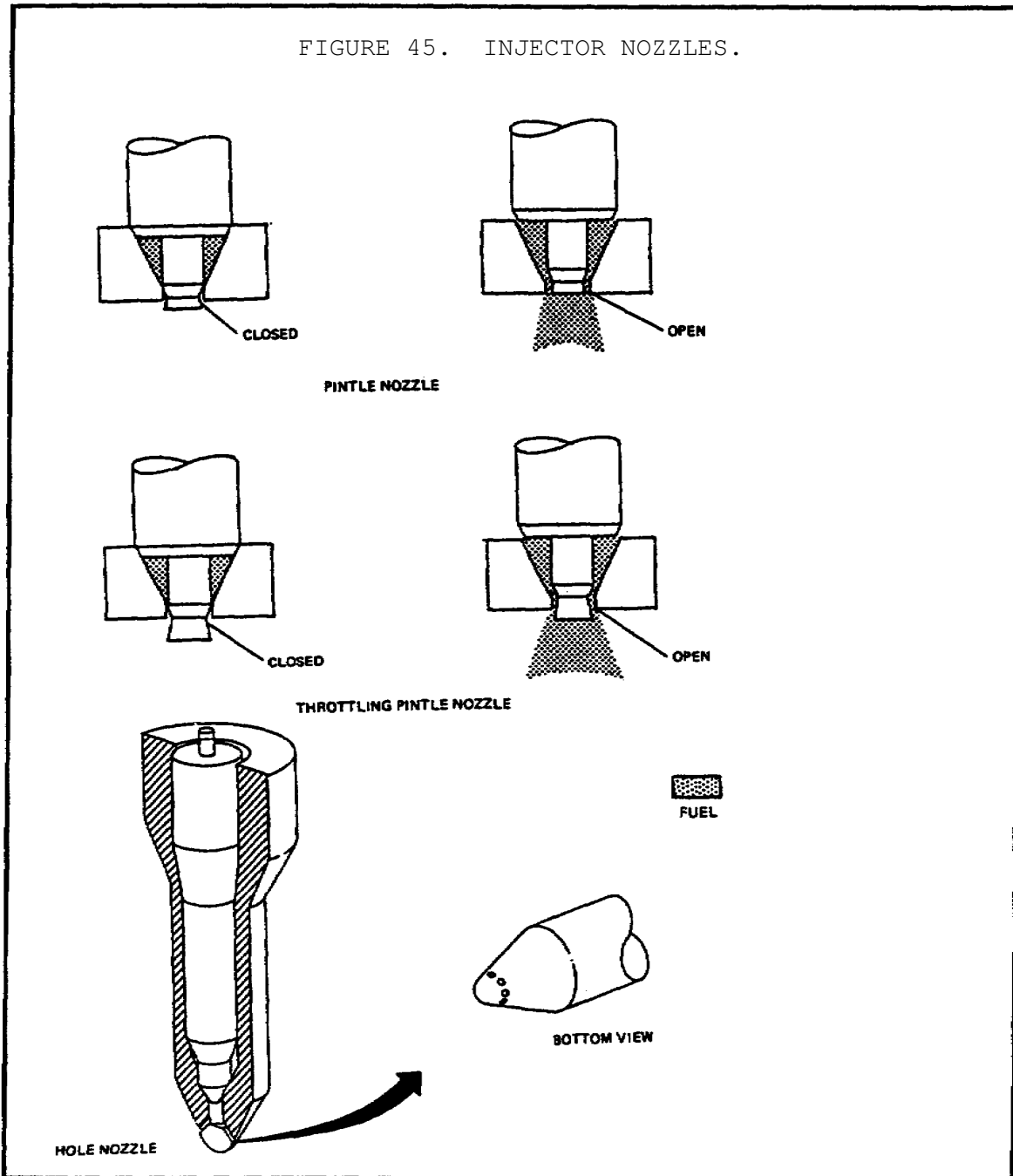
(c) A controlled seepage exists between the lapped surfaces of the nozzle valve and its body to provide for lubrication. The leakage or overflow passes around the spindle and into the pressure adjusting spring chamber. From here, the fuel leaves the injector through the overflow outlet and finally to the overflow lines, which lead back to the low-pressure fuel supply.

(4) *Injector Nozzles* (figure 45 on the following page). Because of the widely differing requirements in the shapes of the fuel spray for various chamber designs, and the wide range of engine power demands, there is a large variety of injector nozzles in use. The spray nozzles are put into two basic groups: pintle nozzles and hole nozzles. Pintle nozzles generally are used in engines having precombustion or turbulence chambers, whereas the hole nozzles generally are used in open chamber engines.

(a) In pintle nozzles, the nozzle valve carries an extension at its lower end in the form of a pin (pintle) which protrudes through the hole in the nozzle bottom. This requires the injected fuel to pass through an annular orifice, producing a hollow, cone-shaped spray, the nominal included angle of which may be from  $0^{\circ}$  to  $60^{\circ}$ , depending on the combustion chamber requirement. The projection of the pintle through the nozzle orifice includes a self-cleaning effect, discouraging the accumulation of carbon at this point.

(b) A specific type of pintle nozzle used extensively in small bore high-speed diesel engines is the throttling nozzle. It differs from the standard pintle nozzle in that the pintle projects from the nozzle for a much greater distance, and the orifice in the bottom of the nozzle body is much longer. The outstanding feature of the throttling nozzle is its control of the rate at which fuel is injected into the combustion chamber. When no fuel is being injected, the pintle extends through the nozzle orifice. At the beginning of the injection period, only a small quantity of fuel

is injected into the chamber because the straight section of the pintle is in the nozzle orifice. The volume of the fuel spray then increases progressively as the pintle is lifted higher, because the straight section leaves the nozzle orifice and the trapped tip of the pintle in the orifice provides a larger opening for the flow of fuel.



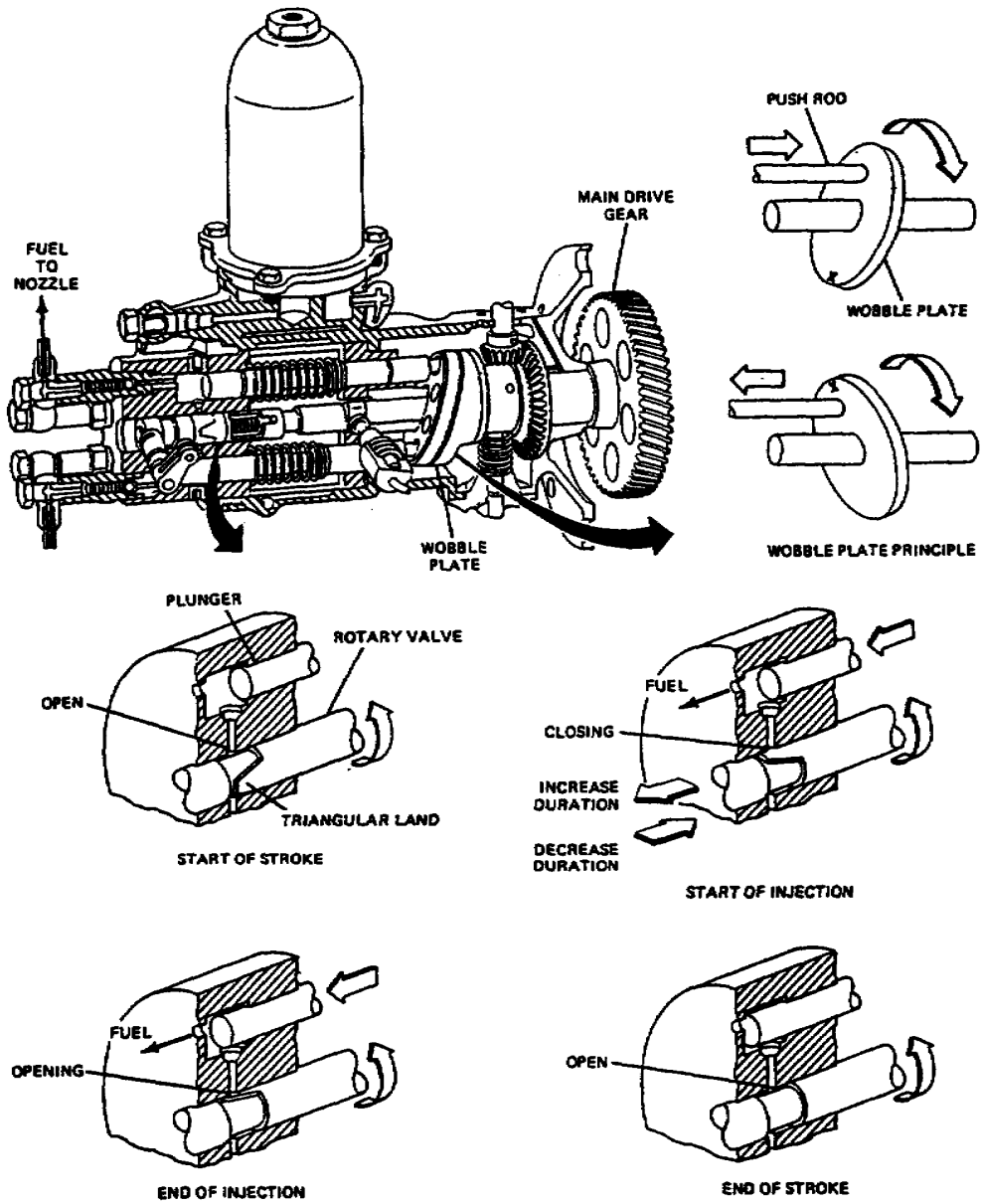
(c) Another type of throttling nozzle has its pintle flush with the nozzle-body tip for no-fuel delivery and extended through the body for maximum fuel delivery. In this type, fuel under high pressure from the injection pump acts on the seat area of the pintle, forcing it outward against a preloaded spring. This spring, through its action on a spring hanger, also returns the pintle to its seat, sealing the nozzle against further injections or dribble when the line pressure is relieved at the pump. When the pintle moves outward due to fuel pressure, an increasingly larger orifice area is opened around the flow angle of the pintle.

(d) The hole nozzles have no pintle but basically are similar in construction to the pintle type. They have one or more spray orifices that are straight, round passages through the tip of the nozzle body beneath the valve seat. The spray from each orifice is relatively dense and compact, and the general spray pattern is determined by the number and the arrangement of the holes. As many as 18 holes are provided in larger nozzles, and the diameter of these drilled orifices may be as small as 0.006 in. The spray pattern may not be symmetrical, as in the case of the multifuel engine, where the spray pattern is off to one side so as to deposit the fuel properly in the spherical combustion chamber. The size of the holes determines the degree of atomization attained. The smaller the holes, the greater the atomization; but if the hole is too small, it will be impossible to get enough fuel into the chamber during the short time allowed for injection. If the hole is too large, there will be an overrich mixture near the nozzle tip and a lean mixture at a distance from it. Using multiple holes in the injector tips usually overcomes both difficulties because the holes can be drilled small enough to provide proper atomization and in a sufficient number to allow the proper amount of fuel to enter during the injection period.

c. *Wobble Plate Pump System* (figure 46 on the following page).

(1) *General System Operation.* The wobble plate pump system basically is the same as the multiple unit injection system. The difference in the systems lies in the injection pump. In a wobble plate pump, all of the pump plungers are actuated by a single wobble plate instead of a camshaft that

FIGURE 46. WOBBLE PLATE INJECTION PUMP.



has a separate cam for each pump plunger. Also, the metering of the fuel is accomplished by a single axially located rotary valve in the wobble plate unit, whereas the rotary movement of the individual plungers controls the amount of fuel in the multiple unit injection pump.

(2) *Wobble Plate Pump Principles.* A plate is mounted on a shaft and set at an angle to it so that as the shaft rotates, the plate moves laterally in relation to any given point on either side of it. The pump derives its name from the fact that the plate appears to wobble back and forth as it rotates. The end of the push rod is placed in a guide plate that lays against the wobble plate. The push rod is held in a bore in the pump body so that it can move only in a direction parallel to the wobble plate shaft. The rotation of the wobble plate then causes the guide plate to wobble, thus moving the push rod back and forth. The push rod is connected to the pump plunger so that movement to the left actuates the pump on its delivery stroke and a spring returns it on the suction stroke.

(3) *The Wobble Plate Injection Pump.* As in the multiple unit injection pump, the wobble plate injection pump contains an individual plunger-type pump for each cylinder. The pump plungers are spaced equally about the wobble plate. As the wobble plate rotates, it will actuate all of the individual injection pumps. At any given time during rotation, half of the plungers will be moving on their delivery stroke while the other half will be on their return stroke.

(a) The rotary metering valve is driven by the same shaft that drives the wobble plate. The rotary valve consists of a lapped cylindrical shaft that is fitted closely in a barrel to prevent fuel from escaping at its ends. Fuel is admitted to the barrel at the center of the valve, which contains a spoonlike reduction in diameter. This reduction in diameter acts as a fuel reservoir.

(b) The reduced portion of the valve is in the shape of a band broken by a triangular land that is the same diameter as the ends of the valve. The reservoir created by the reduced portion of the valve is connected to each pump cavity by individual ports so that the pump cavities may be supplied with fuel. This reservoir receives a



constant supply of low-pressure fuel from the delivery pump. As with the multiple unit injection system, delivery pump pressure is regulated to approximately 15 psi.

(c) The triangular land serves to consecutively block each pump delivery port as it rotates. The triangular land is situated so that it will block each pump delivery port at the same time that the wobble plate is moving the respective pump plunger at the maximum speed through its delivery stroke.

(d) The rotational relationship of the rotary valve and the wobble plate causes each pump to deliver a fuel charge to its respective injector in turn as the pump rotates. The pumps in the injection unit are connected to the fuel injectors to coincide with the firing order of the engine. The pump is gear driven by the engine at a speed of exactly one-half that of the crankshaft. The end result will be the injection of fuel to each cylinder at the beginning of each power stroke.

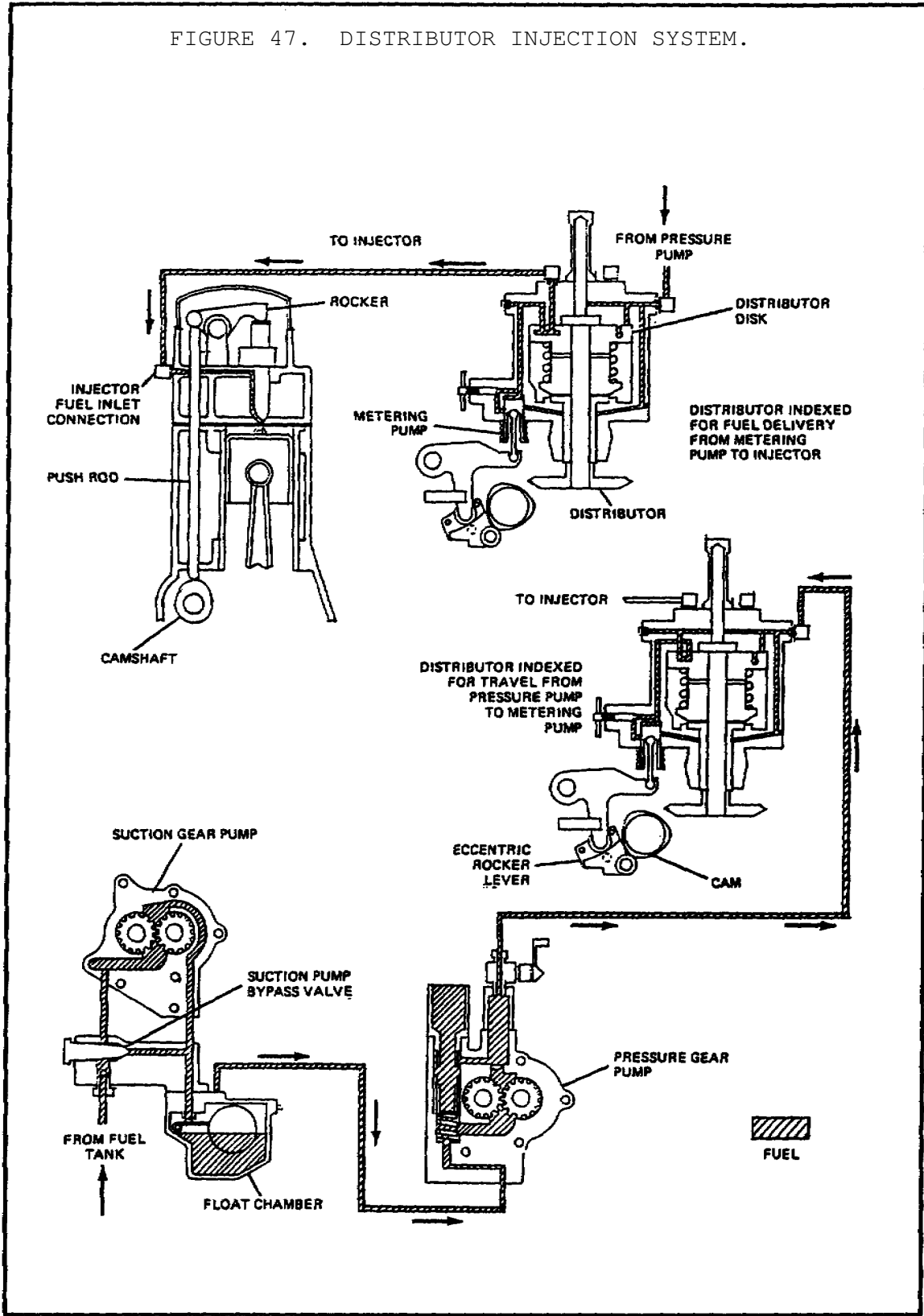
(e) To obtain zero delivery, the valve is moved endwise to a position where the delivery ports are never blocked by the triangular land. When this occurs, the movement of the pump plungers merely causes the fuel to move back and forth in the delivery ports. This results in zero delivery to the injectors due to insufficient pressure to open the spring-loaded delivery valves.

(f) To cause the pump to deliver fuel, the rotary valve is moved endwise so that the triangular land begins to block the delivery ports. Due to the triangular shape of the land, further endwise movement of the rotary valve will increase the time that the port is blocked, increasing fuel delivery. The end result is that fuel delivery can be controlled by the endwise movement of the rotary valve. Endwise movement of the rotary valve is accomplished by the control lever. The position of the control lever is determined by the governor.

#### d. *Distributor-Type Injection System.*

(1) *General System Operation* (figure 47 on the following page). The distributor injection system used in automotive diesel engines is classed as a low-pressure system in that pumping, metering, and distribution operations take place at low pressure. The high pressure required for injection

FIGURE 47. DISTRIBUTOR INJECTION SYSTEM.

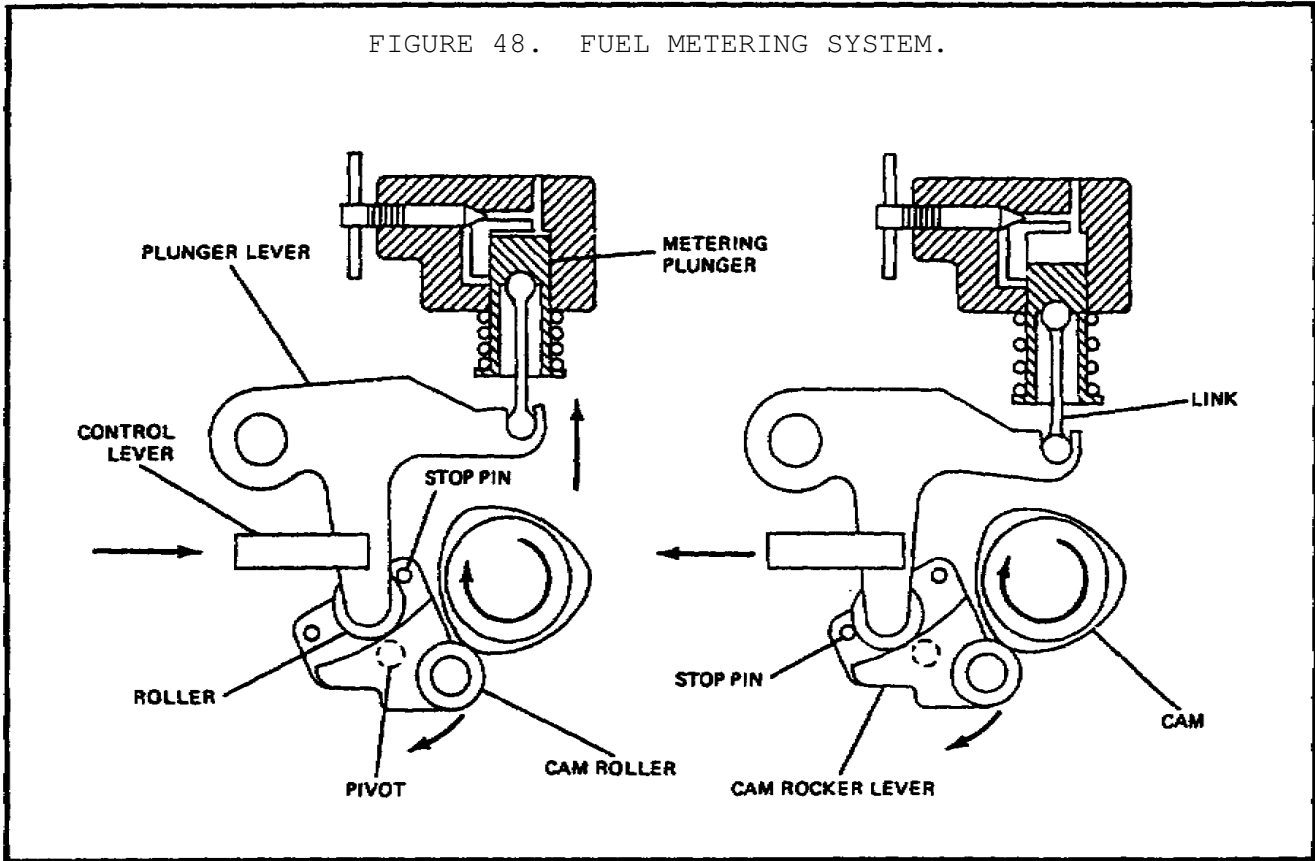


is built up by the injector at each cylinder. A suction pump lifts fuel from the tank and delivers it to the float chamber. From here a second low-pressure pump delivers the fuel to the distributor. Fuel passes through the distributor to the metering pump, where it is divided into measured charges. The fuel charges are then delivered back to the distributor, where they are sent to the injectors in the proper sequence. The measured charges are then sprayed into the engine cylinders, at the proper time and under high pressure, by the fuel injectors.

(2) *Distributor.* The distributor consists of a rotating disk and a stationary cover to which the fuel lines to the individual injectors are connected. The disk and the cover have a series of holes which, when properly indexed, form passages from the fuel supply pump to the metering pump. The disk is timed so that this occurs when the metering plunger is moving down on its suction stroke, thus permitting the metering pump to be filled with oil. As the disk continues to rotate, it lines up with the correct discharge hole in the cover just as the metering plunger begins its delivery stroke, forcing the fuel into the proper injector line. As it continues to rotate, the disk works in the same timed sequence in conjunction with the metering pump to feed fuel to the remaining cylinders. The rotating disk turns at one-half crankshaft speed because power strokes occur every other crankshaft revolution in a four-stroke cycle diesel engine.

(3) *Metering Unit* (figure 48 on the following page). The metering unit is a closely fitted reciprocating pump, obtaining its motion through a link from the plunger lever. The plunger lever is operated by a vertical lever, controlled in turn by an eccentric rocker lever running directly off a cam on the fuel pump main shaft. The position of the vertical lever in the eccentric of the rocker lever determines the travel of the plunger lever and, in turn, the travel of the metering pump plunger. As the pump plunger starts upward on its controlled stroke, it pushes fuel to the injector through passages formed by the rotating distributor disk. The stroke of the metering plunger, which determines the amount of fuel going to each injector, is varied by changing the position of the plunger lever between the stop pins in the cam rocker lever. The position of the plunger lever is adjusted by the governor through the control lever.

FIGURE 48. FUEL METERING SYSTEM.

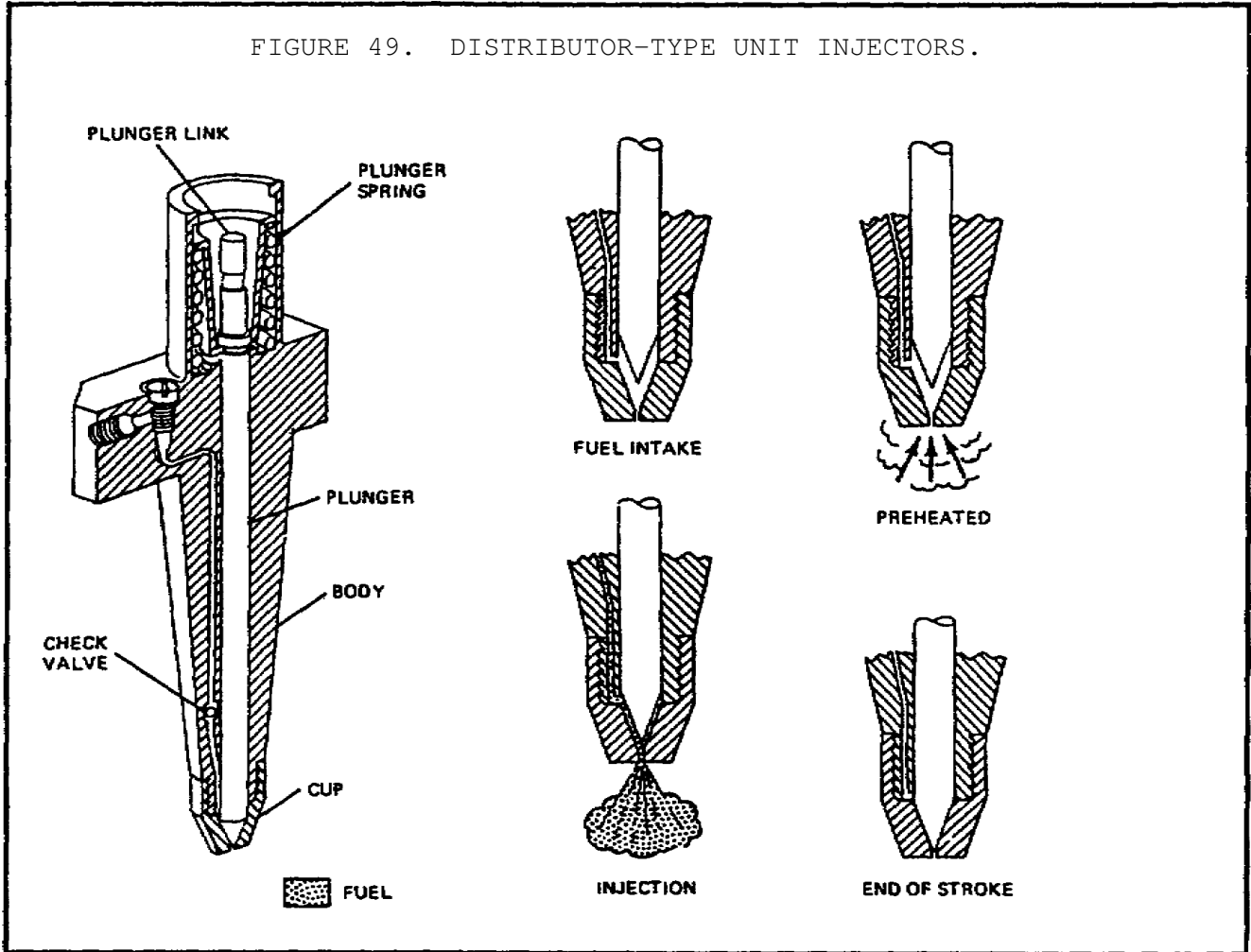


(4) *Injectors* (figure 49 on the following page). The injector consists of a forged body with a properly fitted plunger. This plunger is forced down by the engine camshaft against spring action through a rocker arm and push rod. A fuel cup is mounted on the end of the body, combined with a hole-type nozzle.

(a) The fuel metering pump forces a precisely measured fuel charge into the cup on the intake stroke of the engine. The quantity of the fuel charge is based on the speed and load requirements of the engine. The operation of this system depends on the injector delivery line being full of fuel. It will then follow naturally that any fuel added by the fuel metering pump will expel an equal amount of fuel into the injector.

(b) The fuel lies in the cup during the compression stroke of the engine, and the compressed air is forced through the small spray holes in the cup. The fuel in the tip of the cup is exposed to the intense heat of compression. The air rushing in through the holes in the nozzle tip serves to break the fuel charge into droplets.

FIGURE 49. DISTRIBUTOR-TYPE UNIT INJECTORS.



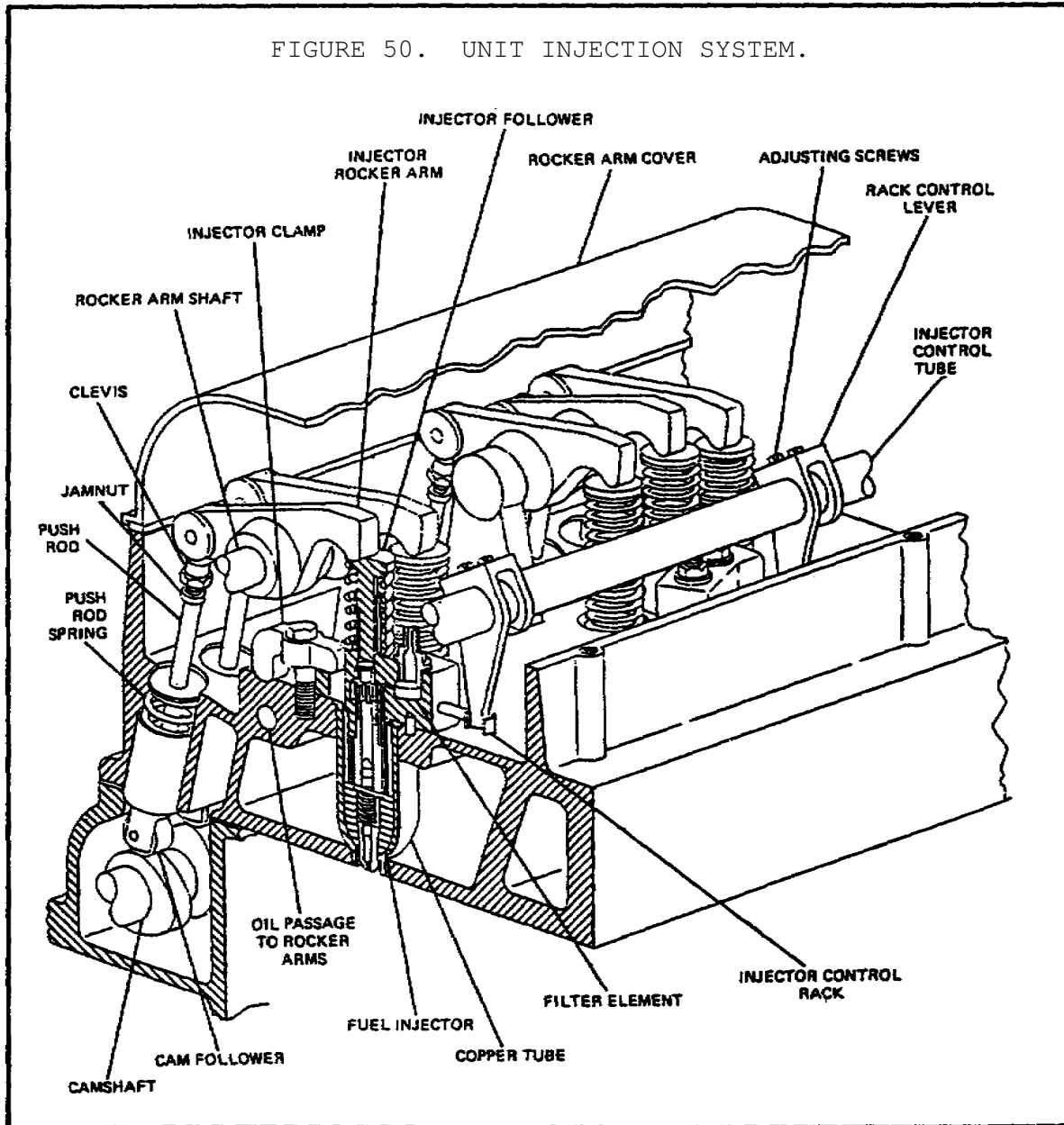
(c) A few degrees before top dead center, at the beginning of the power stroke, the injector plunger is forced down, causing the fuel charge to be sprayed out of the cup through the nozzle holes and into the combustion chamber. The downward movement of the injector plunger is spread out through the entire power stroke.

(d) There is a small check valve located in the inlet passage of the injector body. Its purpose is to allow fuel to enter the injector cup but block high combustion chamber pressure from blowing air into the injector delivery lines.

e. *Unit Injection System* (figure 50 on the following page).

(1) *Overall System Operation.* The unit injection system operates in the same manner as the multiple unit injection system. The difference is that rather than using a centrally located unit to

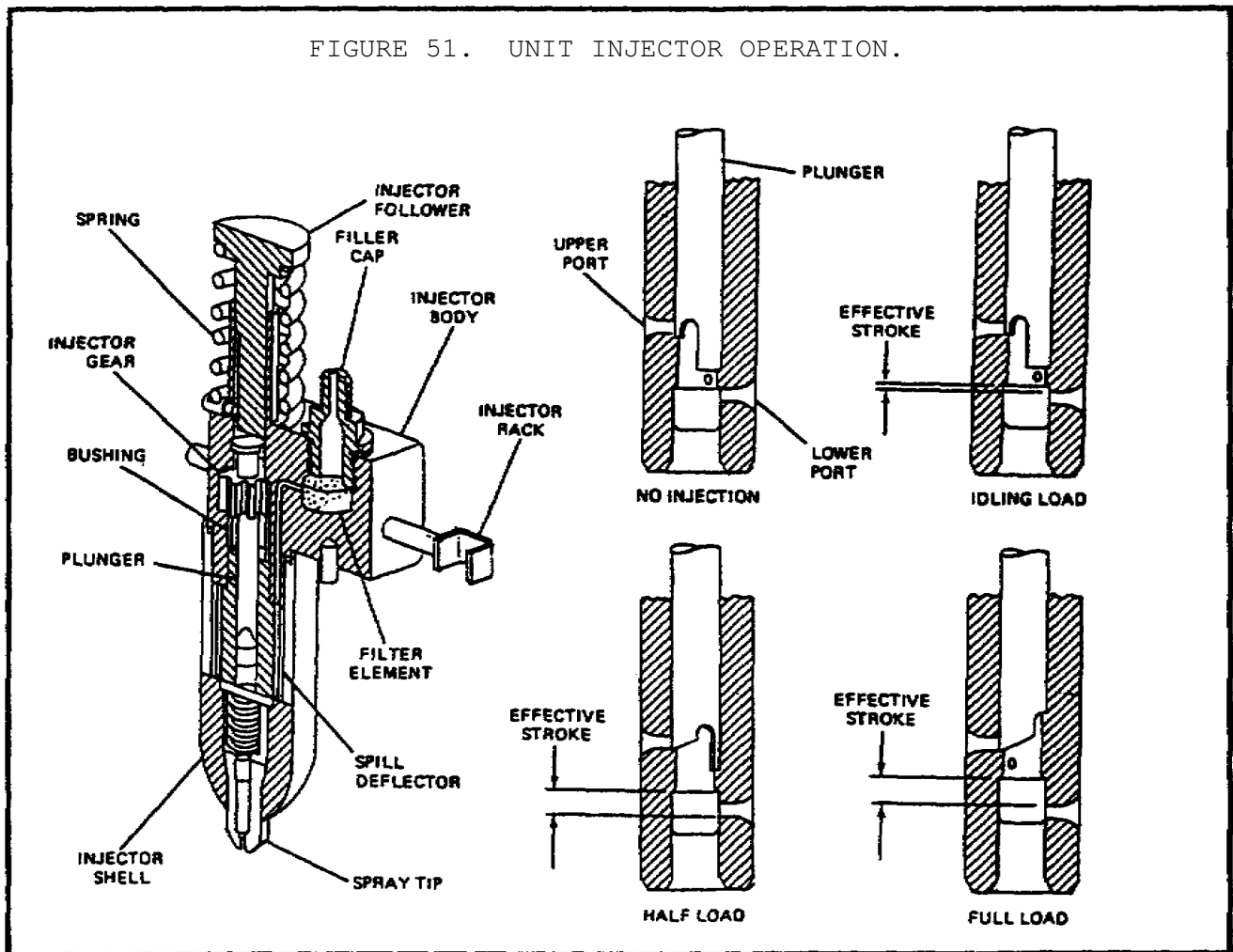
house the high-pressure pumps, control racks, pressure regulators, and delivery valves, they are all incorporated into each injector. This eliminates the need for high-pressure lines or any other apparatus besides the fuel supply pump.



(2) *Fuel Supply.* Fuel is drawn from the fuel tank by the fuel supply pump, through the primary fuel filter, and directly to the individual injector units. The fuel is supplied at low pressure, approximately 20 psi.

(3) *Injector Units* (figure 51). Unit injectors combine the injection pump, the fuel valves, and the nozzle in a single housing. These units provide a complete and independent injection system for each cylinder. The units are mounted in the cylinder head with their spray nozzles protruding into the combustion chamber. A clamp, bolted to the cylinder head and fitting into a machined recess in each side of the injector, holds the injector in place in a water-cooled copper tube that passes through the cylinder head. The tapered lower end of the injector seats in the copper tube, forming a tight seal to withstand the high pressures inside the cylinder. The injector operates as follows:

(a) Fuel is supplied to the injector through the filter cap. After passing through a finegrained filter element in the inlet passage, the fuel fills the annular shaped supply chamber that is created between the bushing and the spill deflector.



(b) The bushing bore is connected to the fuel supply by two funnel shaped ports, one on each side at different heights. The plunger operates up and down in the bushing bore.

(c) The plunger is actuated by a camshaft that is built right into the engine. The operation takes place through a rocker arm and push rod. The push rod has a roller-type cam follower and is spring loaded to prevent component damage in the event of injector nozzle clogging. The plunger is situated under a follower. This follower is spring-loaded to make it follow the camshaft.

(d) The plunger can be rotated in operation around its axis by the gear, which is meshed to the control rack. Each injector rack is connected by an easily detachable joint to a lever on a common control tube which, in turn, is linked to the governor and the throttle.

(e) For metering purposes, a recess with an upper helix and a lower helix, or a straight cutoff, is machined into the lower end of the plunger. The relation of this upper helix and lower cutoff to the two ports changes with the rotation of the plunger. As the plunger moves downward, the fuel in the high-pressure cylinder or bushing is first displaced through the ports back into the supply chamber until the lower edge of the plunger closes the lower port. The remaining oil is then forced upward through the center passage in the plunger into the recess between the upper helix and the lower cutoff, from which it can flow back into the supply chamber until the helix closes the upper port. The rotation of the plunger, by movement of the rack, changes the position of the helix in relation to the ports. This will advance or retard the closing of the ports and the beginning and ending of the injection period. This will result in a regulation of the volume of the fuel charge that is injected into the cylinder.

(f) When the control rack is pulled out completely, the upper port is not closed by the helix until after the lower port is uncovered. This means that all the fuel in the high-pressure cylinder bypasses back to the fuel supply and no fuel is injected into the combustion chamber.



(g) When the control rack is pushed in fully, the upper port is closed shortly after the lower port has been covered, thus producing a full effective stroke and maximum injection.

(h) From the no-delivery to the full-delivery positions of the control rack, the contour of the helix advances the closing of the ports and the beginning of injection.

(i) On the downward travel of the plunger, the metered amount of fuel is forced through the center passage of the valve assembly, through the check valve, and against the spray tip valve. When sufficient fuel pressure is built up, the spray tip valve is forced off its seat and fuel is discharged through the hole-type injector nozzle. The check valve prevents air leakage from the combustion chamber into the fuel system should the spray tip valve not seat properly.

(j) On the return upward movement of the plunger, the high-pressure cylinder is again filled with oil through the ports. The constant circulation of fuel through the injectors back through the return helps to maintain an even operating temperature in the injector, which would otherwise tend to run very hot due to extreme pressures. Constant circulation also helps to remove all traces of air from the system. The amount of fuel circulated through the injector is in excess of maximum needs, thus ensuring sufficient fuel for all conditions.

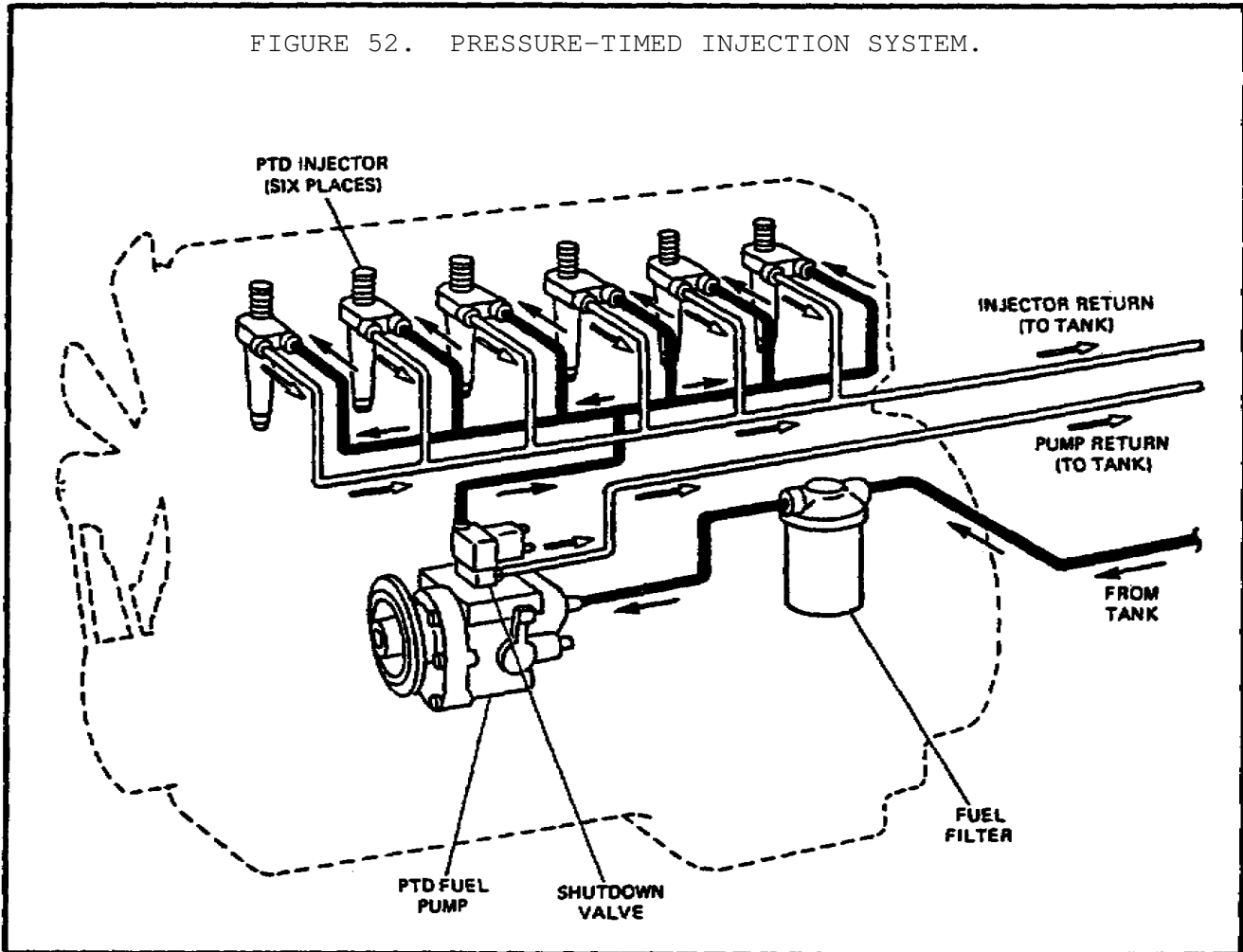
#### f. *Pressure-Timed (PT) Injection System*

(1) *Overall System Operation* (figure 52 on the following page). The pressure-timed injection system has a metering system based on the principle that the volume of liquid flow is proportional to the fluid pressure, the time allowed to flow, and the size of the passage the liquid flows through. The operation of the system is as follows:

(a) A fuel tank with a vented filler cap stores the fuel supply.

(b) Fuel is supplied from the tank to the pressure-timed gear (PTG) pump through the delivery line. An in-line filter is placed in series in the line to trap foreign matter and moisture.

FIGURE 52. PRESSURE-TIMED INJECTION SYSTEM.



(c) A return line from the PTG pump to the fuel tank is provided to bleed off excess fuel so that operating pressures can be regulated.

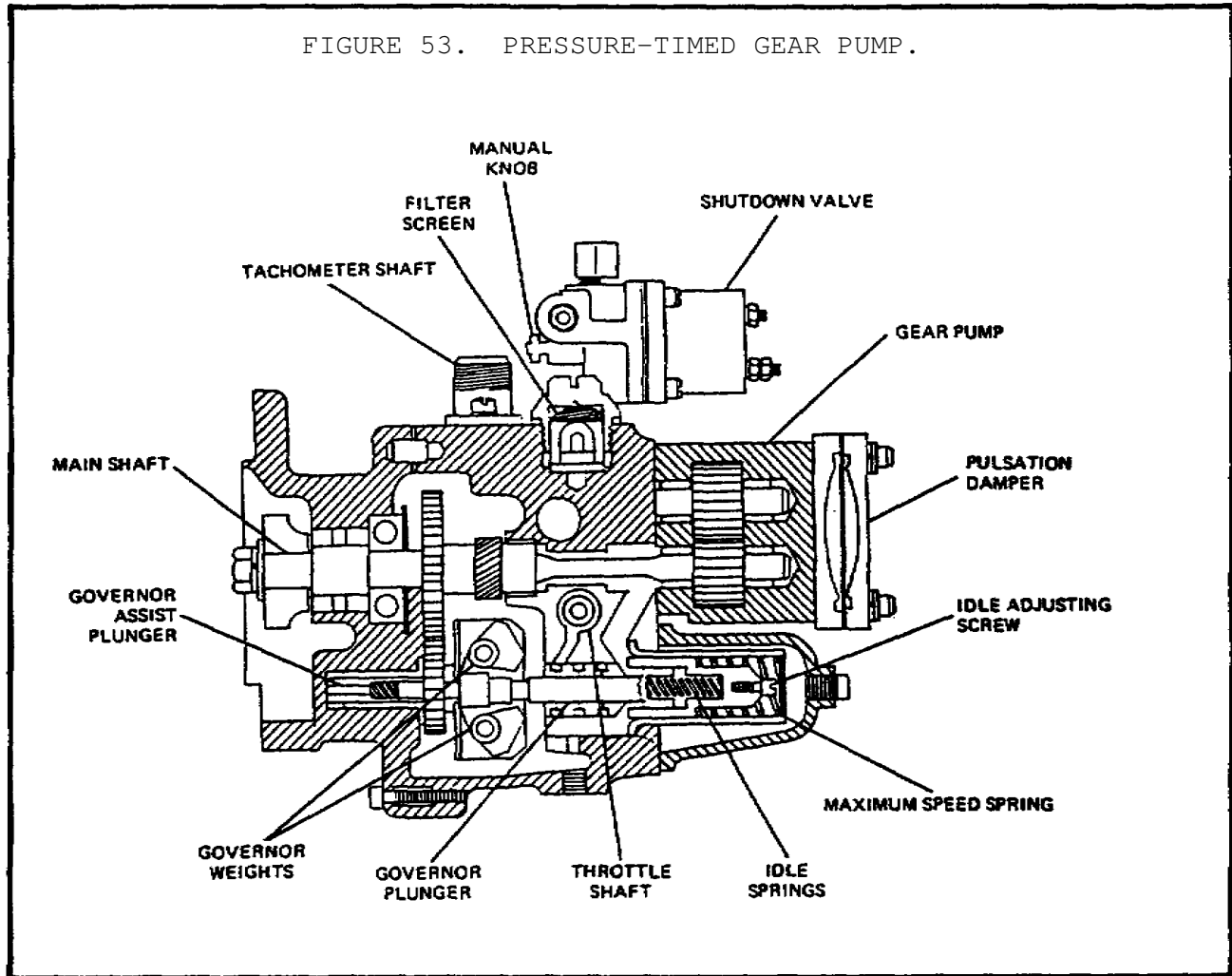
(d) The PTG pump delivers controlled amounts of fuel to pressure-timed delivery (PTD) injectors.

(e) Delivery of fuel to the PTD injectors is through a common-rail type delivery line.

(f) A common-rail type return line connects the PTD injectors to the fuel tank so that excess fuel may be diverted back to the fuel tank.

(2) PTV Injection Pump (figure 53 on the following page). The PTG pump is driven directly by the engine at a one-to-one speed ratio. The pump contains four main components. These four components and their operations are described as follows:

FIGURE 53. PRESSURE-TIMED GEAR PUMP.



(a) The gear-type pump draws fuel from the supply tanks and forces it through the pump filter screen to the governor. It is driven by the pump main shaft and picks up and delivers fuel throughout the fuel system. A pulsation damper mounted to the gear pump contains a steel diaphragm that absorbs pulsations and smooths fuel flow through the fuel system. From the gear pump, fuel flows through the filter screen to the governor screen. The PTG pumps are equipped with a bleed line that is attached to the engine injector return line or to the tank. This prevents excessive fuel temperature within the fuel pump by using the surplus fuel as a coolant. The bleed line functions primarily when the pump throttle is set at idle speed, but gear pump output is high due to engine operating speed, as occurs during downhill operation. A special check valve and/or fitting is used in the gear pump to accomplish the bleed action.

(b) The governor controls the flow of the fuel from the gear pump, as well as the maximum and idle speeds. The mechanical governor is actuated by a system of springs and weights and has two functions: First, the governor maintains sufficient fuel for idling with the throttle control in idle position; second, it will restrict fuel to the injectors above maximum rated rpm. The idle springs (in the governor spring pack) position the governor plunger so the idle fuel port is opened enough to permit passage of fuel to maintain engine idle speed.

During operation between idle and maximum speeds, fuel flows through the governor to the injector in accordance with the engine requirements, as controlled by the throttle and limited by the size of the idle spring plunger counterbore on the PTG fuel pumps. When the engine reaches governed speed, the governor weights move the governor plunger, and fuel flow to the injectors is restricted. At the same time, another passage opens and dumps the fuel back into the main pump body. In this manner, engine speed is controlled and limited by the governor, regardless of throttle position. Fuel leaving the pump flows through the shutdown valve, inlet supply lines, and into the injectors.

(c) The throttle provides a means for the operator to manually control engine speed above idle, as required by varying operating conditions of speed and load. In the PTG pump, fuel flows through the governor to the throttle shaft. At idle speed, fuel flows through the idle port in the governor barrel, past the throttle shaft. To operate above idle speed, fuel flows through the main governor barrel port to the throttling hole in the shaft.

(d) The fuel shutdown valve is located on top of the fuel pump. It shuts off fuel to the injectors. With the master switch on, the solenoid opens the valve. With the switch off, the spring loaded valve returns to the OFF position. In case of an electrical failure, rotation of the manual knob clockwise will permit fuel to flow through the valve. The knob is located on the front valve.

(3) *PTD Injectors.* A PTD injector is provided at each engine cylinder to spray the fuel into the combustion chambers. PTD injectors are of the unit

type, operated by an engine-based camshaft. Fuel flows from a connection at the top of the fuel pump shutdown valve, through a supply line, into the lower drilled passage in the cylinder head at the front of the engine. A second drilling in the head is aligned with the upper injector radial groove to drain away excess fuel. A fuel drain at the flywheel end of the engine allows return of the unused fuel to the fuel tank. There are four phases of injection operation:

(a) *Metering* (figure 54, view A, on the following page). This phase begins with the plunger just beginning to move downward when the engine is on the beginning of the compression stroke. The fuel is trapped in the cup, the check ball stops the fuel from flowing backwards, and the fuel begins to be pressurized. The excess fuel flows around the lower annular ring, up the barrel, and is trapped there.

(b) *Preinjection* (figure 54, view B, on the following page). The plunger is almost all the way down, the engine is almost at the end of the compression stroke, and the fuel is being pressurized by the plunger.

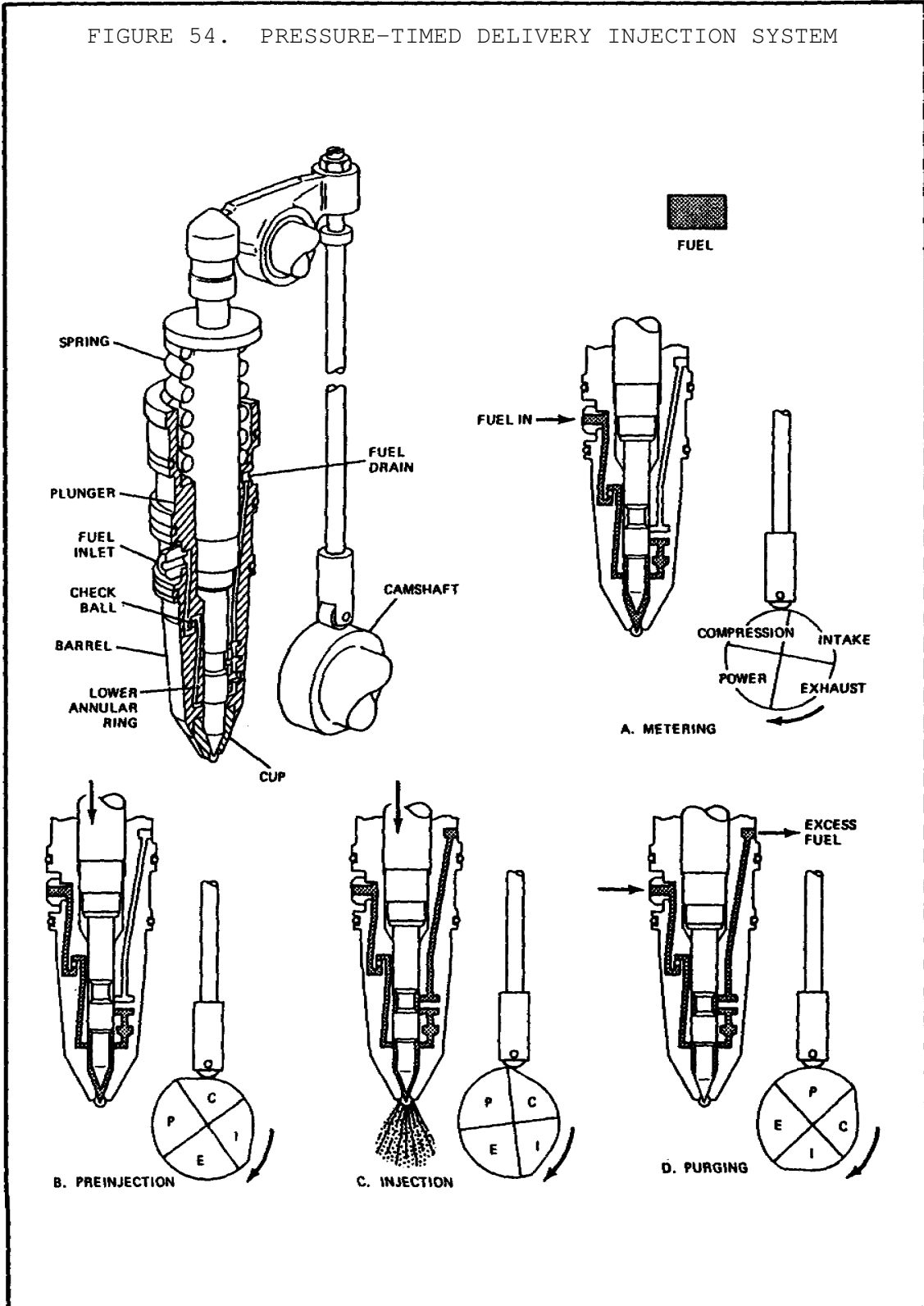
(c) *Injection* (figure 54, view C, on the following page). The plunger is almost all the way down, the fuel is injected out the eight orifices, and the engine is on the very end of the compression stroke.

(d) *Purging* (figure 54, view D, on the following page). The plunger is all the way down, injection is finished, and the fuel is flowing into the injector, around the lower annular groove, up a drilled passageway in the barrel, around the upper annular groove, and out through the fuel drain. The cylinder is on the power stroke. During the exhaust stroke, the plunger moves up and waits to begin the cycle all over again.

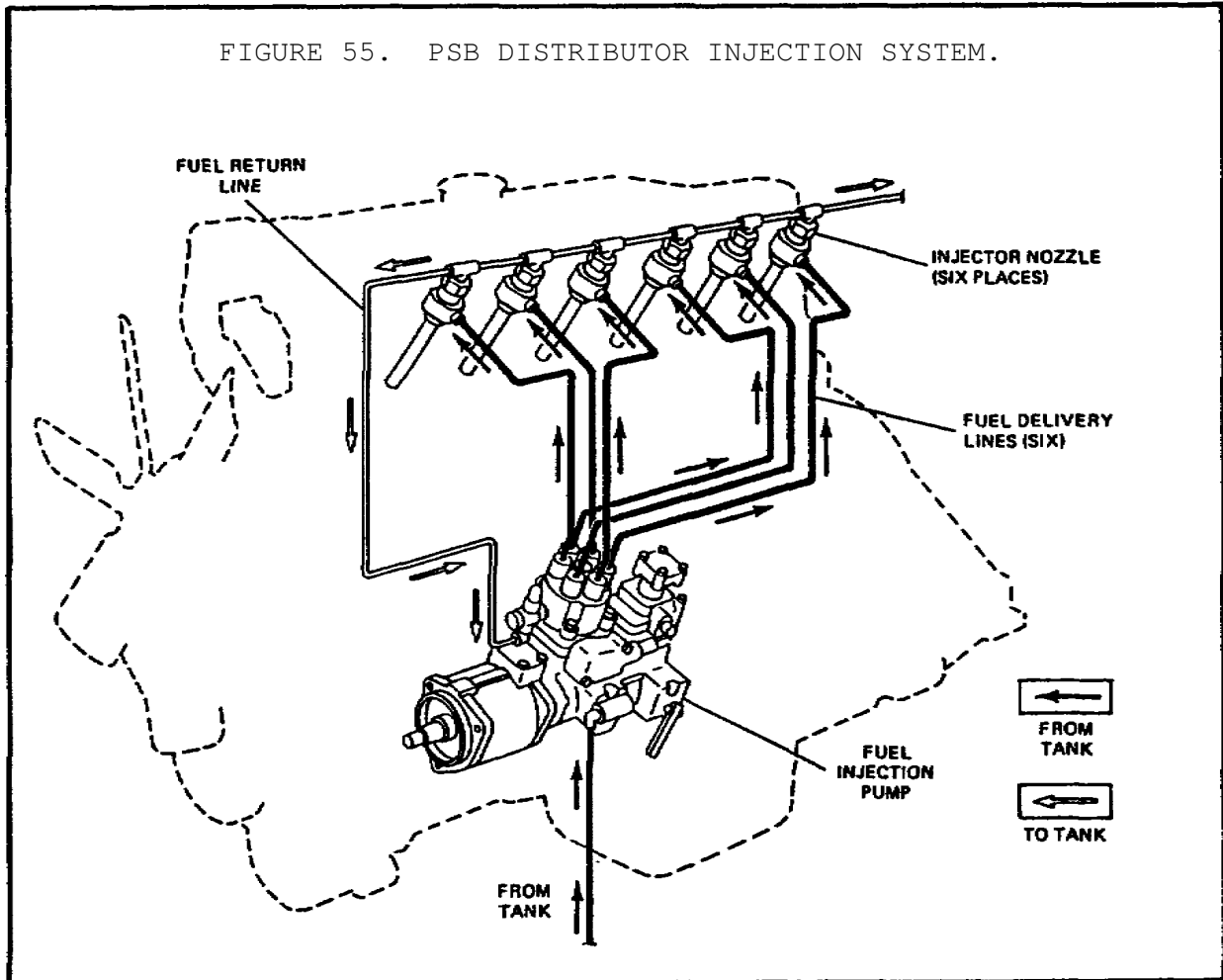
g. *PBS Distributor Injection System.*

(1) *Overall System Operation* (figure 55 on page 93). The PSB distributor system uses a pump that sends measured charges of fuel to each injector at a properly timed interval. The difference in the PSB system is that the charges of fuel are sent directly from the pump at the high pressure that is necessary for injection. This

FIGURE 54. PRESSURE-TIMED DELIVERY INJECTION SYSTEM



eliminates the need for unit-type injectors and the associated linkage and camshafts, making the system less cumbersome. The injectors are of the same basic design as the ones used in the multiple unit injection system. The nozzles usually are of the hole-type.

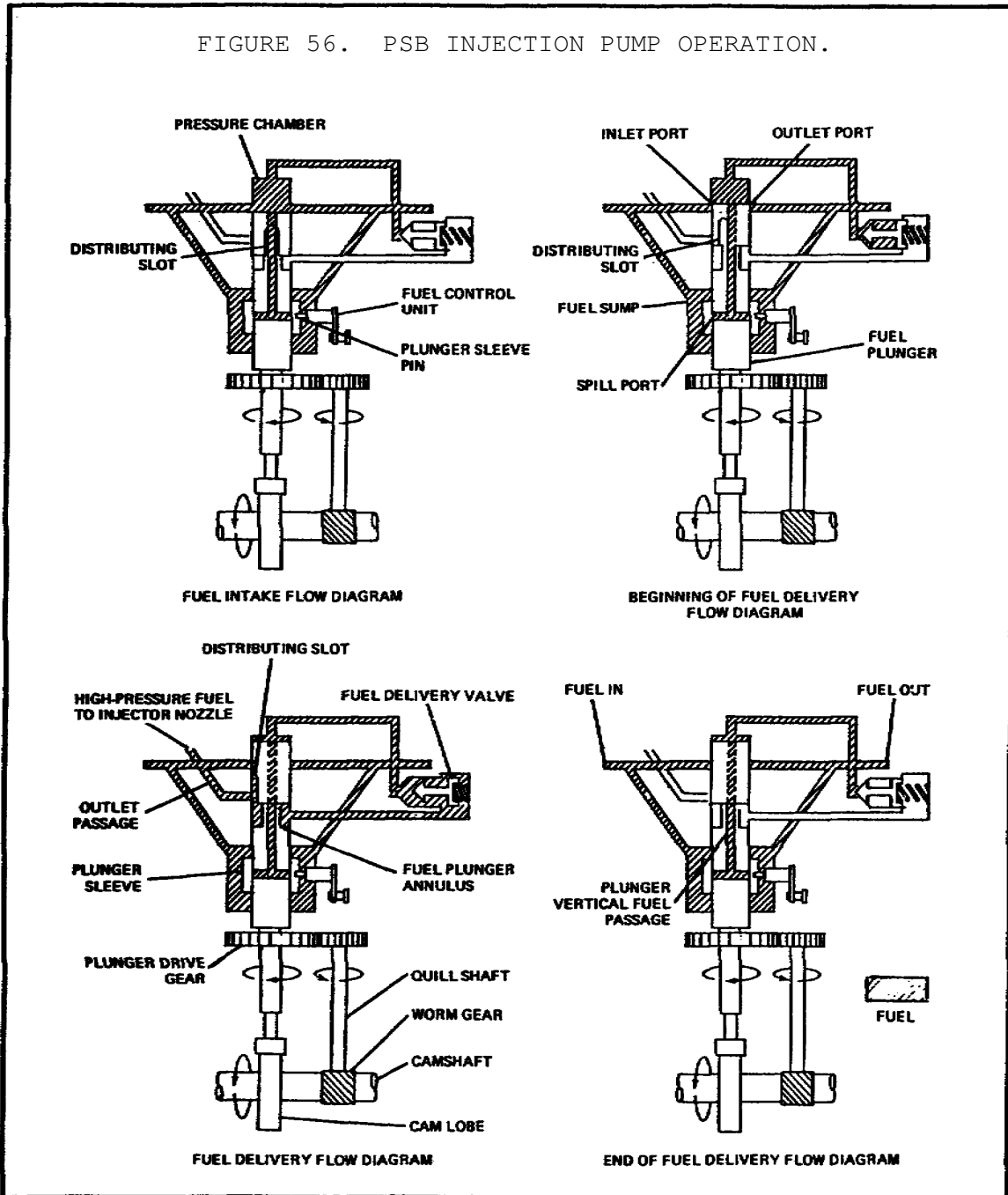


(2) *The PSB Injector Pump.* The PSB injection pump is compact and self-contained, housing all components of the injectors. Operation is shown in figure 56 on the following page.

(a) The PSB pump contains a plunger-type pump that creates the high-pressure fuel charges for the injectors. The pump is driven by a camshaft that is contained within the PBS unit. Fuel is delivered to the PBS pump from the fuel tank by the fuel delivery pump at a regulated pressure of approximately 20 psi. The low pressure fuel supply enters the pump chamber through the inlet port when the plunger is retracted fully. As the plunger

begins its delivery stroke, the fuel inlet passage is blocked, trapping fuel in the pump chamber. The delivery stroke of the plunger then pushes the charge of fuel out of the chamber through the delivery passage. The high-pressure fuel charge then unseats the delivery valve, allowing it to flow into the distribution chamber.

FIGURE 56. PSB INJECTION PUMP OPERATION.





(b) The pump plunger has a spoonlike recess in its diameter about halfway down its sides which, in conjunction with the pump cylinder, forms the distribution chamber. A slot is cut into the plunger at the top of the distribution chamber. As it reciprocates, the plunger is also rotated through a quill gear. As it rotates, the slot lines up with equally spaced passages around the inside of the plunger bore. Each passage is connected to a fuel injector. The reciprocating and rotating motion are timed so that the plunger will go through a delivery stroke as the slot lines up with each injector passage. This enables the PSB injector pump to deliver a fuel charge to each consecutive injector every time the plunger makes one complete revolution.

(c) The PSB pump is geared to the engine so that the camshaft rotates at crankshaft speed. The cam contains half as many lobes as the engine has cylinders (there would be three cam lobes if the engine had six cylinders). The pump plunger is geared to rotate at one-half of camshaft speed. This arrangement allows the PSB pump to deliver a charge of fuel to each injector for every two crankshaft revolutions corresponding to the requirements of a four-stroke cycle diesel.

(d) A hole, called a spill port, is drilled through the lower portion of the pump plunger. The spill port is connected to the pump chamber by another drilled passage. The spill port is covered by a plunger sleeve whose position is adjusted by the control lever through an eccentrically mounted pin.

(e) The movement of the control lever controls the up and down position of the plunger sleeve. The position of the control lever is determined by the governor. When the sleeve is in its extreme downward position, the spill port is immediately uncovered as the plunger begins its delivery stroke. This causes all of the pressure from the pump chamber to bleed off to the pump return. In this position, there will be no fuel delivery to the injectors.

(f) When the plunger sleeve is in the extreme upward position, the spill port is covered until the plunger almost reaches the end of the delivery stroke. This position will deliver maximum fuel to the injectors. As the plunger moves upward, the

pressure developed in the pump chamber unseats the delivery valve. Fuel flows into the distribution chamber and is sent by the slot in the plunger to whatever injector is scheduled to receive it.

(g) The amount of fuel delivered by each injection charge will increase proportionately as the plunger sleeve is moved from its extreme downward to its extreme upward position. The higher the plunger sleeve, the longer the effective pump stroke (plunger movement before the spill port is uncovered).

#### 4. Fuel Supply Pumps

a. *General.* Fuel injection pumps must be supplied with fuel under pressure for the following reasons:

(1) The injection pumps lack the suction ability to draw fuel from the tank by themselves.

(2) It is important to supply fuel in excess to the injection pump so that fuel may be used to cool and lubricate the system before bypassing it back to the tank.

(3) Without a supply pump, the system would lose its prime whenever the pump is in no-delivery mode.

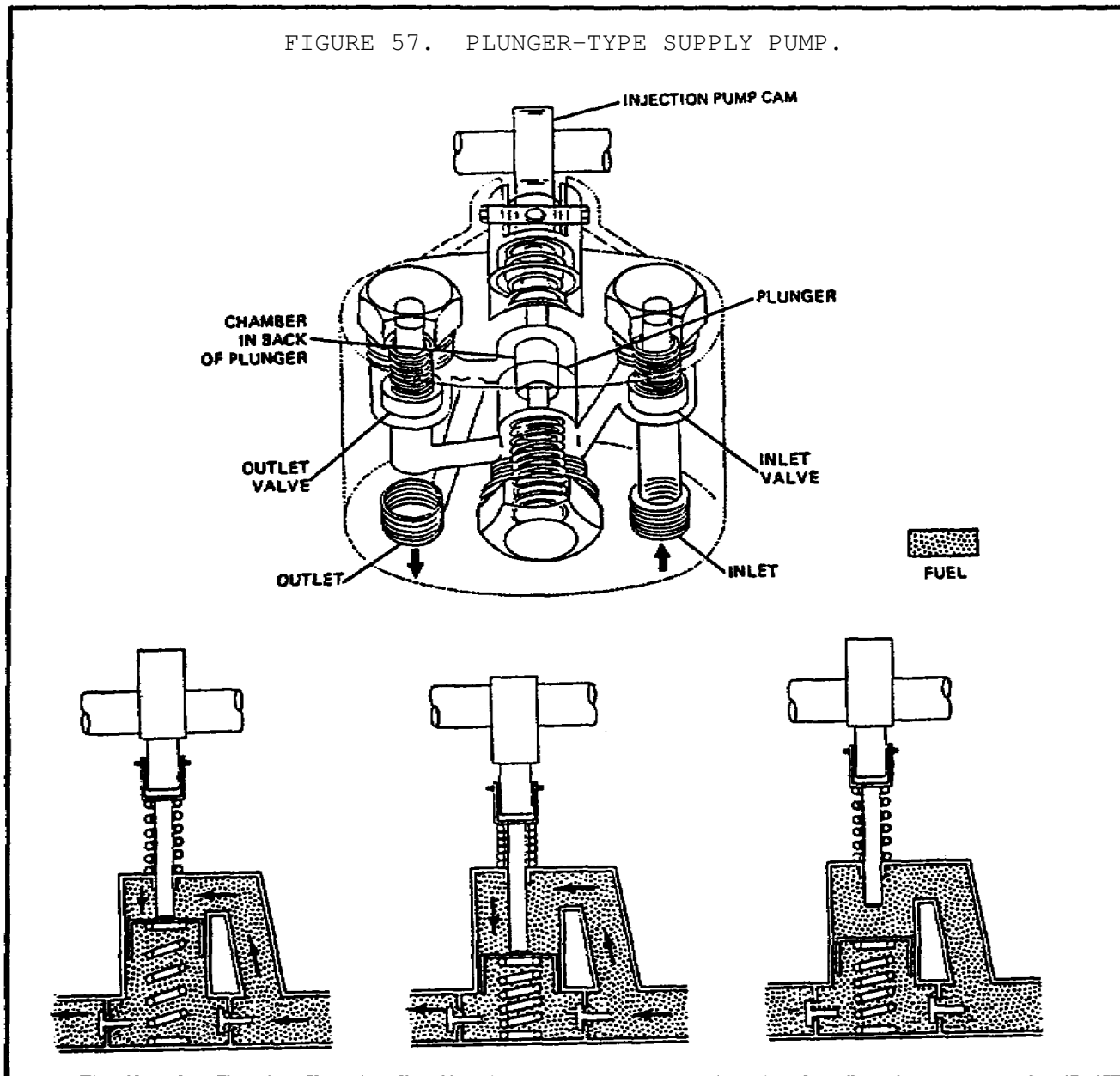
The supply pumps in use generally are of the positive displacement type with a performance that is independent of any reasonable variations in viscosity, pressure, or temperature of the fuel. In a majority of the equipment, the fuel supply pump is built into the injection pump unit. This cuts down on fuel tubing and the complexity of the equipment, and allows the supply pump to share the same engine power takeoff as the injection pump.

b. *Vane-Type Supply Pump.* The basic overall operation of the vane-type supply pump is the same as the vane-type oil pump.

c. *Plunger-Type Supply Pump* (figure 57 on the following page).

(1) This type of pump is always mounted on the injection pump, where it is driven by the injection pump camshaft. It is a variable-stroke, self-regulating pump that will build pressure only up to a predetermined point.

FIGURE 57. PLUNGER-TYPE SUPPLY PUMP.



(2) Operation.

(a) The plunger follows the camshaft by the force of its plunger spring. As the follower comes off the high point of the cam lobes, the plunger moves toward the retracted position. This plunger movement creates a suction in the pump chamber, causing fuel to enter through the inlet valve

(b) As the cam lobe comes around again, it forces the plunger upward. This forces the fuel out of the chamber through the outlet valve and to the injection pump.

(c) The cam follower drives the plunger through a spring. The spring is calibrated so that it will flex rather than drive the plunger when the pressure in the pump chamber reaches the desired maximum. This effectively regulates pump pressure.

d. *Gear-Type Supply Pump.* The basic overall operation of the gear-type supply pump is the same as the gear-type oil pump.

## 5. Governors

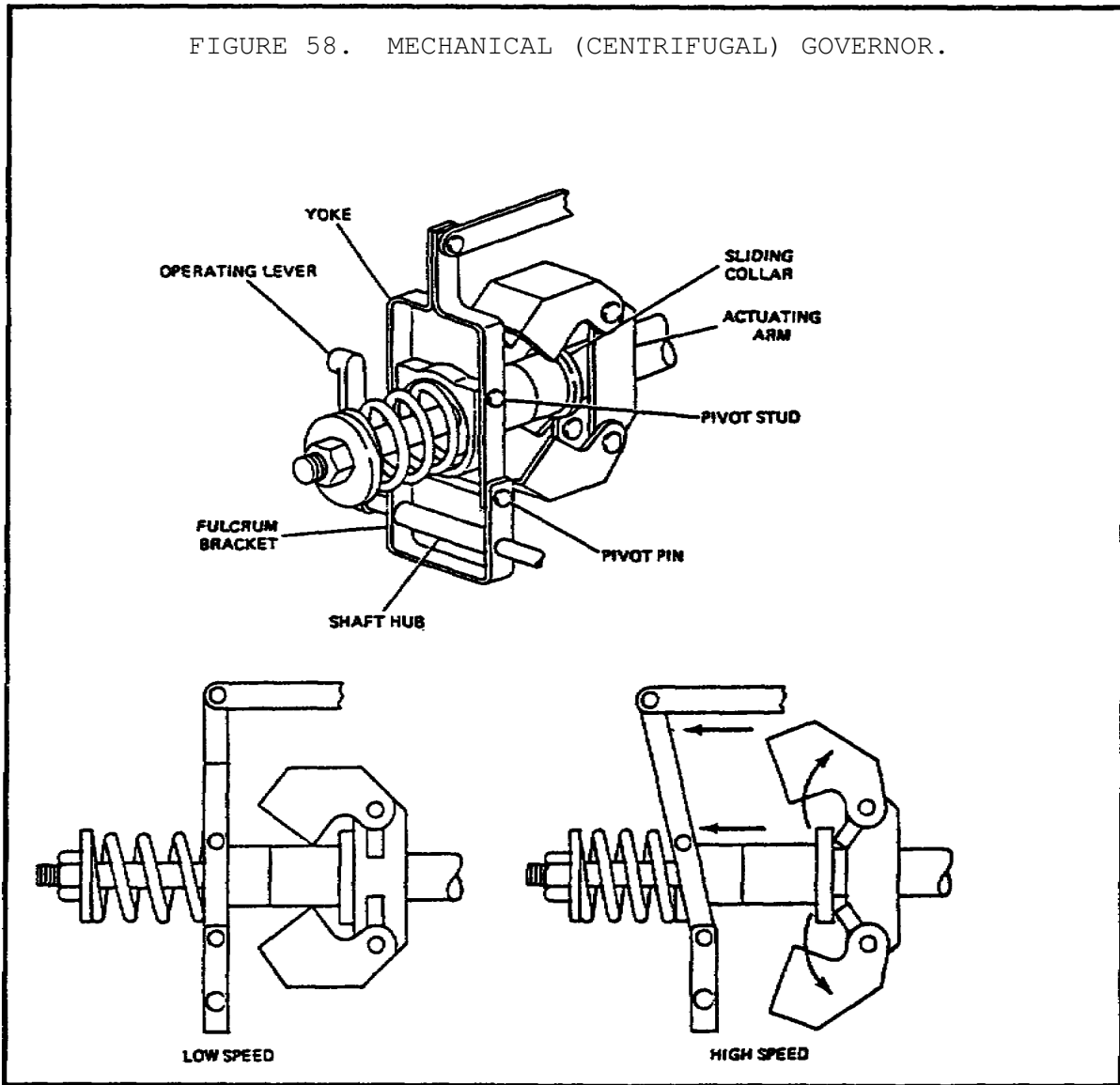
a. *General.* All diesel engines require governors to prevent overspeeding of the engines under light loads. Automotive diesel engines also demand control of idling speed. Any of the governors provide a variable-speed control which, in addition to controlling minimum and maximum speeds, will maintain any intermediate speed desired by the operator. Engine speed in a diesel is controlled by the amount of fuel injected. The injection, therefore, is designed to supply the maximum amount of fuel that will enable it to operate at full load while reaching a predetermined maximum speed (rpm). If, however, the maximum fuel charge were supplied to the cylinders while the engine was operating under a partial or unloaded condition, the result would be overspeeding and certain engine failure. Thus, it can be seen that the governor must control the amount of fuel injected in order to control the engine speed.

b. *Actuation.* Governors may be actuated through the movement of centrifugal flyweights or by the air-pressure differential produced by a governor valve and venturi assembly.

The centrifugal flyweight type may incorporate a mechanical linkage system to control the injection pump, or it may include a hydraulic system to transmit the action of the weights to the pump. On engines where the rate of acceleration must be high, the governor-controlling weights must be small to obtain the required rapid response from the governor. The problem is that the smaller flyweights will not exert enough force to control the injection pump properly. When this is the case, the flyweights will be used to control a hydraulic relay valve, which, in turn, will control the injection pump through a servo piston.

c. Mechanical (Centrifugal) Governors (figure 58).

(1) The operation of the mechanical governor is based on the centrifugal force of rotating weights counterbalanced by springs. When the speed of the engine increases, the weights fly outward, pulling with them suitable linkage to change the setting of the pump control rod. The governor linkage is connected to the injection pump in such a manner that the spring moves the control mechanism toward the full-fuel position. The outward movement of the governor flyweights, through the sliding governor sleeve, will move the pump control rod toward the no-fuel position against the force of the governor spring.



(2) With this type of governor, the operator controls the tension of the governor spring to control the quantity of fuel rather than operating the fuel control rod directly. The fuel delivery control system of the injection pump is connected to the governor yoke in such a manner that any movement of the yoke will directly affect the quantity of the fuel injected. The spring tension is controlled by the operating lever, the movement of which is determined by the position of the foot throttle. The travel of the operating lever is limited by the idle and maximum-speed screws. When the weights are fully collapsed (engine stopped), the spring moves the sliding sleeve and yoke so that the fuel injection pump is in the full-fuel position. When the weights are fully extended, the sliding sleeve and the yoke move to the rear and decrease the amount of fuel delivery.

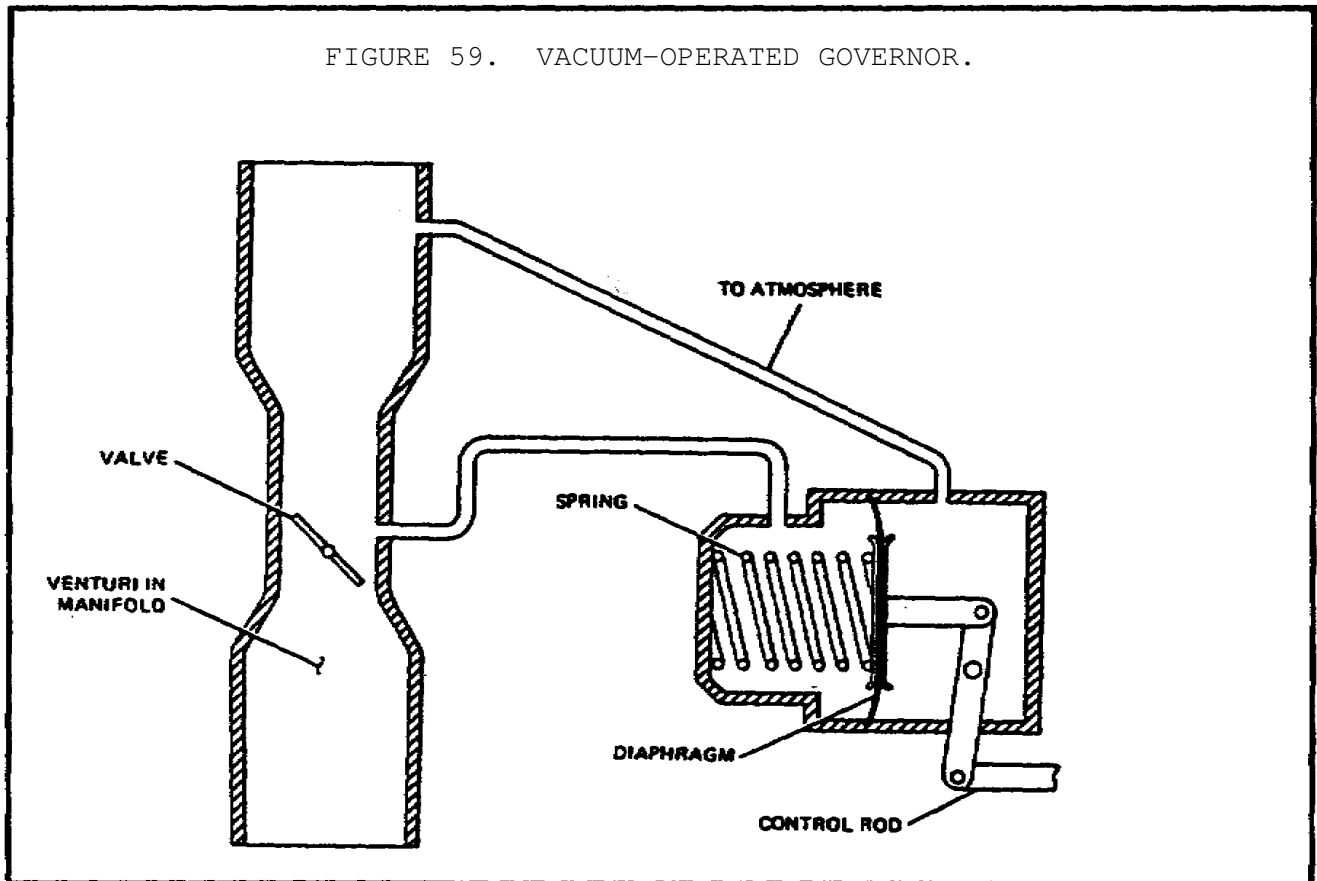
(3) If the load on the engine is decreased, the engine tends to accelerate, However, when the engine does accelerate, the increased centrifugal force causes the governor flyweights to move outward, resulting in the movement of the fuel control rod through the governor sleeve toward the no-fuel position. This will cause an equilibrium to develop between the flyweights and the governor spring. The movement of the operating lever varies the spring tension. This will cause a change in the point of equilibrium between the spring and the flyweights, effectively changing the engine speed for any given load.

(4) To accelerate the vehicle with a given load, the foot throttle is depressed, which in turn increases the governor spring tension. The increase in tension causes the governor sleeve to move the control rod through the yoke toward the full-fuel position. As engine speed increases, the flyweights will move outward until they reach the point of equilibrium with the governor spring. At this point, engine speed will stabilize.

d. *Vacuum Governor* (figure 59 on the following page).

(1) The vacuum governor operates by employing pressure drop, created by the velocity of the air passing through a venturi located in the air-intake manifold. The governor consists essentially of an atmospheric suspended diaphragm connected by linkage to the control rod of the injection pump.

The chamber on one side of the diaphragm is open to atmosphere, and on the other side it is sealed and connected to the venturi in the manifold. In addition, there is a spring acting on the sealed side of the chamber, which moves the diaphragm and the control rod to the full-fuel position normally.



(2) When the engine is running, the pressure in the sealed chamber is reduced below the atmospheric pressure existing in the other chamber. The amount of pressure reduction depends on the position of the governor valve and speed of the engine. It is this pressure differential that positions the diaphragm and, consequently, the control rod of the injection pump. The governor valve is controlled by a lever that is connected by suitable linkage to the foot throttle. There is no mechanical connection between the foot throttle and the control rod of the injection pump.

(3) If the engine is operating under load and the speed (rpm) is below governed speed, the velocity of air passing through the venturi is comparatively low and only a slight pressure differential is present. This will cause the spring to move the diaphragm and the injector pump

control rack toward the full-fuel position. As the engine speed picks up, the pressure differential on both sides of the diaphragm and the spring will achieve equilibrium and the position of the control rod will stabilize. The same operating principles will apply in reverse to prevent engine overspeed. As the engine speed increases, the velocity of air through the venturi increases, causing a corresponding increase in the pressure differential on both sides of the diaphragm. The increase in pressure differential causes the diaphragm and the control rod to move against the pressure of the spring toward the no-fuel position. The control rod's position will stabilize when equilibrium is achieved in the diaphragm unit. When the engine is operating at wide-open throttle, the pressure differential is about zero and spring force will move the control rack to the full-fuel position.

(4) For any position of the governor valve between idling and full load of the engine, the diaphragm finds its relative position. Because any movement of the diaphragm also is transmitted to the control rod, the amount of fuel delivery is definitely controlled at all speeds. The diaphragm is moved in the direction of less fuel delivery as the pressure drop between the chambers is increased. The spring will move the control rod in the direction of greater fuel delivery as the pressure drop is decreased.

## 6. Timing Device

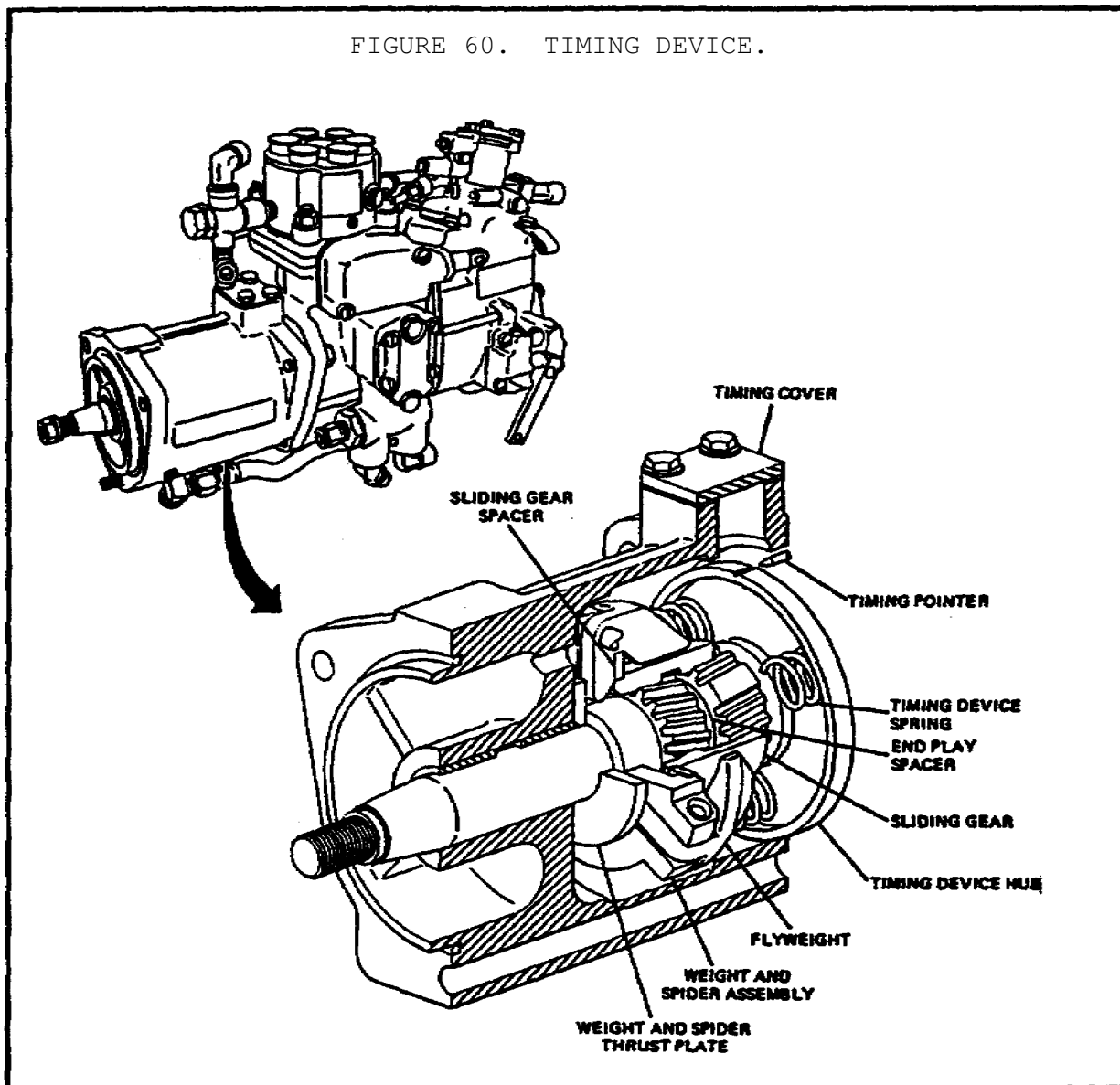
a. *General.* A large percentage of fuel injection pumps have timing devices incorporated in them. Varying the time when fuel injection begins will improve diesel engine performance and fuel economy, for the same reason that varying spark timing will improve the performance of a gasoline engine.

b. *Description* (figure 60 on following page).

(1) The timing device usually consists of an aluminum casting with mounting flanges at both ends. A bore in the housing guides and supports the spider assembly. A timing opening, with a cover, is located in the top of the housing and is used to observe the position of the timing pointer in relation to the timing mark on the timing device hub during injection pump timing procedures.



FIGURE 60. TIMING DEVICE.



(2) The timing device hub, with external left-hand helical splines for engaging the internal helical splines of the sliding gear, has a tapered bore and keyway. The hub is secured to the camshaft extension by a woodruff key, nut, and setscrew. The hub is usually counterbored to receive the timing device springs. The springs oppose the flyweight forces of the weight and spider assembly.

(3) The weight and spider assembly has external right-hand helical splines which mesh with the internal helical splines of the sliding gear. The splined end is machined to receive the end play spacer. Three flyweights are pinned to a flange

adjacent to the splines. The weight and spider thrust plate, located between the flange and the timing device housing, carries the back thrust of the flyweights and prevents housing wear.

(4) The sliding gear has internal left-hand helical splines at one end and internal right-hand helical splines at the other, and meshes with the external splines of both the weight and spider assembly and the timing device hub. Correct assembly of the spline train is ensured by a wide land on both the hub and weight and the spider assembly. The sliding gear has a missing tooth on each set of internal splines to receive the wide lands.

Three arms extend from the outer surface of the sliding gear to provide seats for the three timing device springs. The force on these springs is controlled by a sliding gear spacer.

c. *Operation* (figure 61 on the following page).

(1) As the engine rotates the weight and spider assembly, centrifugal force opens the flyweights from their collapsed position against the force of the three timing device springs.

(2) As the flyweights swing out, the sliding gear is forced toward the timing device hub.

(3) The longitudinal movement of the sliding gear on its helical spline causes a slight change in the rotational relationship of the injection pump to the engine, causing injection to begin slightly earlier in the power stroke.

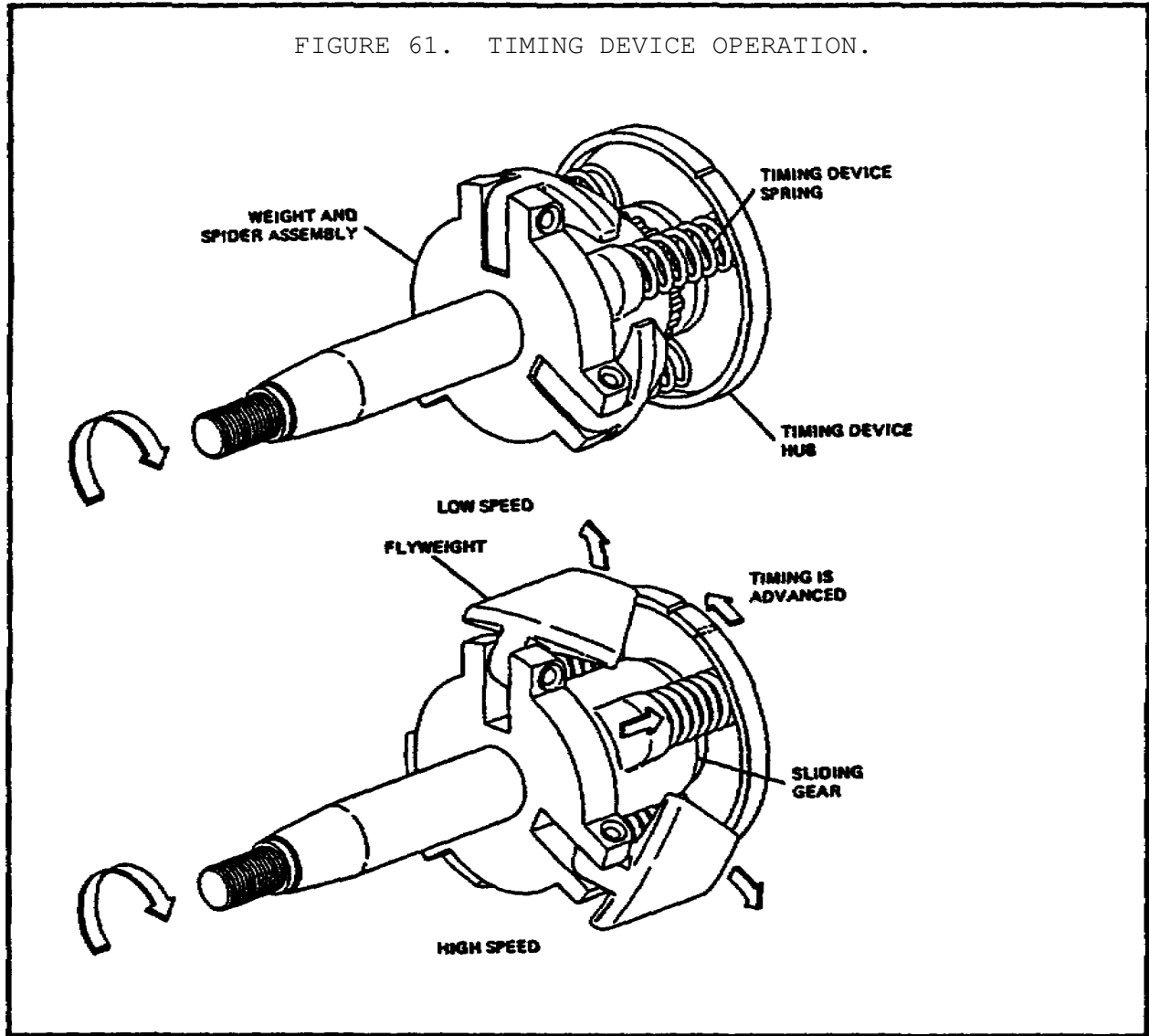
## 7. Cold Weather Starting Aids

a. *Purpose.* Diesel engines are very difficult to start in cold weather. This is due mainly to the low volatility of the fuel. The two most popular methods of assisting a diesel engine in starting are:

(1) Preheating the induction air in the intake manifold so that adequate vaporization will take place for combustion.

(2) Injecting a fuel into the engine that remains volatile enough in cold weather to initiate combustion.

FIGURE 61. TIMING DEVICE OPERATION.

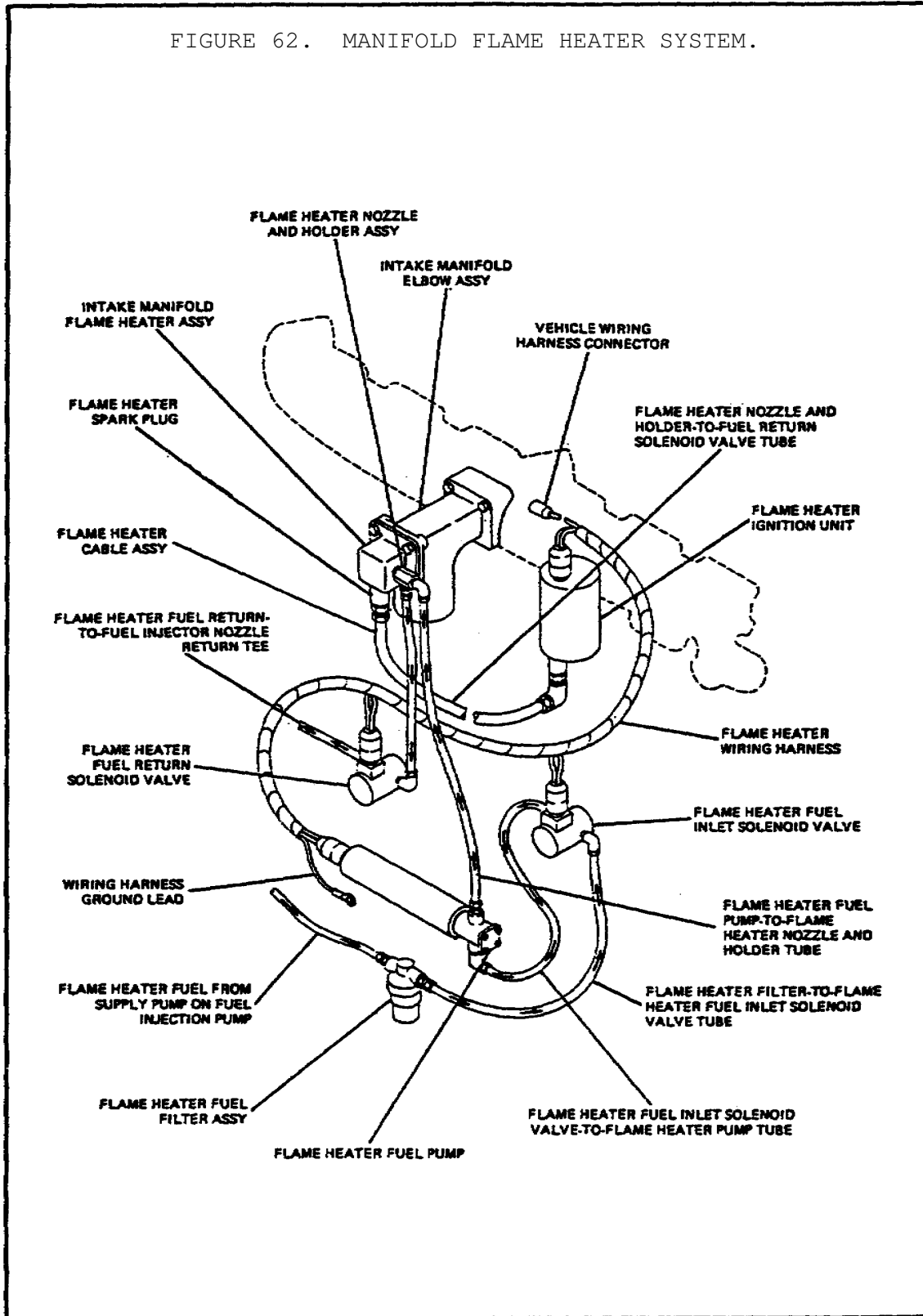


b. *Intake Manifold Flame Heater System* (figure 62 on the following page).

(1) *General*. Engines are equipped with a flame-type manifold heater for heating the induction air during cold weather starting and warmup operations.

(2) *Operation*. The flame heater assembly is composed of a housing, spark plug, flow control nozzle, and two solenoid control valves. The spark plug is energized by the flame heater ignition unit. The nozzle sprays fuel under pressure into the intake manifold elbow assembly. The fuel vapor is ignited by the spark plug and burns in the intake manifold, heating the air before it enters the combustion chamber.

FIGURE 62. MANIFOLD FLAME HEATER SYSTEM.



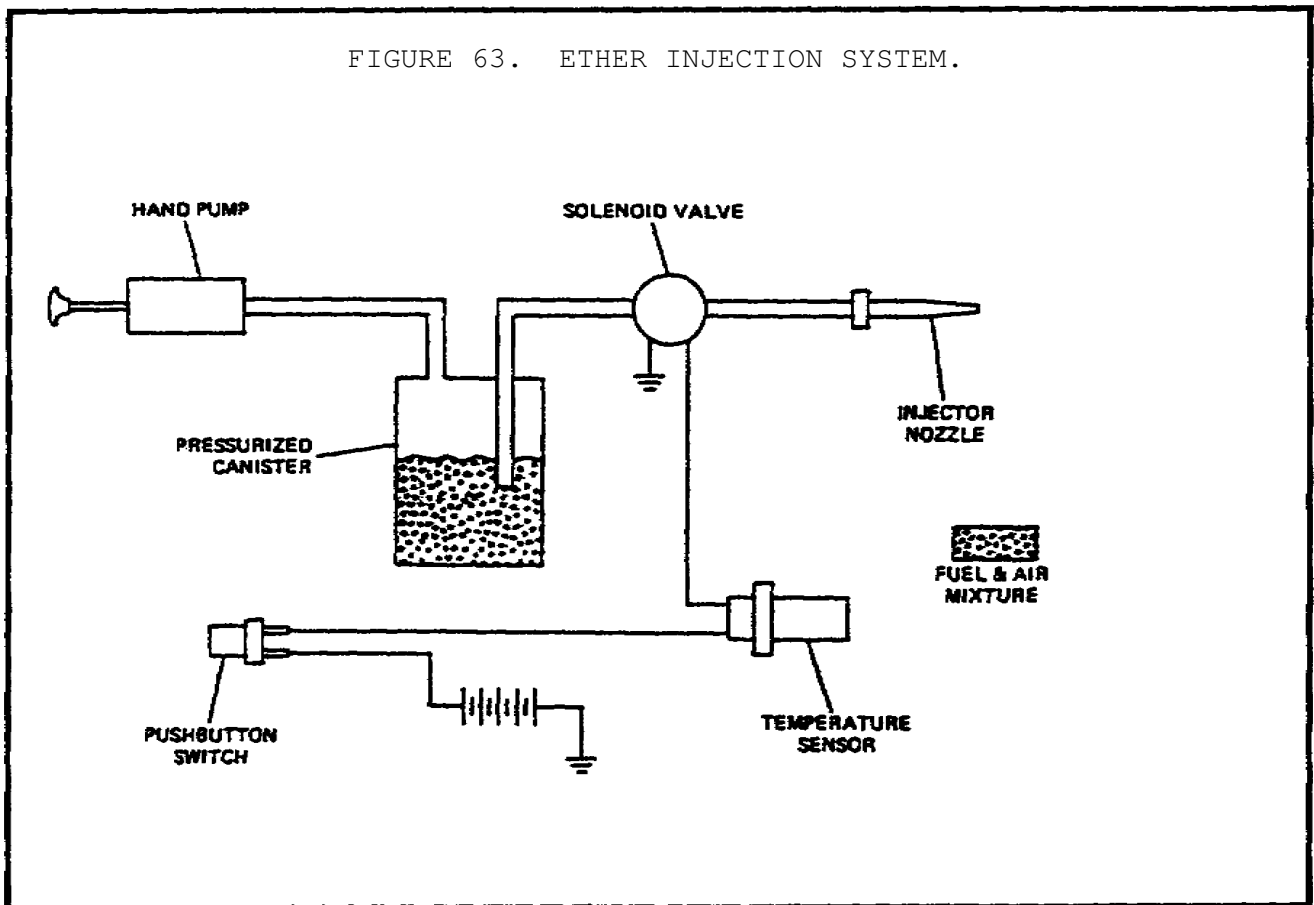
(a) Because this system uses fuel from the fuel tank of the vehicle, its components must be compatible with all approved fuels when the system is used with a multifuel engine.

(b) The flame fuel pump assembly is a rotary-type, driven by an enclosed electric motor. The fuel pump receives fuel from the vehicle fuel tank through the vehicle's supply pump and delivers it to the spray nozzle. The pump is energized by an ON-OFF switch located on the instrument panel.

(c) The intake manifold flame heater system has a filter to remove impurities from the fuel before it reaches the nozzle.

(d) Two fuel solenoid valves are used in the flame heater system. The valves are energized (open) whenever the flame heater system is activated. The valves ensure that fuel is delivered only when the system is operating. They stop fuel flow the instant that the engine or the heater system is shut down.

c. Ether Injection System (figure 63).



(1) *General.* The ether injection system assists in the cold weather starting of a diesel engine by injecting ether into the intake manifold. Ether, which is very volatile, will vaporize readily in cold weather, initiating combustion.

(2) *Operation.* A pressurized canister containing ether is fitted to the engine. The flow of ether from the canister to the spray nozzle is controlled by a solenoid valve that closes when it is deenergized. This solenoid is controlled by a pushbutton switch on the instrument panel.

(a) When the switch is pushed, the solenoid is energized. This opens the ether canister. Pressure from the canister pushes ether through a connecting tube to the nozzle, where it discharges into the intake.

(b) The system contains a coolant temperature sensor that will keep the system from functioning when coolant temperature is above 50° F.

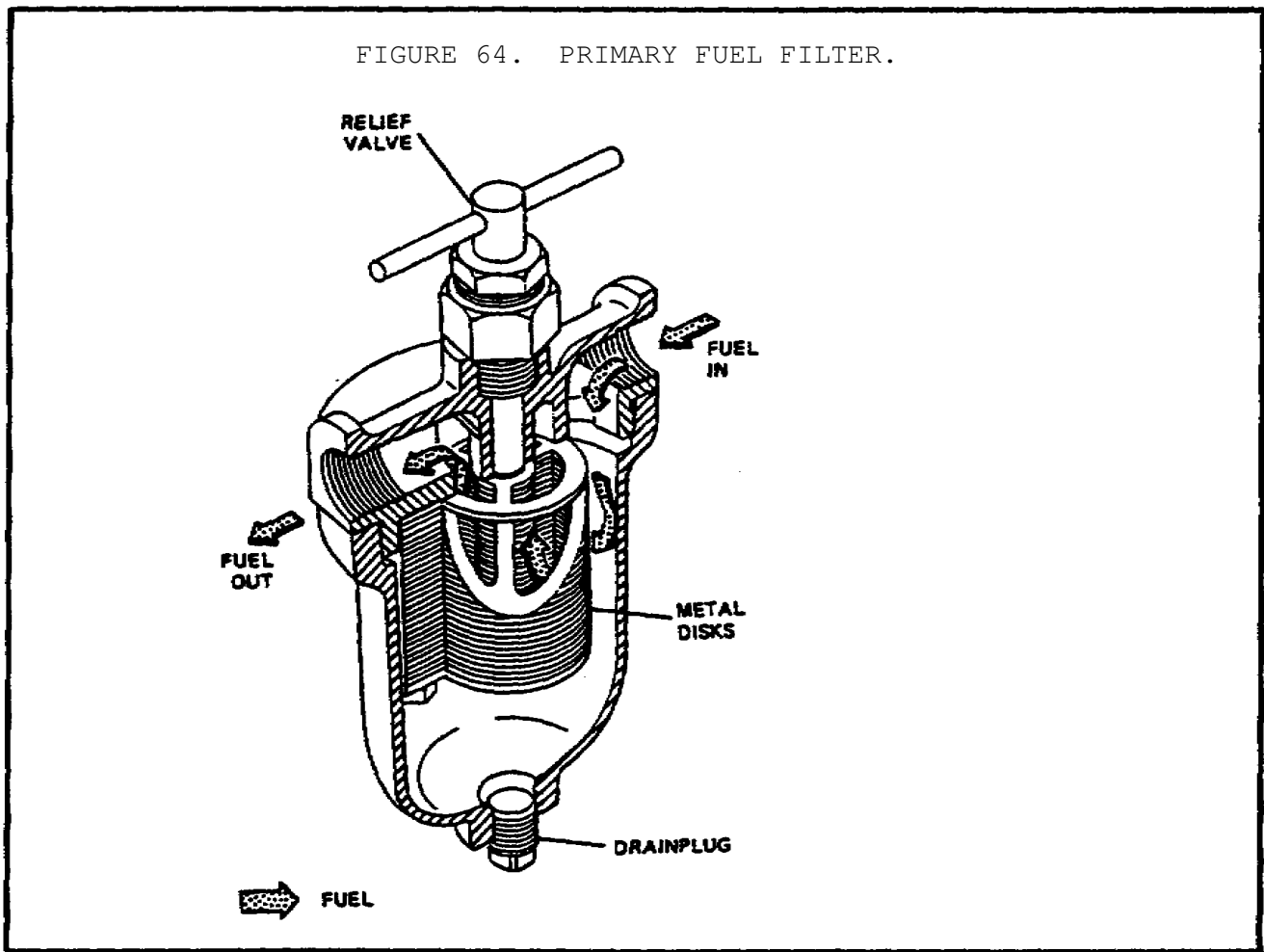
## 8. Fuel Filters

a. *General.* Thorough and careful filtration is especially necessary to keep diesel engines efficient. Diesel fuels are more viscous than gasoline and contain more gums and abrasive particles that may cause premature wear of injection equipment. The abrasives may consist of material that is difficult to eliminate during refining, or they may even enter the tank during careless refueling. Whatever the source, it is imperative that means be provided to protect the system from abrasives.

b. *Configuration.* Most diesel engine designs include at least two filters in the fuel supply systems to protect the closely fitted parts in the pumps and nozzles. The primary filter usually is located between the fuel tank and the fuel supply pump. The primary filter contains a coarse filter medium that removes the larger foreign matter. The secondary filter usually is located between the fuel supply pump and the fuel injection pump. The secondary filter contains a fine filter medium that removes even the most minute traces of foreign matter from the fuel. Additional filtering elements are frequently installed between the injection pump and the nozzle.

c. *Types.* Diesel fuel oil filters are referred to as full-flow filters, because all the fuel must pass through them before reaching the injection pumps. A diesel fuel filter usually incorporates an air valve to release any air that might accumulate in the filter during operation.

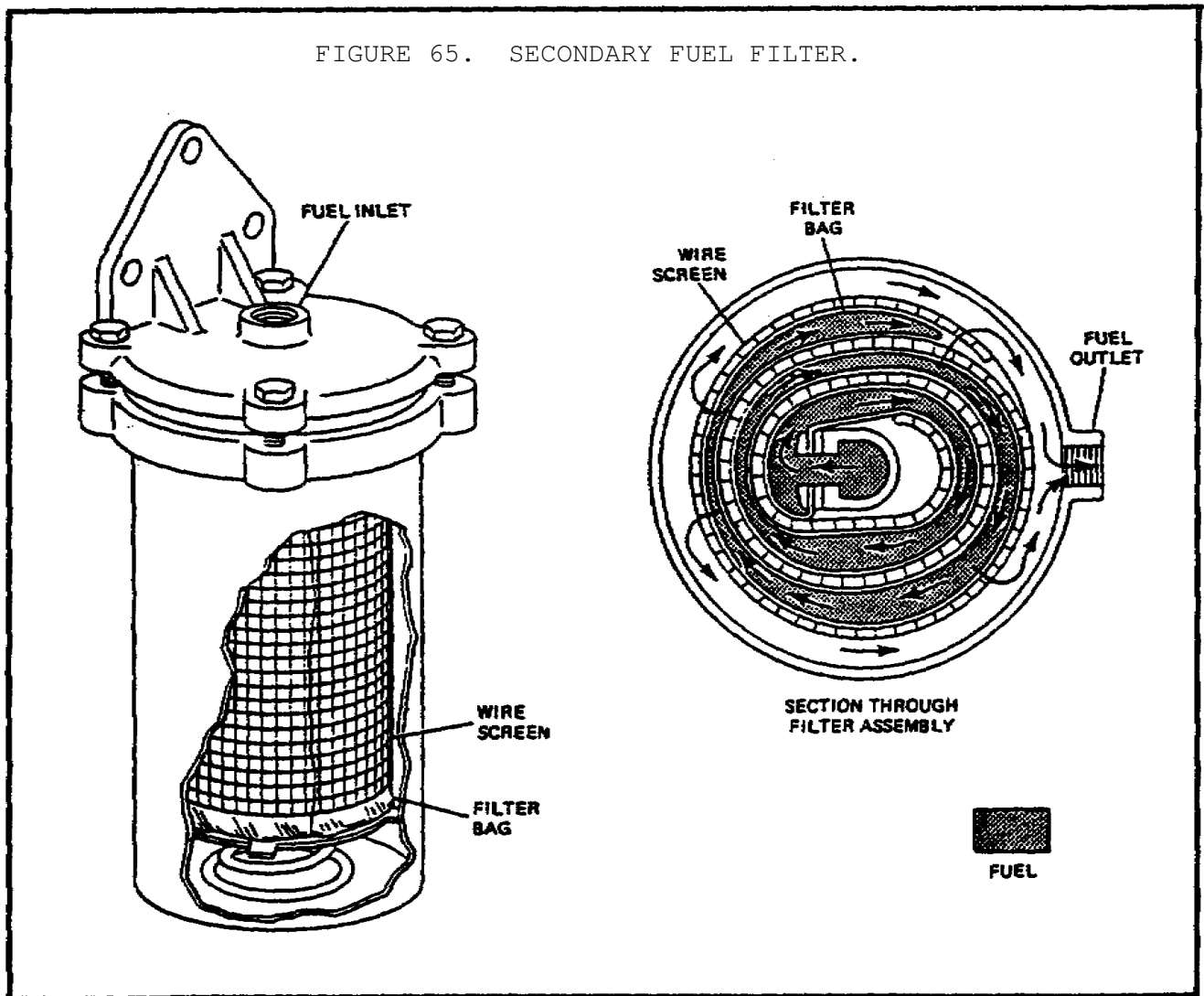
(1) *Primary Filters* (figure 64). Metal filters are used as primary filters because the fine particles that will pass through them are not injurious to the supply pump. The filter element is usually of the metal disk type. Solids larger than 0.005 in. remain outside the metal disks, while larger foreign matter and the majority of the water settles to the bottom of the bowl. From here, the foreign matter can be removed through a drainplug. A ball relief valve in the filter cover enables the oil to bypass the filter element if the disks become clogged.



(2) *Secondary Filters* (figure 65 on the following page). Fabric filters, because of their greater filtering qualities, are most commonly used

as main filters for protecting the fuel injection pump. Many of the filters in use are similar to lubricating oil filters. The bag-type filter also is used. The filtering medium is a large bag of close, evenly woven, lintless, acid-resisting textile material. Maximum benefit is derived from the bag's large area by keeping the sides of the bag separated by a wire-screen mat. The screen is the same size as the bag, and the two are fastened detachably to a central feeding spool and wound around it. Layers of bag and screen thus are alternated through the winding, and the entire surface of the bag is available for filtering purposes. The fuel to be filtered flows from the filter inlet at the top, through the spool, and out of the ports to the inside of the bag. The dirt, solids, abrasives, and carbon are caught in the bag, and the clean fuel passes outward and to the filter outlet. The bag may be removed, cleaned, and reinstalled.

FIGURE 65. SECONDARY FUEL FILTER.





## 9. Engine Retarder System

a. *Purpose.* Engine retarder systems are used on many larger vehicles equipped with diesel engines. They are designed to provide additional stopping ability to a vehicle in motion. These systems also relieve the service brakes of excessive heat buildup and wear due to prolonged application. An auxiliary means of power absorption is used to accomplish the additional braking process. Basically, three different engine retarder systems are currently in use.

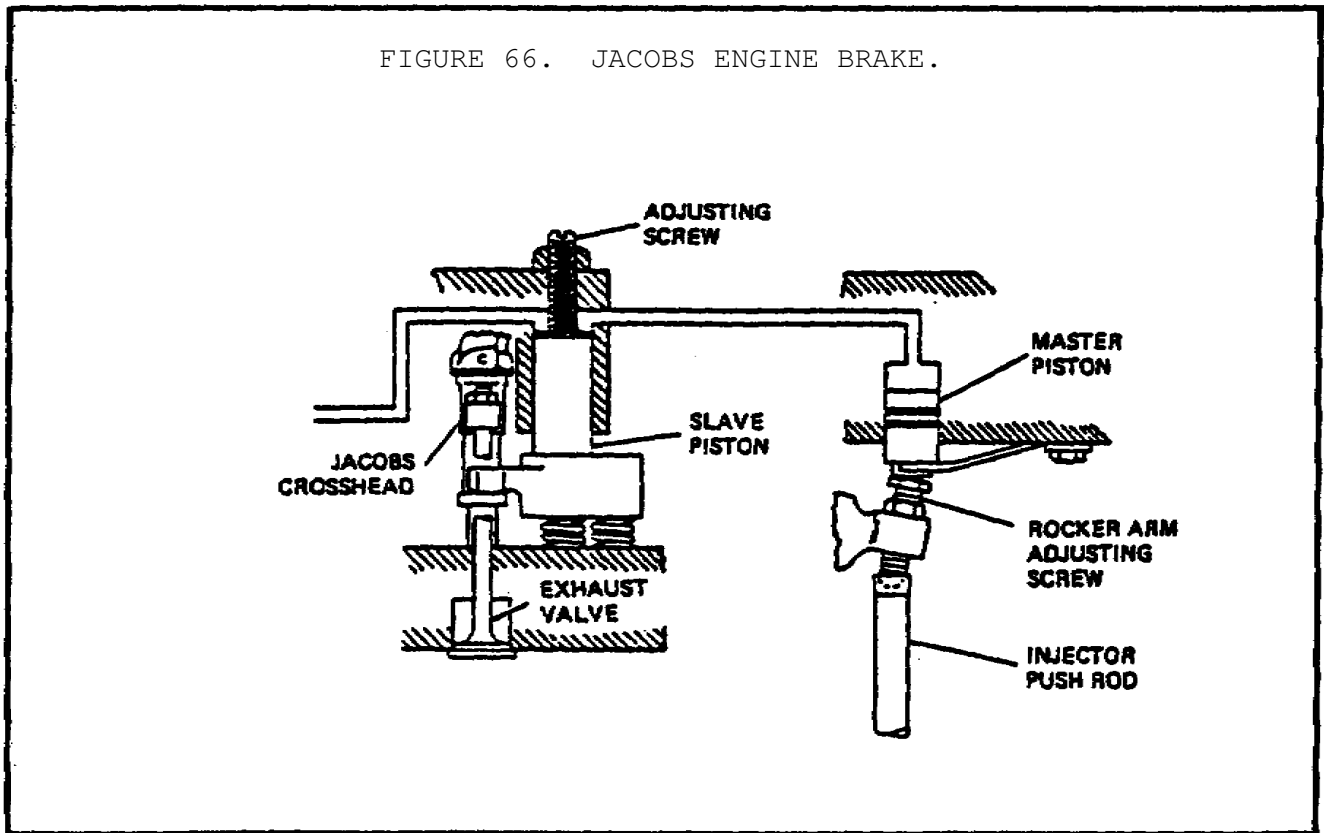
b. *Compression Brake.* The compression brake operates by restricting the exhaust gas flowing from the engine. The system basically consists of a butterfly valve fitted into the exhaust pipe between the exhaust manifold and muffler. The system is activated by a switch mounted in the cab. The valve is controlled by an air or vacuum switch mounted on the accelerator pedal. The system operates by restricting the exhaust gases, causing a pressure rise in the exhaust manifold. This pressure increase can vary from 30 to 40 psi. The compression brake causes a pressure buildup in the cylinder during the exhaust stroke. The engine then becomes a low-pressure pump driven by the wheels. This, in turn, slows down or retards the vehicle.

c. *Hydraulic Retarder.* The hydraulic retarder is a pedal-operated unit mounted in the transmission. This system assists the service brakes in controlling the vehicle's speed during long downhill braking or when slowing down in stop and go traffic. The system consists of a retarder cavity located between the converter and transmission housing. The cavity contains a rotor that is connected to the turbine output shaft. Stationary reaction vanes are mounted on both sides of the rotor. When the transmission fluid fills the cavity, it churns against the reaction vanes and slows down the rotor. The retarding efforts are then transmitted to the drive line to slow down the vehicle.

The retarder will continue to operate as long as the retarder pedal is depressed. The rotational energy is transformed into heat energy and absorbed by the transmission fluid. If the retarder is operated continuously, however, the fluid temperature can rise faster than it can be cooled.

Once this happens and the fluid temperature approaches a predetermined level, a warning light on the instrument panel indicates that the retarder operation should be discontinued until the fluid cools down and the warning light goes out. When the retarder pedal is released, the retarder valve closes and the fluid in the cavity automatically discharges and permits the rotor to turn without drag.

d. *Jacobs Engine Brake* (figure 66). The Jacobs engine brake consists of a slave piston mounted over the exhaust valve. The system operates by opening the exhaust valve near the top of the compression stroke. This releases the compressed cylinder charge into the exhaust system. This blowdown of compressed air into the exhaust system prevents the return of energy from the piston on the expansion stroke. The result is an energy loss because the work done in compressing the charge is not returned to usable energy. The system is operated by a three-position switch that allows the driver to select the degree of braking required. The three-position switch is set to allow braking on two, four, or all cylinders. This enables the driver to predetermine how much braking will be needed to stop the vehicle.



## PRACTICAL EXERCISE

### 1. Instructions

On a plain piece of paper, respond to the requirements listed below.

### 2. First Requirement

Answer these questions regarding the characteristics of diesel fuel.

a. Diesel fuels are considered residue of the refining process. Are the refining specification requirements as exacting as gasoline or less exacting?

b. Foreign material present in diesel fuel can cause damage to finely machined injector parts. Name two ways in which this damage can occur.

c. What is the fluid trait that determines the size of the diesel fuel droplet, which, in turn, governs the atomization and penetration quality of the fuel injector spray?

d. Describe "ignition quality" as it applies to diesel fuel.

e. When a diesel engine produces a noticeable knock during times when the engine is under a light load, this condition is referred to as \_\_\_\_\_, or \_\_\_\_\_.

f. Multifuel engines will operate on four groups of fuel, two of which are primary and alternate I fuels. Name the remaining two fuel groups.

g. Before fuel enters the fuel density compensator, it must first pass through a fuel pressure regulator that keeps the fuel at a constant pressure regardless of engine speed or load range. What is this constant pressure (in psi)?

### 3. Second Requirement

Answer the following questions dealing with the principles, construction, and function of diesel fuel systems.

- a. What is the simplest form of diesel combustion chamber design?
- b. A precombustion chamber is an auxiliary chamber that is located at the top of the cylinder. How is this chamber normally connected to the main combustion chamber?
- c. Prior to actual ignition of the air inside the turbulence chamber, it is estimated that the velocity of the air in the chamber is several times that of crankshaft speed. What is this approximate speed?
- d. Name the combustion chamber design that was made specifically for use in the multifuel engine.
- e. What are the two methods of injecting fuel into a compression-ignition engine?
- f. Name the three basic functions of a diesel injection system.
- g. The general operation of a multiple unit injection system is described below. Fill in the blanks.

(1) The fuel supply pump and the fuel filter provide a \_\_\_\_\_ supply of fuel to the \_\_\_\_\_ pump. Pressure usually is regulated to approximately \_\_\_\_\_ psi.

(2) The multiple unit injector contains an \_\_\_\_\_ pump for each engine cylinder. Fuel is delivered to the \_\_\_\_\_ at each cylinder from the multiple unit injector in a timed sequence and a \_\_\_\_\_ amount based on accelerator pedal \_\_\_\_\_ and \_\_\_\_\_.

(3) The injectors receive \_\_\_\_\_ charges from their respective injection pumps and spray it into the \_\_\_\_\_ in a \_\_\_\_\_ that is tailored to provide the best overall performance for their particular application.

- h. Name the specific type of injection pumps that are arranged in a line so that they may be driven by a common camshaft. The lobes of the camshaft are arranged so that they coincide with the firing order of the engine.

- i. What are the names of the two basic groups of spray injector nozzles?
- j. The wobble plate pump system is basically the same as the multiple unit injection system. The difference between the two systems lies in the injection pump. Describe what this difference is.
- k. A distributor-type injection system uses a fuel metering pump that forces a precisely measured fuel charge into the cup on the intake stroke of the engine. What controls the quantity of this fuel charge?
- l. Name the injection system that operates in the same manner as a multiple unit injection system, but rather than using a centrally located unit to house the high-pressure pumps, control racks, pressure regulators, and delivery valves, they are all incorporated into each cylinder.
- m. The overall system operation of a pressure-timed injection system is described below. Fill in the blanks.
- (1) A \_\_\_\_\_ with a vented filler cap stores the fuel supply.
- (2) Fuel is supplied from the tank to the \_\_\_\_\_-\_\_\_\_\_ (\_\_\_\_\_) pump through the delivery line. An in-line filter is placed in \_\_\_\_\_ in the line to trap \_\_\_\_\_ and moisture.
- (3) A return line from the PTG pump to the fuel tank is provided to \_\_\_\_\_ fuel so that operating pressure can be regulated.
- (4) The PTG pump delivers \_\_\_\_\_ of fuel to pressure timed deliver PTD injectors.
- (5) Delivery of \_\_\_\_\_ to the PTD injectors is through a common-rail type \_\_\_\_\_ line.
- (6) A common-rail type return line connects the \_\_\_\_\_ to the \_\_\_\_\_ so that excess fuel may be diverted back to the fuel tank.
- n. What are the two types of fuel supply pumps?

LESSON 1. PRACTICAL EXERCISE - ANSWERS

1. First Requirement
  - a. As exacting.
  - b. (1) Particles of dirt can cause scoring of the injector components  
(2) Moisture in the fuel can cause corrosion of the injector components
  - c. Viscosity.
  - d. The ignition quality of a fuel is its ability to ignite spontaneously under the conditions existing in the engine cylinder.
  - e. Ignition delay or ignition lag.
  - f. (1) Alternate II fuel  
(2) Emergency fuel
  - g. 20 psi.
2. Second Requirement
  - a. Open chamber.
  - b. The precombustion chamber is connected to the main combustion chamber by a restricted throat or passage.
  - c. 50 times the crankshaft speed.
  - d. Spherical combustion chamber.
  - e. (1) Air injection  
(2) Solid injection
  - f. (1) To meter the fuel accurately  
(2) To distribute the fuel equally to all of the cylinders at a high enough pressure to ensure atomization  
(3) To control the start, rate, and duration of the injection

g. (1) low-pressure  
multiple unit injection  
15

(2) individual injection  
injectors  
regulated  
position  
engine speed

(3) fuel charges  
combustion chambers  
spray pattern

h. Multiple unit injection pump.

i. (1) pintle nozzles

(2) hole nozzles

j. In a wobble plate pump, all of the pump plungers are actuated by a single wobble plate instead of a camshaft that has a separate cam for each pump plunger.

k. Speed and load requirements of the engine.

l. Unit injection system.

m. (1) fuel tank

(2) pressure-timed gear (PTG)  
series  
foreign matter

(3) bleed off excess

(4) controlled amounts

(5) fuel  
delivery

(6) PTD injectors  
fuel tank

n. (1) Vane-type

(2) Plunger-type