

**US ARMY LIGHT WHEEL VEHICLE MECHANIC
MOS 63B SKILL LEVEL 3 COURSE**

WHEELED VEHICLE ENGINES

SUBCOURSE NO. OD 1001

United States Army Combined Arms Support Command

Ordnance Missile and Munitions

Fort Lee, Virginia 23801-1511

Eight Credit Hours

GENERAL

The Wheeled Vehicle Engines subcourse, part of the Light Wheel Vehicle Mechanic MOS 63B Skill Level 3 subcourse, is designed to teach the knowledge necessary to understand principles of operation, identify types and components, and perform maintenance and troubleshoot internal combustion engines. Information is provided on spark- and compression-ignition engines, engine inspection, and lubrication and cooling systems. The subcourse is presented in five lessons, each lesson corresponding to a terminal objective as indicated below.

Lesson 1: FUNDAMENTALS OF SPARK-IGNITION ENGINES

TASK: Describe the fundamentals of spark-ignition engines.

CONDITIONS: Given information about the principles of operation, construction, and classification of spark-ignition engines.

STANDARDS: Solve 70 percent of the multiple-choice items covering fundamentals of spark-ignition engines.

Lesson 2: FUNDAMENTALS OF COMPRESSION-IGNITION ENGINES

TASK: Describe the fundamentals of compression-ignition engines.

CONDITIONS: Given information about the construction and principles of operation of two- and four-stroke-cycle compression-ignition engines and the different types of compression-ignition engines.

STANDARDS: Solve 70 percent of the multiple-choice items covering fundamentals of compression-ignition engines.

Lesson 3: ENGINE INSPECTION

TASK: Describe the inspecting, testing, and troubleshooting procedures for engines.

CONDITIONS: Given information about procedures for inspection of the engine and use of test equipment.

STANDARDS: Solve 70 percent of the multiple-choice items covering engine inspection and testing.

Lesson 4: ENGINE LUBRICATION SYSTEMS

TASK: Describe the principles of engine lubrication and crankcase ventilation systems.

CONDITIONS: Given information about principles of operation and maintenance of engine lubrication and crankcase ventilation systems.

STANDARDS: Solve 70 percent of the multiple-choice items covering engine lubrication and crankcase ventilation systems.

Lesson 5: ENGINE COOLING SYSTEMS

TASK: Describe the principles of engine liquid-cooling systems.

CONDITIONS: Given information about the fundamentals of liquid-cooling system components and inspecting, testing, and repairing representative engine liquid-cooling systems.

STANDARDS: Solve 70 percent of the multiple-choice items covering engine liquid-cooling systems.

PREFACE

The Army Institute for Professional Development (AIPD) administers the consolidated Army Correspondence Course Program (ACCP), which provides high- quality, economical training to its users. The AIPD is accredited by the Accrediting Commission of the National Home Study Council (NHSC), the nationally recognized accrediting agency for correspondence institutions.

Accreditation is a process that gives public recognition to educational institutions which meet published standards of quality. The NHSC has developed a thorough and careful evaluation system to assure that institutions meet standards of academic and administrative excellence before it awards accreditation.

The many TRADOC service schools and DOD agencies that produce the ACCP materials administered by the AIPD develop them to the NHSC standards.

The AIPD is also a charter member of the Interservice Correspondence Exchange (ICE). The ICE brings together representatives from the Army, Navy, Air Force, Marine Corps, and Coast Guard to meet and share ideas on improving distance education.



TABLE OF CONTENTS

Section	page
TITLE PAGE	i
TABLE OF CONTENTS	iii
ADMINISTRATIVE INSTRUCTIONS.....	v
GRADING AND CERTIFICATION INSTRUCTIONS	v
INTRODUCTION TO WHEELED VEHICLE ENGINES.....	vi
Lesson 1: FUNDAMENTALS OF SPARK-IGNITION ENGINES	
Learning Event 1: Describe Principles of Operation, Construction, and Classification of Engines.....	1
Learning Event 2: Describe Components and Construction of Multicylinder Engines.....	28
Practice Exercise.....	51
Answers to Practice Exercise.....	52
Lesson 2: FUNDAMENTALS OF COMPRESSION-IGNITION ENGINES	
Learning Event 1: Describe Principles of Operation and Construction of Four-Stroke Cycle Engines.....	53
Learning Event 2: Describe Principles of Operation and Construction of Two-Stroke- Cycle Engines.....	68
Practice Exercise.....	73
Answers to Practice Exercise.....	74

Section	Page
Lesson 3: ENGINE INSPECTION	
Learning Event 1: Describe Visual and Operational Inspection Techniques.....	75
Learning Event 2: Describe Spark-Ignition Engine Testing Procedures	84
Practice Exercise	91
Answers to Practice Exercise	92
Lesson 4: ENGINE LUBRICATION SYSTEMS	
Learning Event 1: Describe Principles of Operation and Components of Lubrication Systems	93
Learning Event 2: Describe Purpose of Crankcase Ventilation System	112
Learning Event 3: Describe Maintenance Procedures for Engine Lubrication Systems	118
Practice Exercise	121
Answers to Practice Exercise	122
Lesson 5: ENGINE COOLING SYSTEMS	
Learning Event 1: Describe Principles of Operation and Components of Liquid-Cooling Systems	123
Learning Event 2: Describe Maintenance and Troubleshooting Procedures for Liquid-Cooling Systems	142
Practice Exercise	153
Answers to Practice Exercise	154
EXAMINATION	155

ADMINISTRATIVE INSTRUCTIONS

SUBCOURSE CONTENT

This subcourse contains five lessons, each related to wheeled vehicle engines. An introduction presents an overall view of the subject. Each lesson then covers a specific topic pertaining to fundamentals or maintenance of internal combustion engines. Each lesson is followed by a practice exercise. An examination covering all five lessons is provided at the end of the subcourse.

Supplementary Requirements

Materials Needed. You will need a No. 2 pencil and paper to complete this subcourse.

Supervisory Assistance. No supervision is needed for completion of this subcourse.

References. No supplementary references are needed for this subcourse.

GRADING AND CERTIFICATION INSTRUCTIONS

INSTRUCTIONS TO THE STUDENT

This subcourse has an examination that consists of multiple choice test items covering two lessons. You must score a minimum of 75 percent on this test to meet the objectives of the subcourse. Answer all questions on the enclosed ACCP examination response sheet. After completing the examination, place the answer sheet in the self-addressed envelope provided and mail it to the Institute for Professional Development (IPD) for scoring. IPD will send you a copy of your score.

Eight credit hours will be awarded for successful completion of this subcourse.

*** * * IMPORTANT NOTICE * * ***

THE PASSING SCORE FOR ALL ACCP MATERIAL IS NOW 70%.

PLEASE DISREGARD ALL REFERENCES TO THE 75% REQUIREMENT.

INTRODUCTION TO WHEELED VEHICLE ENGINES

Often the maintenance needed on an engine requires a lot of knowledge and very little physical effort. This is the kind of repair work that separates the good mechanics from the bad ones very quickly. Without the proper knowledge, mechanics may work for hours before they correct a simple problem. Sometimes they may never get an engine running correctly. A good mechanic that understands engines can repair one in a few minutes. This subcourse is written with the intention of starting you on the correct road to becoming a good mechanic. In it we describe the different engine parts and how they operate together to make an engine run the way it should.

LESSON 1

FUNDAMENTALS OF SPARK-IGNITION ENGINES

TASK

Describe the fundamentals of spark-ignition engines.

CONDITIONS

Given information about the principles of operation, construction, and classification of spark-ignition engines.

STANDARDS

Solve 70 percent of the multiple-choice test items covering fundamentals of spark-ignition engines.

REFERENCES

TM 9-8000

Learning Event 1:

DESCRIBE PRINCIPLES OF OPERATION, CONSTRUCTION, AND CLASSIFICATION OF ENGINES

ORIGIN OF FORCE FOR ENGINE OPERATION

Everyday we see many examples of how heat energy, produced by burning any combustible substance from wood to gasoline, can be made to perform useful work. When a gun is fired, the burning gunpowder performs useful work, so let's study its action for a moment.

When you pull the trigger, the firing pin strikes the primer in the shell case. The primer then ignites the gunpowder. The burning gunpowder expands rapidly and exerts pressure on the bullet. This pressure gets so high so fast (50,000 pounds per square inch (PSI) or higher in a high-powered Army rifle), it is

said to explode. The pressure created by the burning gunpowder forces the bullet out of the barrel at a very fast speed. The energy created by the burning gunpowder is heat energy which does the useful work of speeding the bullet on its journey.

In an automotive internal combustion engine, pressure is exerted on a piston in a cylinder in the same way pressure is exerted on the bullet, forcing it to move. However, instead of using gunpowder to create heat energy, we use a mixture of fuel and air.

COMBUSTION

Any fuel such as gasoline, wood, or paper will not burn by itself. A gas, called oxygen, must be present to mix and burn with the fuel. (Oxygen is a colorless and odorless gas that is contained in the air around us.)

This can be proven with a small jar, an airtight lid, and a wooden match. Strike the match, place it inside the jar, and close the lid tightly. The match will burn fast at first and then begin to die down. The flame will probably go completely out before the match is all burned.

The reason for the fire going out before the match was burned is that all the oxygen sealed in the jar was burned or used up. For complete combustion of the fuel, an engine must also have an ample supply of air to mix with the fuel. Since the engine gets the oxygen from the air, we generally refer to it as air instead of oxygen.

TYPES OF ENGINES

Automotive engines may be grouped or classified according to the types of fuel burned, cooling system used, or the arrangement of the valves or cylinders. The most common way of grouping them is by the type of fuel they burn; for example, gasoline, diesel, and multifuel engines. Multifuel engines are designed to burn many different fuels.

Types of Cooling Systems

Engines are classified by type of cooling system as being air- or liquid-cooled. Actually, all engines are cooled by air to some extent. However, they are only classed as air-cooled when air is the only external means of carrying heat away from the cylinders.

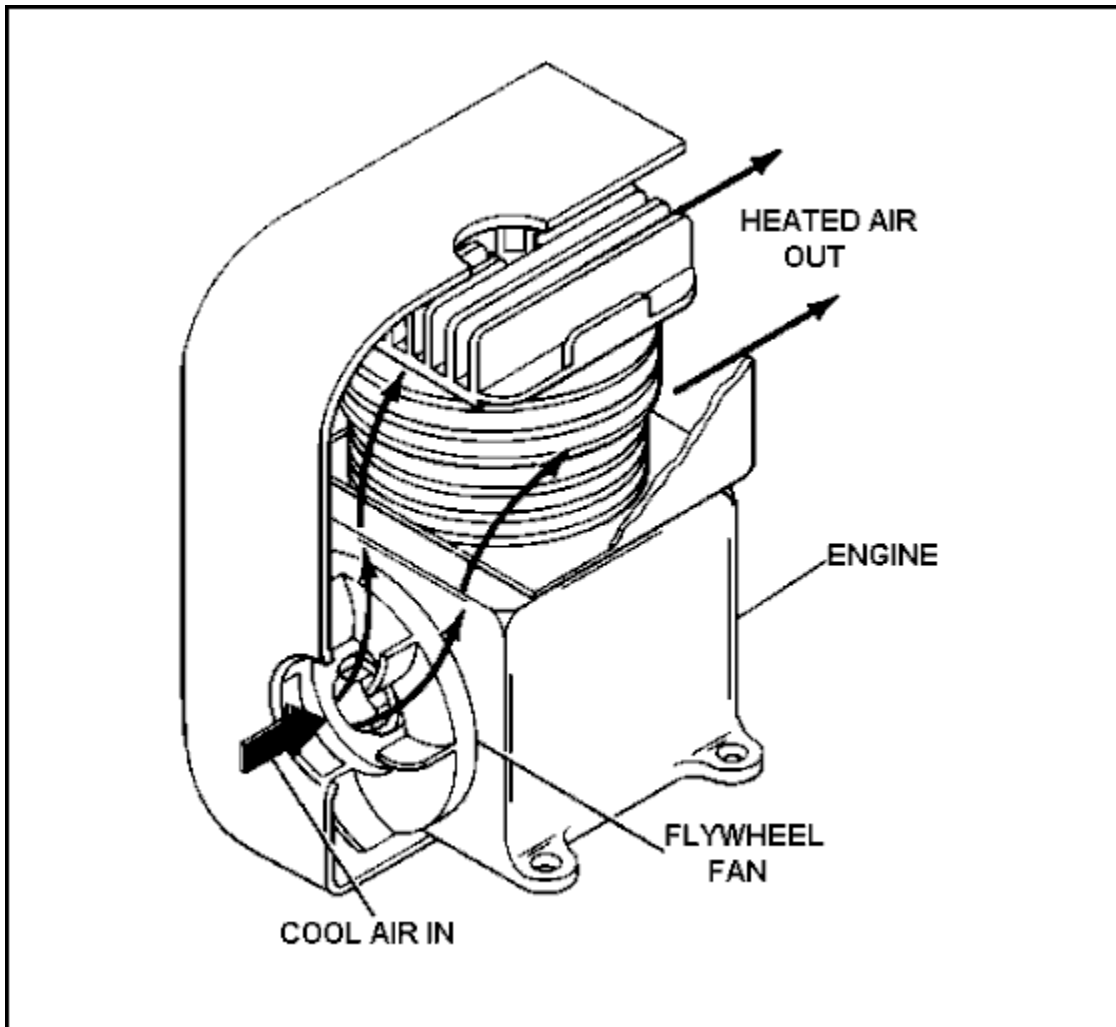


FIGURE 1. AIR-COOLED ENGINE.

Air-Cooled. Small engines that are used on lawnmowers, chain saws, and power generating plants are air-cooled. Air-cooled engines are also very common in combat tracked vehicles and aircraft. They have fins made on the outside of the cylinders and heads to expose more metal surface to the air for better cooling. Air deflectors and baffles are generally placed around the cylinders and heads to direct the flow of cooling air. The airflow is supplied by a fan.

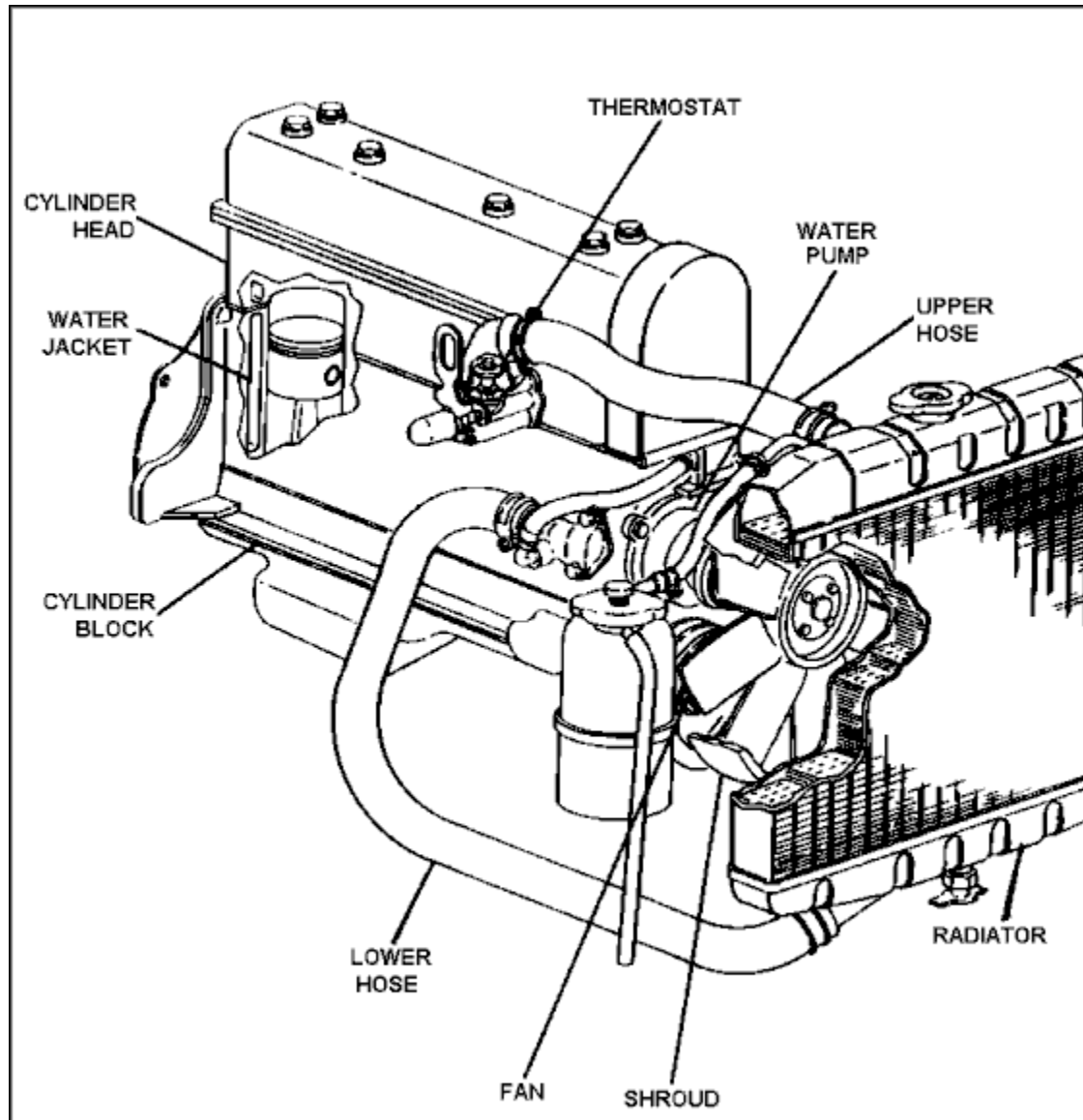


FIGURE 2. LIQUID-COOLED ENGINE.

Liquid-Cooled. Liquid-cooled engines have passageways or a water jacket around the cylinders and in the head to hold a liquid coolant. A pump is used to circulate the coolant through the engine water jackets and an external container called the radiator. Liquid-cooled engines also have a fan, but it is for circulating air between cooling fins on the radiator to carry heat away from the liquid coolant.

Valve Arrangements

Engines that are classed by the position or arrangement of the intake and exhaust valves are called L-, T-, I-, or F-head engines. The letters L, T, I, and F are formed by drawing a line through the cylinder and the valves. However, whether the valves are located in the engine block or the cylinder head is also taken into account for this classification.

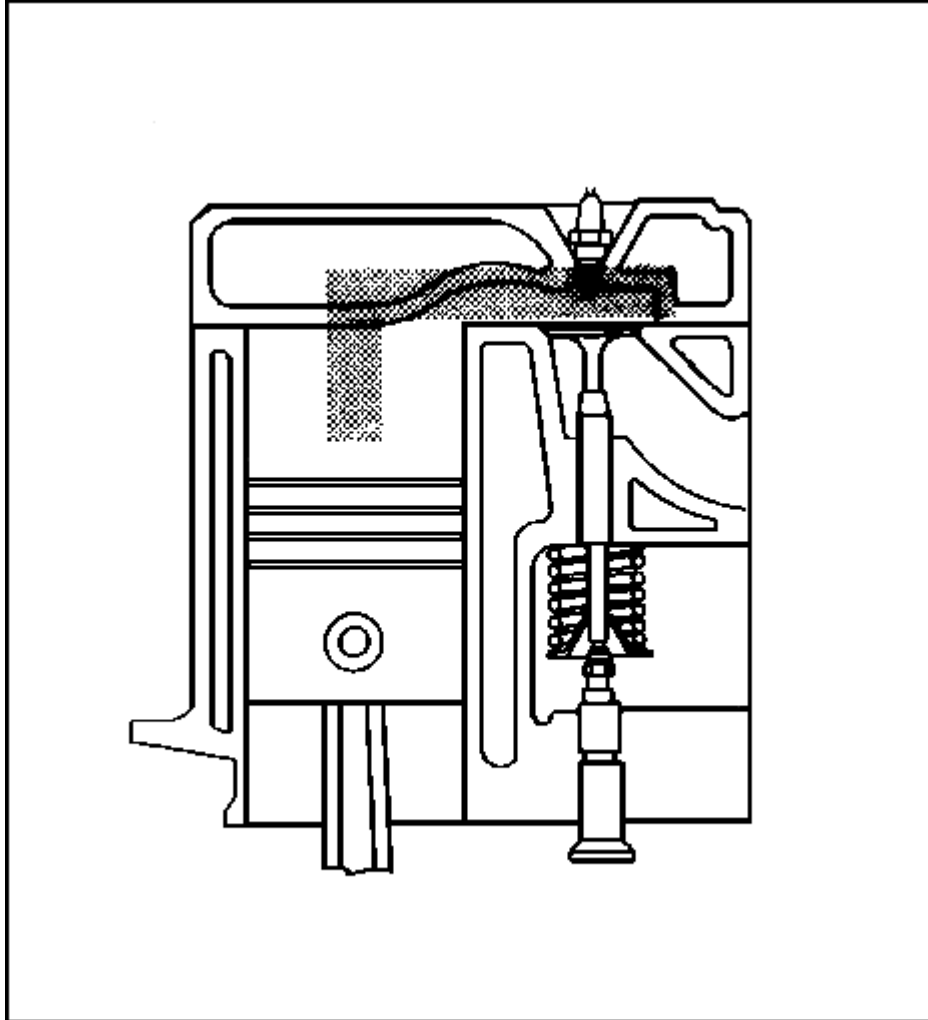


FIGURE 3. L-HEAD ENGINE.

L-head. In the L-head engine, both valves are located in the engine or cylinder block on one side of the cylinder. Notice that a line drawn up through the cylinder and over to the valve heads forms an upside down letter L

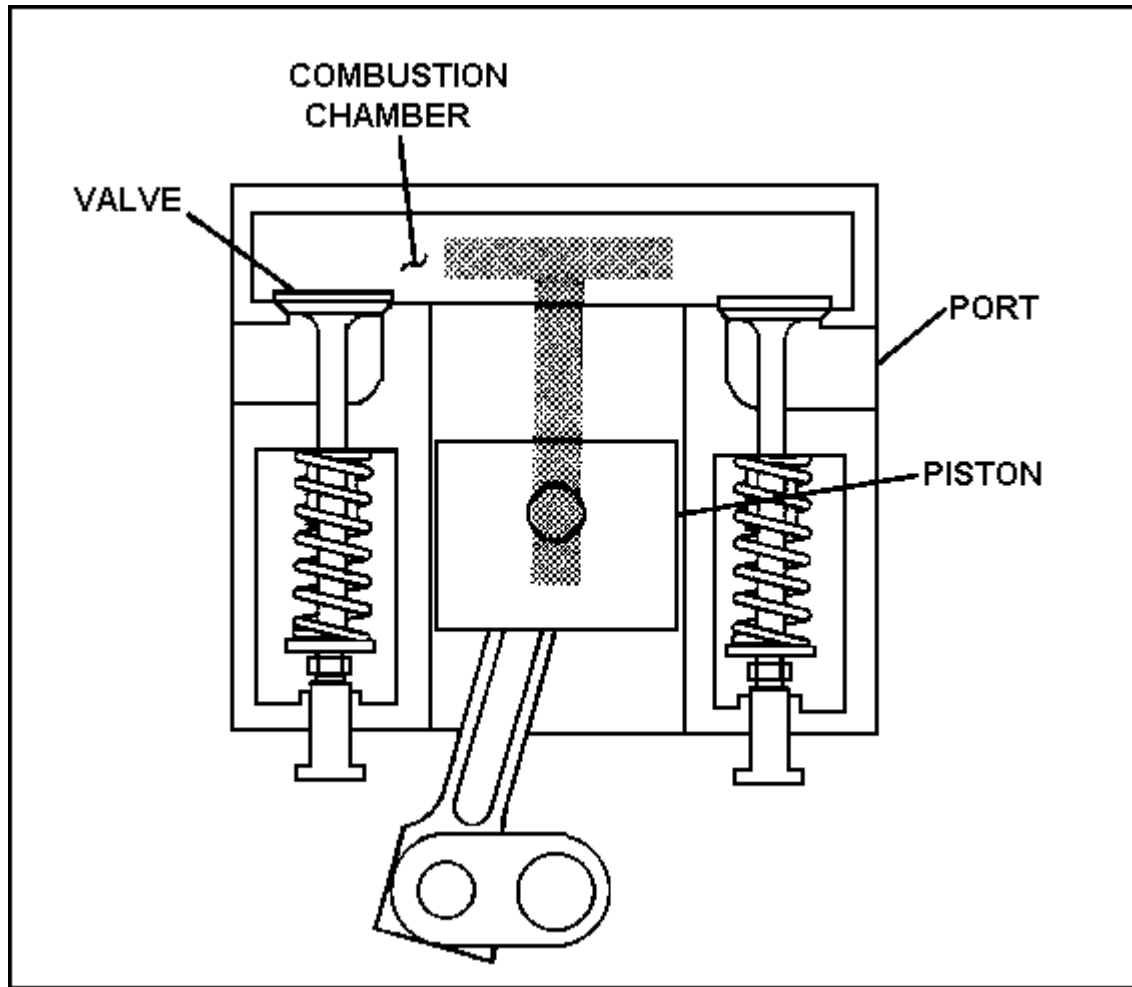


FIGURE 4. T-HEAD ENGINE.

T-Head. In the T-head engine, the valves are located on opposite sides of the cylinder. Lines drawn through the cylinder and across the valves will form the letter T.

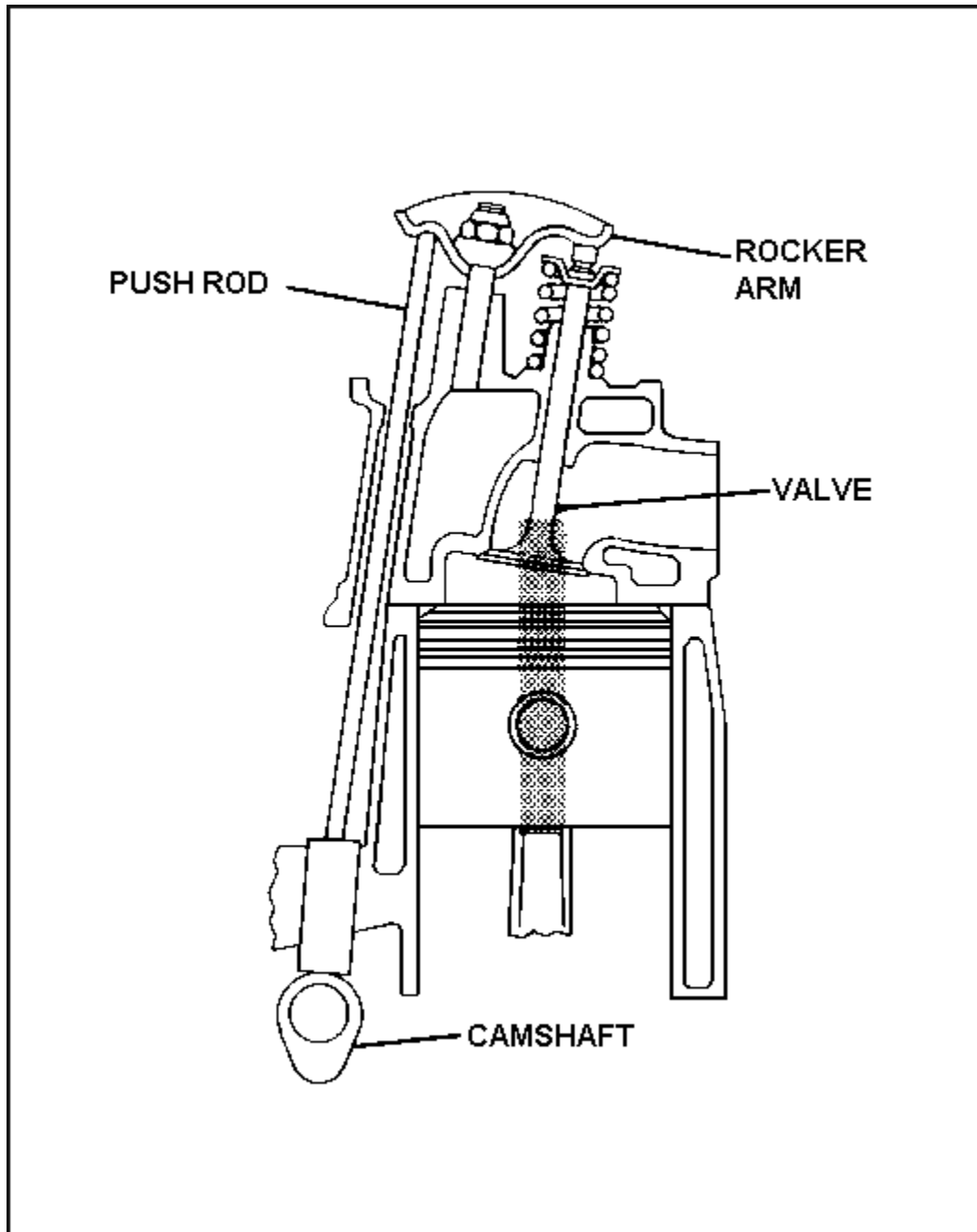


FIGURE 5. I-HEAD ENGINE.

I-Head. In the I-head engine, both valves are in the cylinder head, and for this reason, it is sometimes called an overhead valve engine. The valves may be arranged in a straight line, one directly behind the other as shown in the picture. In this case, a straight line can be drawn through the valves and cylinder to form the letter I. In other engines, the valves may be staggered with one on the right side of the cylinder and the other on the left side. The letter I is no longer formed, but the classification is still the same.

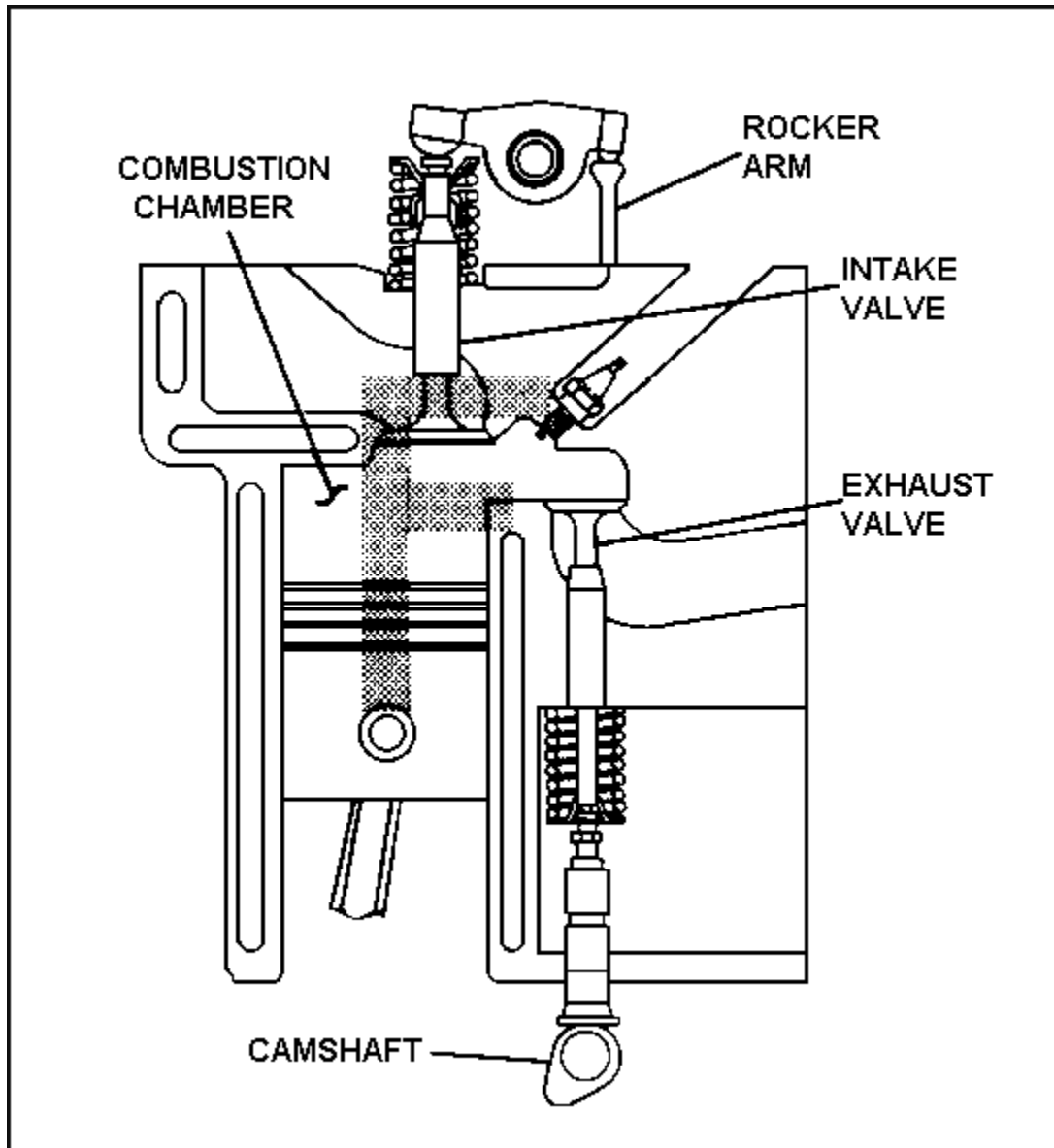


FIGURE 6. F-HEAD ENGINE.

F-Head. The F-head engine is a combination of the L- and I- head, having one valve in the cylinder block and one in the head. If one line is drawn through the cylinder and then separate lines extended through the valve heads, the letter F is formed.

Cylinder Arrangement

Most engines have several cylinders enabling them to be classified by the way the cylinders are arranged. The most common arrangements are in-line, V-type, horizontal-opposed, and radial. The cylinders of the radial engine are placed in a circle around a common crankshaft. However, the use of this engine has been limited almost entirely to aircraft so we will not discuss it here.

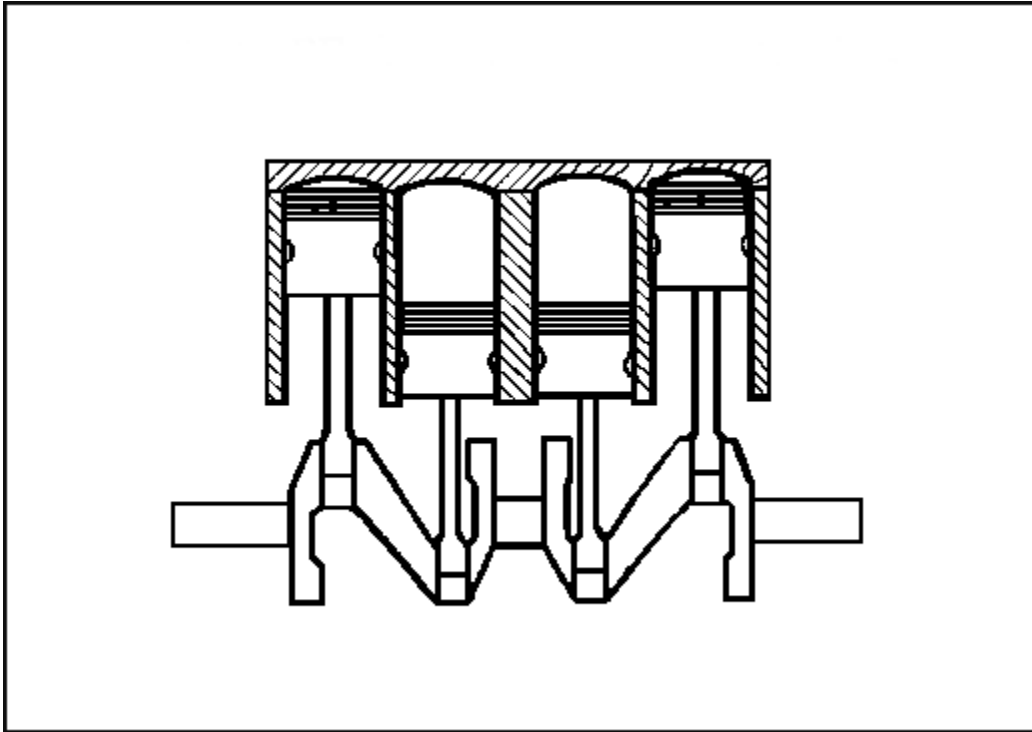


FIGURE 7. IN-LINE ENGINE.

In-Line. In-line engines have the cylinders aligned in one straight row. All the piston connecting rods are connected to one crankshaft that has a separate throw for each cylinder. The number of cylinders most commonly used in the in-line engine is either four or six. An eight-cylinder in-line was used for a time, but it is no longer in common use.

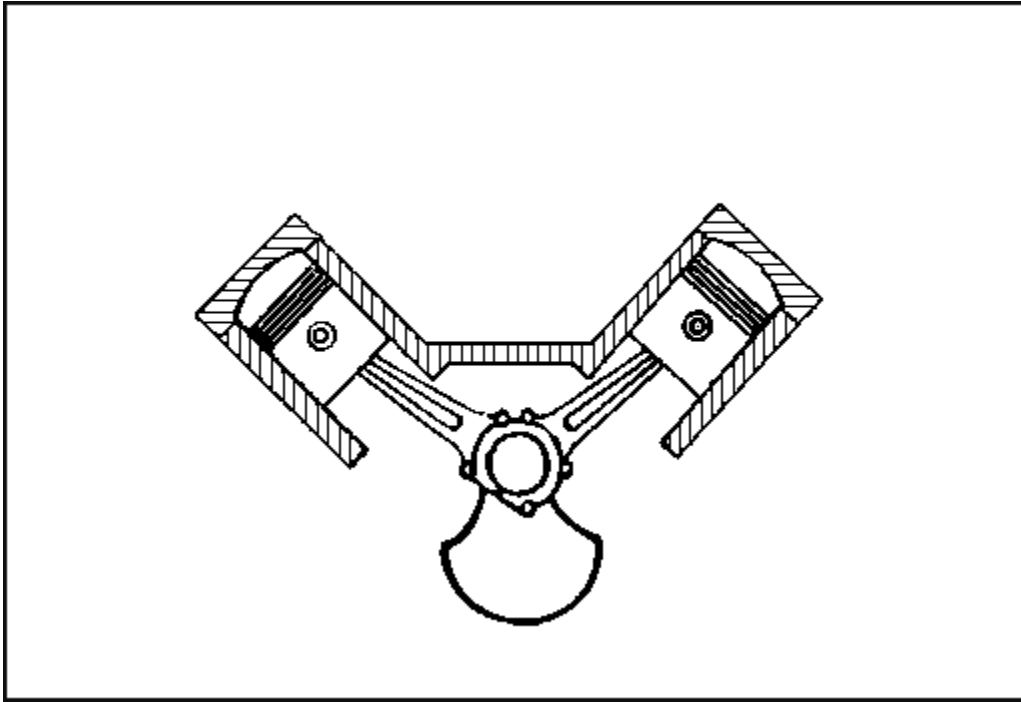


FIGURE 8. V-TYPE ENGINE.

V-Type. In the V-type engine, two banks or rows of in-line cylinders are mounted in a V-shape above a common crankshaft. Usually, two connecting rods, one from each bank of cylinders, are connected to one throw of the common crankshaft. The V-type arrangement is generally used when the engine has eight or more cylinders because it can be made shorter than an in-line engine.

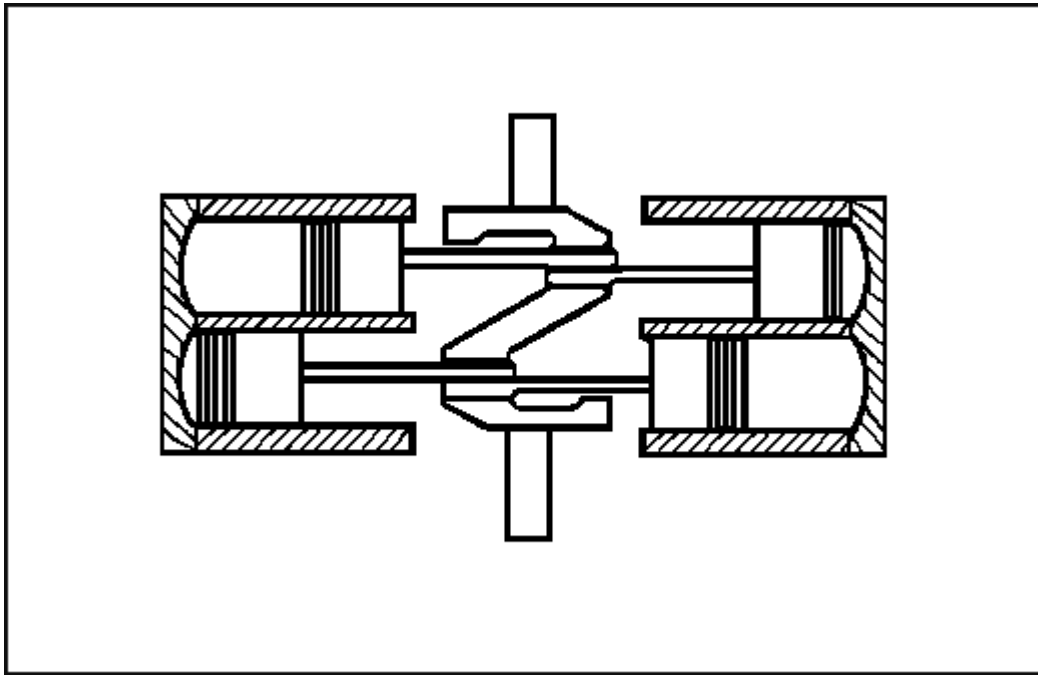


FIGURE 9. HORIZONTAL-OPPOSED ENGINE.

Horizontal-Opposed. The horizontal-opposed engine has its cylinders laid on their sides in two straight rows directly opposite each other. The crankshaft is in the center of the engine between the rows or banks of the cylinders. By being made this way, the engine is not very high and can be mounted under the body of the vehicle it is used in. The horizontal-opposed engine is often called a pancake engine because of its flat shape. These engines are generally air-cooled.

BASIC ONE-CYLINDER ENGINE

The internal combustion engines we will study in this lesson are built to produce rotary-mechanical motion from heat energy. They can be built light enough for a man to carry; for example, the engine on a small lawnmower. The engine may also be large and heavy. Examples of such power plants include the engines used to drive large tanks and trucks. Fortunately, you do not have to study each of these engine types to understand how they operate, because they all operate on the same basic principles. With this in mind, let's read about the different parts of the engine.

Engine Block

The engine block, sometimes called the cylinder block, serves as the foundation for, and houses most of, the other engine parts. The block contains the cylinder which can be compared to the bore of a gun. The cylinder is perfectly round and machined to a smooth finish. The lower end of the engine block is flared out to form the upper half of a cavity for housing other parts. The lower half of the cavity is enclosed on the bottom by a separate housing or pan, commonly called the oil pan. The entire cavity is called the crankcase.

Piston

Fitted into the cylinder is a movable piston that receives the energy or the force from the combustion of the fuel-air mixture. The piston is comparable to the bullet of the gun. The top of the piston, called the piston head, is closed. The lower part, or skirt, of the piston is open and fits in the cylinder very tightly. This prevents the piston from tipping or slapping about in the cylinder. The upper part of the piston has grooves to accept metal rings. A hole is machined just below the ring grooves so the piston can be pinned to a rod.

Piston Rings

Although it's a small amount, there must be some clearance between the piston skirt and the cylinder wall so the piston can slide freely. Piston rings are placed in the piston ring grooves to prevent gases from leaking through this operating clearance. The metal piston rings are not a solid band but are cut through in one spot. This way, the cut ends can be spread apart and the ring passed over the piston to place it in the ring groove. The split ends (ring gap) do not form a perfect seal, so more than one ring is used, and the joints are staggered to reduce leakage.

Cylinder Head

The top end of the cylinder is closed with a cylinder head that is secured to the engine block with several bolts. The space between the cylinder head and the piston forms a chamber for the combustion of the fuel-air mixture. To prevent leakage, a metal or metal-asbestos cylinder head gasket is placed between the head and the block. A spark plug for igniting the fuel-air mixture is screwed into a threaded hole in the top of the head that extends into the combustion chamber.

Valves

When an engine is operating, the fuel-air mixture is continually entering the combustion chamber through intake ports. The burned mixture or exhaust is expelled through exhaust ports. When combustion occurs, the inlet and exhaust ports into the combustion chamber must be closed to prevent leakage of the expanding gases. Metal doors called valves are placed in the port openings to automatically control the flow of gases and to seal the port openings. These are opened and closed by the valve operating mechanism that will be discussed later.

Valve Construction. A valve is made with a stem and has a head to seal the round openings of the intake and exhaust ports. The sealing surfaces of the valve and valve seat are accurately machined so it can make a perfect seal.

Valve Spring and Guide. The stem of the valve is fitted into a guide to ensure the valve rests squarely on its seat each time it closes. A valve spring encircles the valve stem and provides tension to hold the valve head tight against its seat. The spring is attached to the valve by a retainer cap and valve spring locks or keepers that fit in grooves in the end of the valve stem.

Piston Pin

To harness the force exerted against the piston, a connecting rod is coupled to the piston by means of a piston pin. The pin passes through holes or bosses in the piston and a hole in the rod. Once connected, the rod is free to swing back and forth under the piston by turning on the pin.

Connecting Rod

In addition to the piston-pin-hole at its top, the connecting rod has a larger hole at its bottom. The larger hole is split so the bottom part or cap can be removed. This is so that it can be clamped around the machined bearing surface on a shaft (crank-shaft) using bolts. The inside of the hole is generally machined to accept a two-piece bearing.

Crankshaft

To do useful work the engine must produce a rotary (turning) motion, but the piston moves in a straight line, up and down in the cylinder. To solve this problem a crankshaft is used.

Construction. The crankshaft is a shaft with offset portions at its center. This offset is commonly called a throw or crank. There are machined bearing surfaces at each end of the shaft and in the center of the throws.

Mounting. The crankshaft is mounted in the engine block and is free to rotate in bearings fitted around its bearing surfaces. The lower end of the connecting rod is then clamped around the crankshaft throw bearing surface. When the piston is forced down as combustion occurs, the connecting rod will cause the crankshaft to turn. If the crankshaft is rotated continuously, the piston must move up and down while the lower end of the connecting rod moves in a circle with the crankshaft throw.

Combustion pressure can no longer rotate the crankshaft once the piston reaches the bottom of its stroke, and the crankshaft throw is pointed down. At this time, the crankshaft is forced to continue rotating by a heavy wheel called the flywheel.

Flywheel

The flywheel is bolted to one end of, and rotates with, the crankshaft. It stores energy during the power strokes of the piston. The stored energy is then released during the nonpower strokes of the piston causing the crankshaft to rotate smoothly with no sudden speed changes.

Valve Operating Mechanism

Now let's consider the problem of opening and closing the valves. In a simple one-cylinder engine, this problem is solved with the camshaft, tappets, and timing gears.

Camshaft. The camshaft rotates on machined bearing surfaces fitted in the engine block. Offset portions, called cams (one for each valve), are also machined on the shaft. The high point of a camshaft cam is the lobe or toe of the cam while the lowest part is the base circle or heel. The camshaft is mounted in the engine block so the cams are located directly under the valve stems or tappets.

Tappets. The tappets are round, bar-like parts that have a threaded hole in one end to receive an adjusting bolt. Tappets are also commonly called cam followers or valve lifters. They are installed in bored holes in the engine block between the camshaft cams and the valve stems.

- The tappet adjusting screw is adjusted so there is a slight amount of clearance between the valve stem and the screw head. This adjustment must be made with the tappet resting on the base circle of the cam.
- If the camshaft is turned, the cam lobe will push the tappet up in its bore. In turn, the tappet contacts the valve stem, compressing the valve spring and opening the valve. As the camshaft continues to rotate, the cam lobe moves on past the tappet, and the spring forces the valve closed. The amount the valve opens and how long it stays open for a given engine speed depends on the shape of the cam lobe.

Timing Gears. We now have a way of opening and closing the valves, but how is the camshaft turned? At what speed is it turned? What controls the time that the valve opens? Since the crankshaft is always turning when the engine is running, it seems only logical to use the spinning crankshaft to turn the camshaft. This can be done by two timing gears. One gear is keyed to the crankshaft and meshes with the second gear which is keyed to the camshaft.

- **Camshaft Speed.** For reasons that will be explained later when discussing engine operation, the camshaft must turn half as fast as the crankshaft. To do this, a small timing gear is used on the crankshaft and a larger gear with twice as many teeth is used on the camshaft. With this arrangement, turning the crankshaft two turns will rotate the camshaft one turn.

- **Valve Timing.** From information already presented in this lesson, you can see valves will have to open and close at certain times in relation to piston position. This is called valve timing. Since the piston position is determined by the crankshaft position and the valves by the camshaft, the relative position of the two shafts will determine the valve timing. Once positioned properly, the relative position of the two shafts is maintained by the meshed teeth of the timing gears. The gears generally have timing marks stamped on them that must be aligned during assembly of the engine to obtain the correct valve timing or positioning of the crankshaft and camshaft.

Accessory Systems

If the engine is to give satisfactory service, it will need several accessory systems. Complete understanding of these systems is not needed to understand how the engine parts work. Therefore, we will do no more than identify the needed accessories at this time so you will be aware of their existence.

Fuel System. There must be a way of storing fuel, mixing it with the air, and then carrying the mixture to the cylinder.

Ignition System. There must also be a method of producing a high-voltage spark to jump across the spark plug gap at the proper time for igniting the fuel-air mixture.

Exhaust System. Once the fuel-air mixture is ignited and burned, there must be some means of carrying the hot exhaust gases away from the cylinder.

Cooling System. Combustion of the fuel-air mixture creates so much heat that the engine parts will be ruined if cooling is not provided. Cooling may be done by causing either air or a liquid to flow over the heated surfaces.

Lubrication System. Last, but by no means least, there must be a system to supply lubrication to points where friction occurs, such as the crankshaft bearings and between the cylinder wall and piston.

THE FOUR-STROKE CYCLE

The simple engine that we have just built operates on the same principles that Dr. Otto, a German scientist, used in 1876. Common names that engines are called when using these principles are Otto cycle, four-cycle, and four-stroke-cycle engines. We will call them four-stroke-cycle engines in this lesson.

The term "four-stroke cycle" refers to the number of times the piston moves up and down between power (combustion) strokes. The four strokes are called intake, compression, power, and exhaust. We will discuss them in the order in which they were just named. But before we do, let's define some common terms that will be used often.

Cranking. The engine is not self-starting. The piston has to be moved in the cylinder by some outer force to get it started. This is called cranking and is done in a lot of different ways. For example, to crank a lawnmower you pull on a rope that is wrapped around a pulley which spins the crankshaft. On a modern car, the engine is cranked by an electric starter motor that turns the crankshaft.

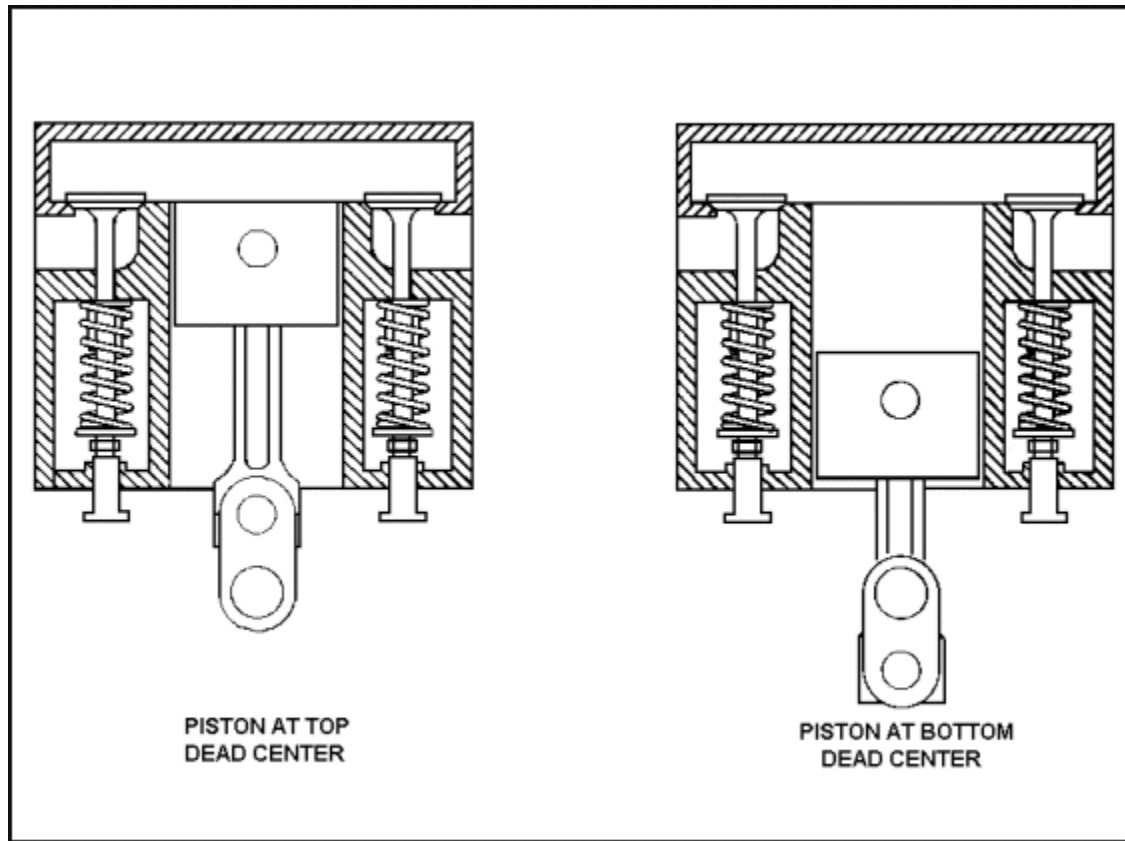


FIGURE 10. PISTON POSITIONS.

TDC and BDC. When you hear someone say the letters TDC or BDC, they are talking about the position of the piston in the cylinder. TDC is just a short way of saying top dead center, and BDC is saying bottom dead center. At TDC the crankshaft throw is pointed straight up, and the piston is at its highest point of travel in the cylinder (top). The crankshaft and piston positions are just the opposite at BDC.

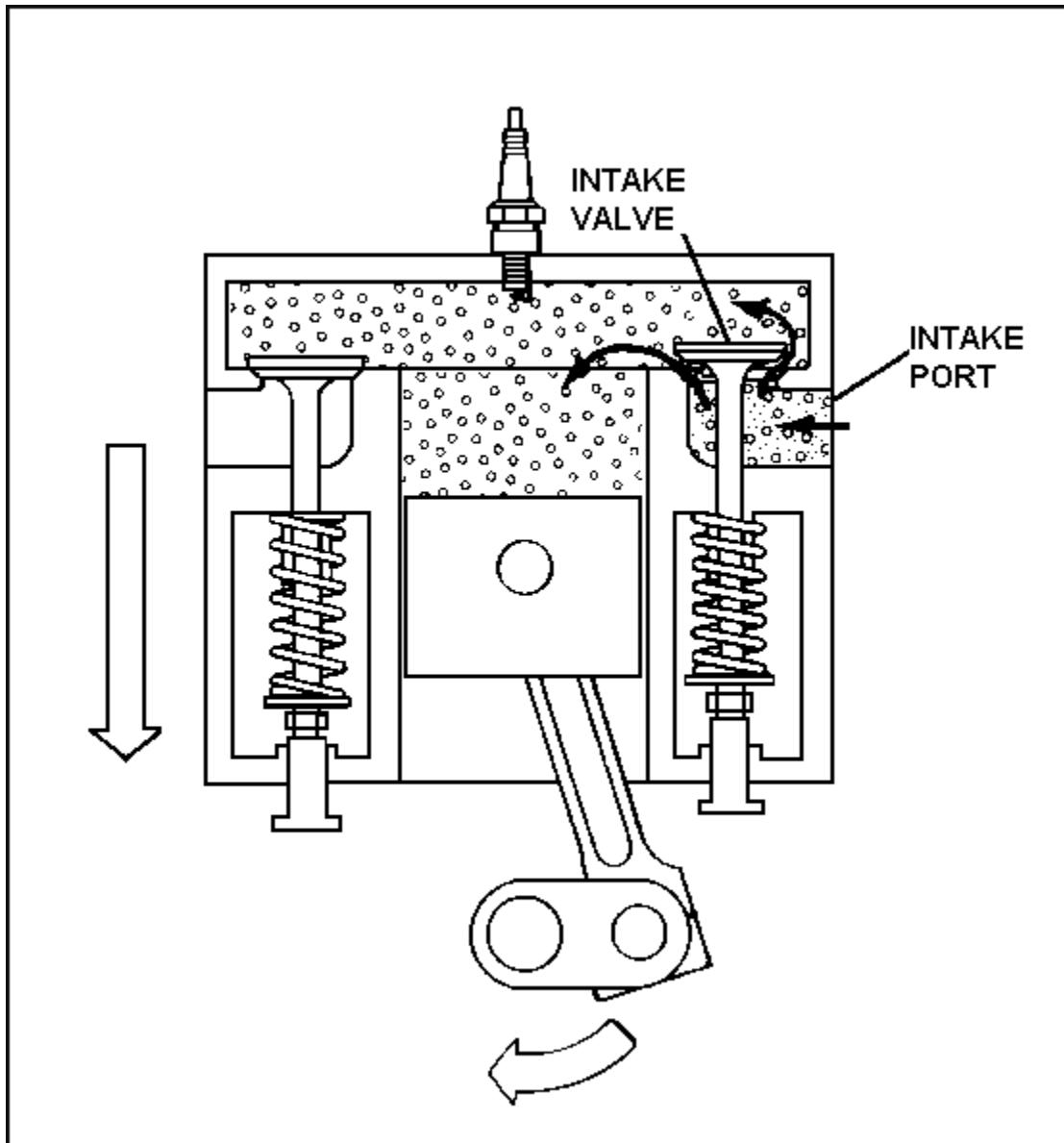


FIGURE 11. INTAKE STROKE.

Intake Stroke

As the crankshaft is rotated by cranking, the piston is moved to TDC to start the intake stroke. At the same time the timing gears turn the camshaft, the cam lobe under the intake valve is beginning to open the intake valve.

As the rotating crankshaft pulls the piston down, it draws or sucks the fuel-air mixture past the open intake valve into the combustion chamber.

When the piston reaches BDC, the intake stroke ends. The cam lobe has moved from under the tappet, allowing it to rest on the base circle of the cam. The valve spring now closes the intake valve and seals the fuel-air mixture in the combustion chamber.

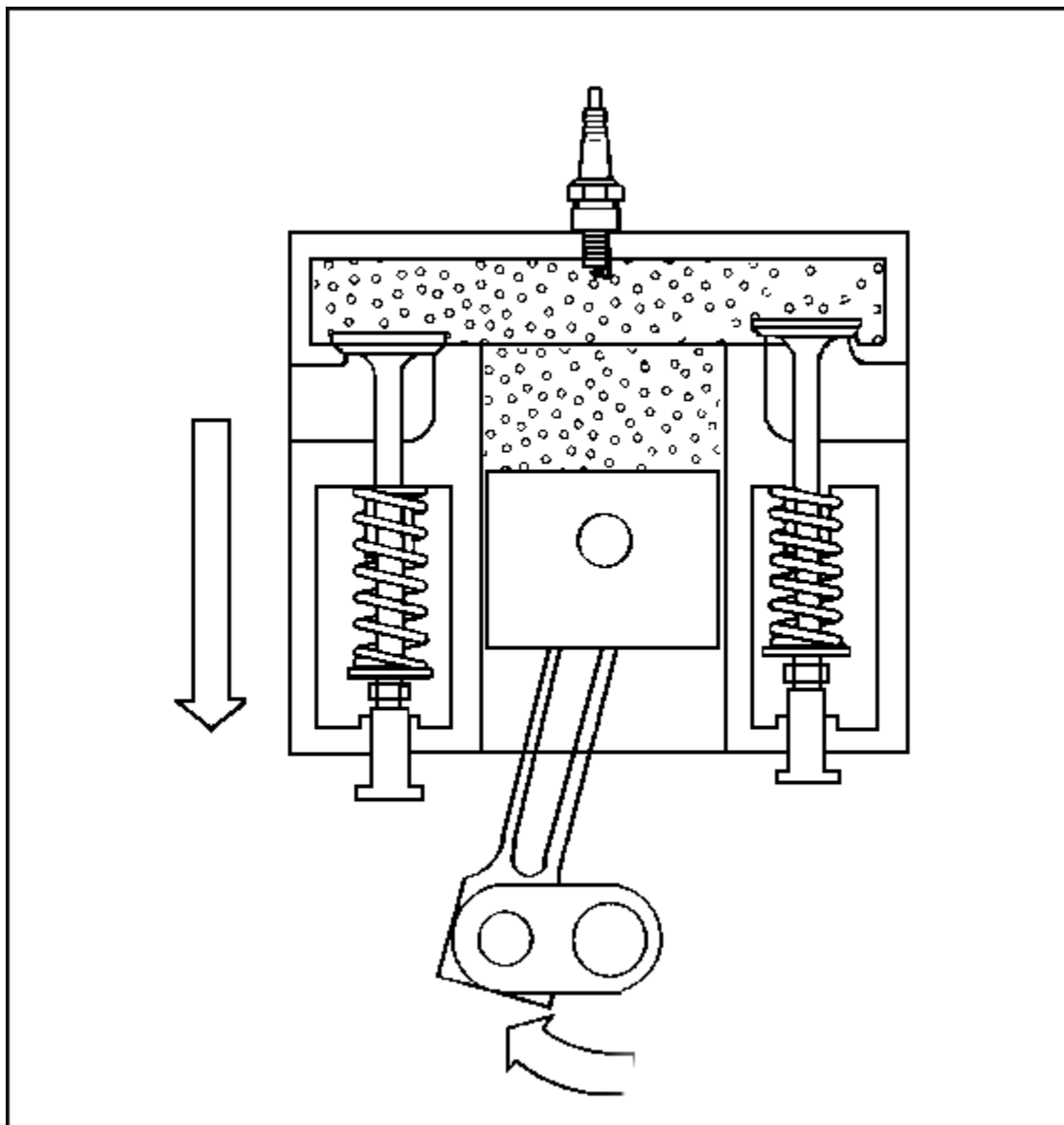
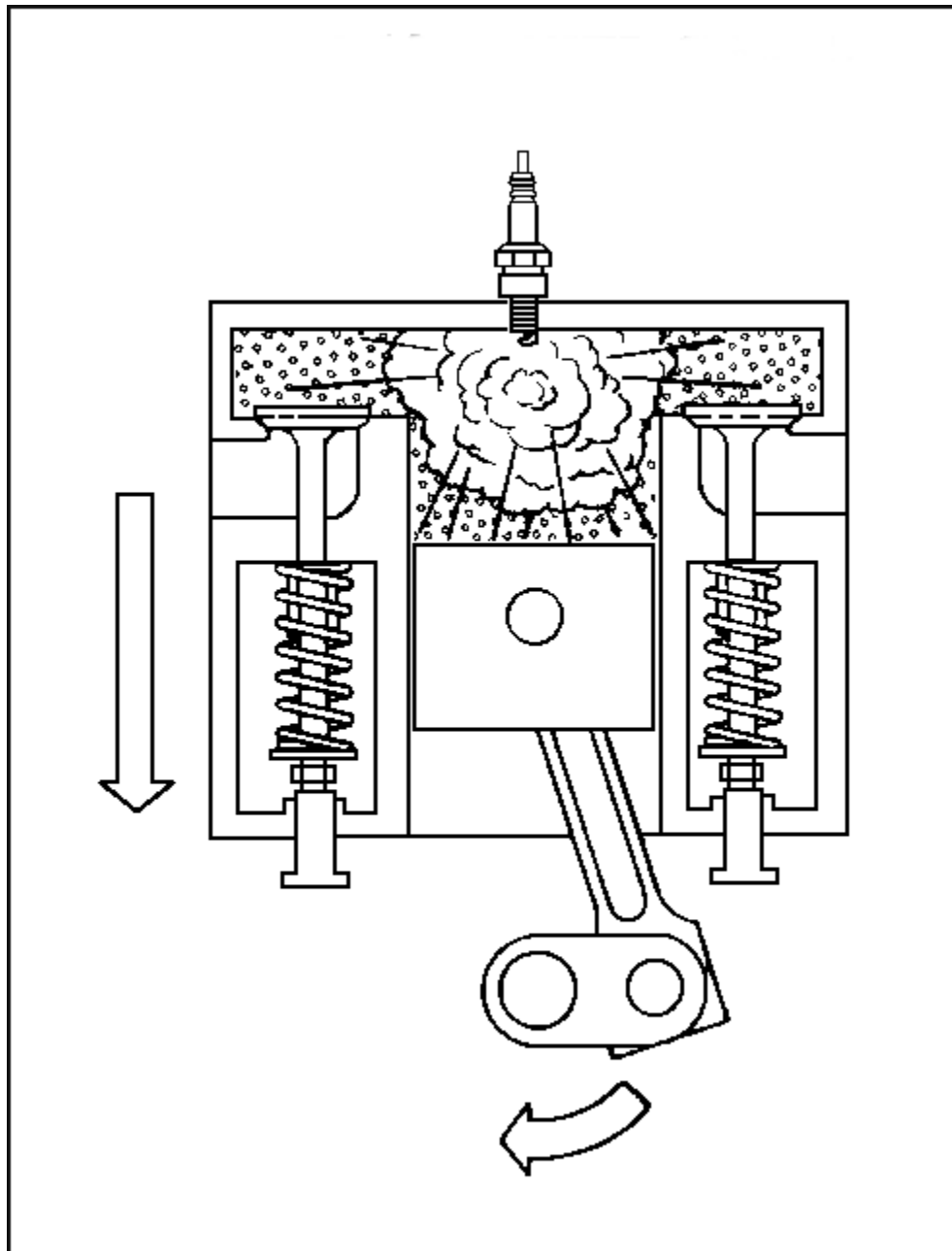


FIGURE 12. COMPRESSION STROKE.

Compression Stroke

Continued cranking now causes the piston to be moved upward. The fuel-air mixture is forced into a smaller space or is compressed, as the piston gets closer to the cylinder head, because both valves are closed. This builds up pressure inside the combustion chamber to make the fuel-air mixture more explosive.

**FIGURE 13. POWER STROKE.****Power Stroke**

Just as the piston finishes the compression stroke, the ignition system causes an electrical spark to jump across the spark plug gap. (The spark occurs inside the combustion chamber.) This really happens just before the piston reaches TDC, but for our purposes here, we will think of it as being at TDC.

The compressed fuel-air mixture is ignited or set on fire by an electric spark. The mixture burns so fast that it explodes. This causes high pressure in the cylinder that drives down on the piston head with great force.

The downward force on the piston is transmitted through the connecting rod to the crankshaft throw. The result is a powerful twist on the crankshaft which gives it a spin. Due to the heavy flywheel, the crankshaft now continues to turn through the nonpower strokes without cranking.

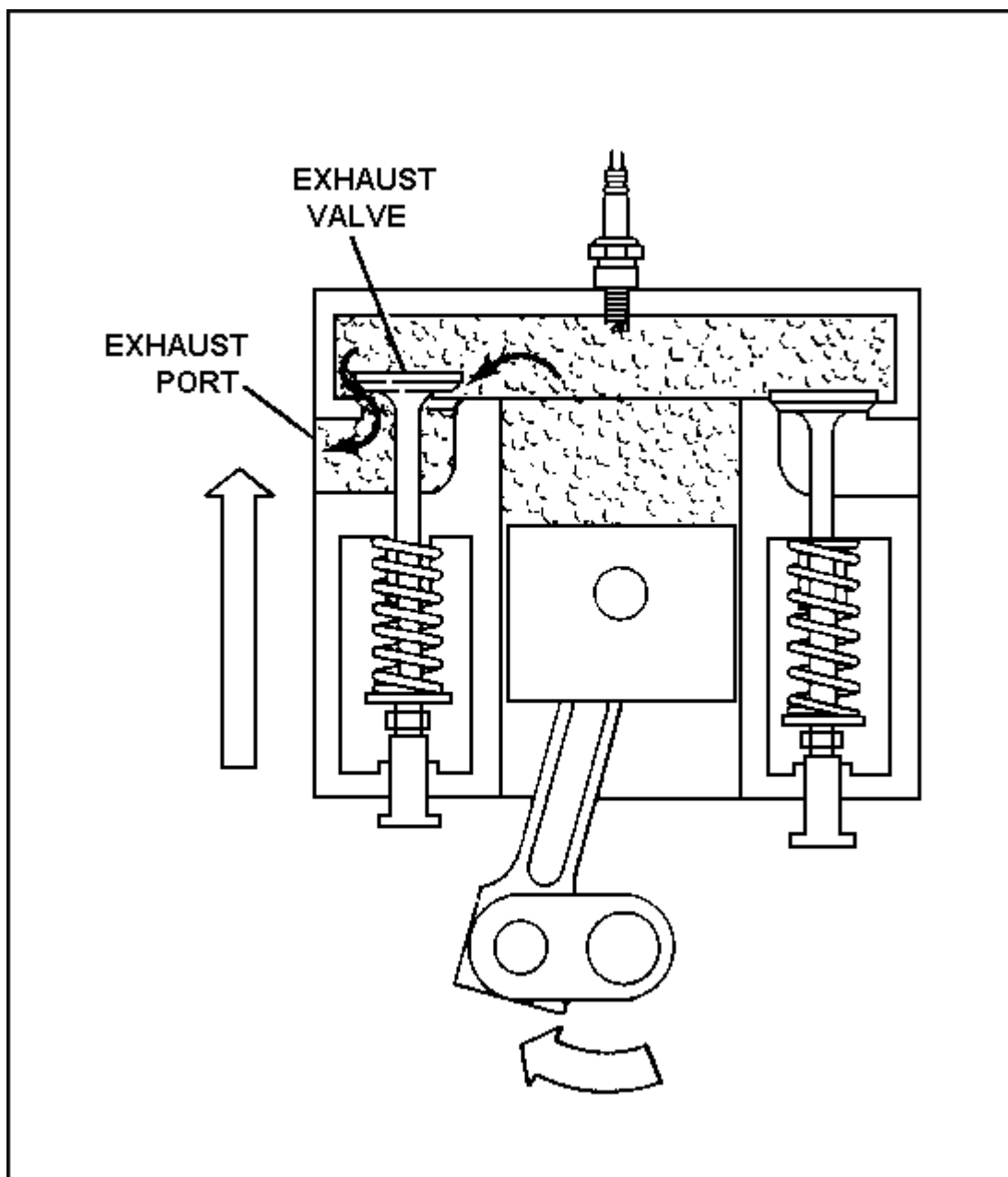


FIGURE 14. EXHAUST STROKE.

Exhaust Stroke

When the piston reaches BDC, the timing gears have turned the camshaft far enough so the cam lobe under the exhaust valve contacts the tappet and opens the exhaust valve. The rotating crankshaft moves the piston up, pushing burned gases out of the cylinder past the open exhaust valve.

By the time the rising piston reaches TDC, the camshaft has turned far enough to allow the exhaust valve to close. At this same time, the intake valve cam lobe has moved into position to open the intake valve. This has the piston and valves in the proper position to begin another intake stroke and to repeat all four strokes again.

Engine Operation - Four-Stroke Cycle

The crankshaft rotates half a turn to complete each stroke of the four piston strokes of intake, compression, power, and exhaust. By adding four half turns, you will find the crankshaft must rotate two turns to complete all four strokes. This is called one cycle of engine operation.

While the crankshaft is turning around twice (completing one cycle), it is receiving power for about half a turn or one-fourth of the time.

On every power stroke, when the fuel-air mixture is ignited, the crankshaft will receive a hard twist. Then with the aid of the flywheel, it will coast for one and one-half turns through the remaining strokes.

One cycle of engine operation requires that each valve be opened and closed one time. With a cam on the camshaft under each valve, one turn of the camshaft opens and closes both valves as needed.

Therefore, the crankshaft must rotate two turns and the camshaft one turn for each cycle of engine operation. Remember the crankshaft timing gear has half as many teeth as the camshaft timing gear to cause a difference in rotations of the shafts.

Engine speed and power output on gasoline engines are controlled by a throttle valve placed in the fuel-air mixture inlet. Closing this valve restricts or limits the amount of mixture flowing to the cylinder. This reduces engine speed and power output. Of course, opening the valve allows more mixture to be drawn or sucked into the cylinder, therefore increasing engine speed and power.

THE TWO-STROKE CYCLE

Another method of engine operation is the two-stroke cycle. It is used mostly in small gasoline engines and also with some large diesel engines. In this lesson we will only discuss the small gasoline engines, as diesel engines are covered in another lesson.

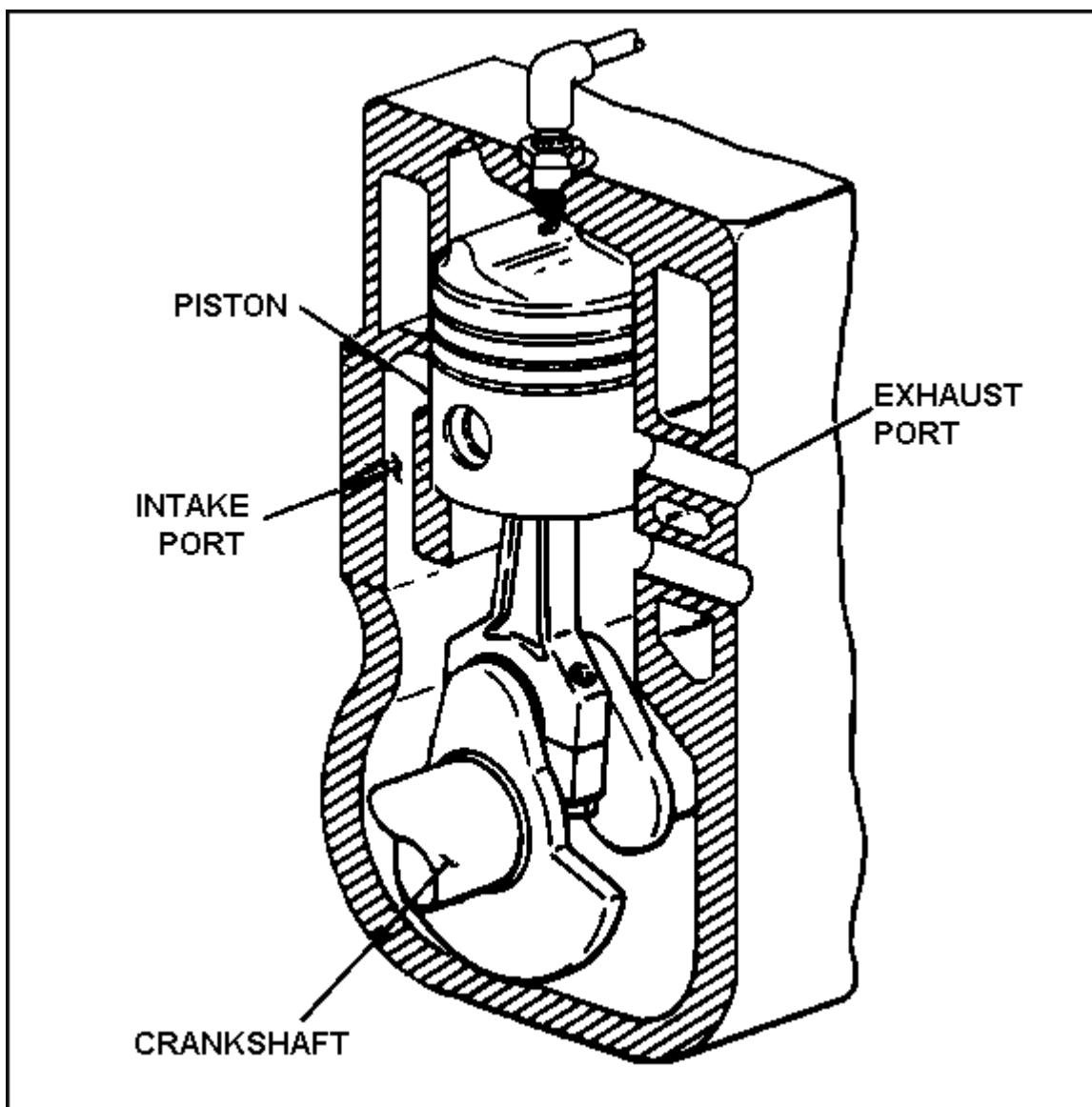


FIGURE 15. TWO-STROKE-CYCLE ENGINE.

Construction of the Two-Stroke-Cycle Engine

The two- and four-stroke-cycle engines differ because the two-stroke cycle uses ports in the cylinder wall in lieu of valves. By using intake and exhaust ports in the cylinder wall, the valves, tappets, camshaft, and timing gears are not needed.

The exhaust port is located slightly higher in the cylinder than the intake port. The intake port is connected to the crankcase by an internal passageway in the engine block.

Most two-cycle engines in use today have a fuel-air mixture intake valve located in a mixture inlet into the crankcase. The intake valve or reed valve, as it is sometimes called, will allow mixture to flow into the crankcase. However, if the mixture tries to flow in the opposite direction, the valve closes and seals the crankcase.

Because the two-stroke-cycle engine needs less parts, it can be made lighter and smaller than the four-stroke-cycle engine. Therefore, two-stroke-cycle engines are very common where light weight and small size are needed; such as on chain saws, outboard motors, and lawnmowers.

Engine Operation - Two-Stroke Cycle

Now let's take a look at how the two-stroke-cycle engine operates. Imagine that the cylinder is already full of fuel-air mixture and the piston is at the bottom of the cylinder. The engine is cranked; first, the piston moves up past the intake and exhaust ports to seal the cylinder, then it begins to compress the mixture. At the same time, the rising piston increases the space inside the crankcase creating low pressure or suction in that area. This low pressure draws fresh fuel-air mixture past the intake valve into the crankcase.

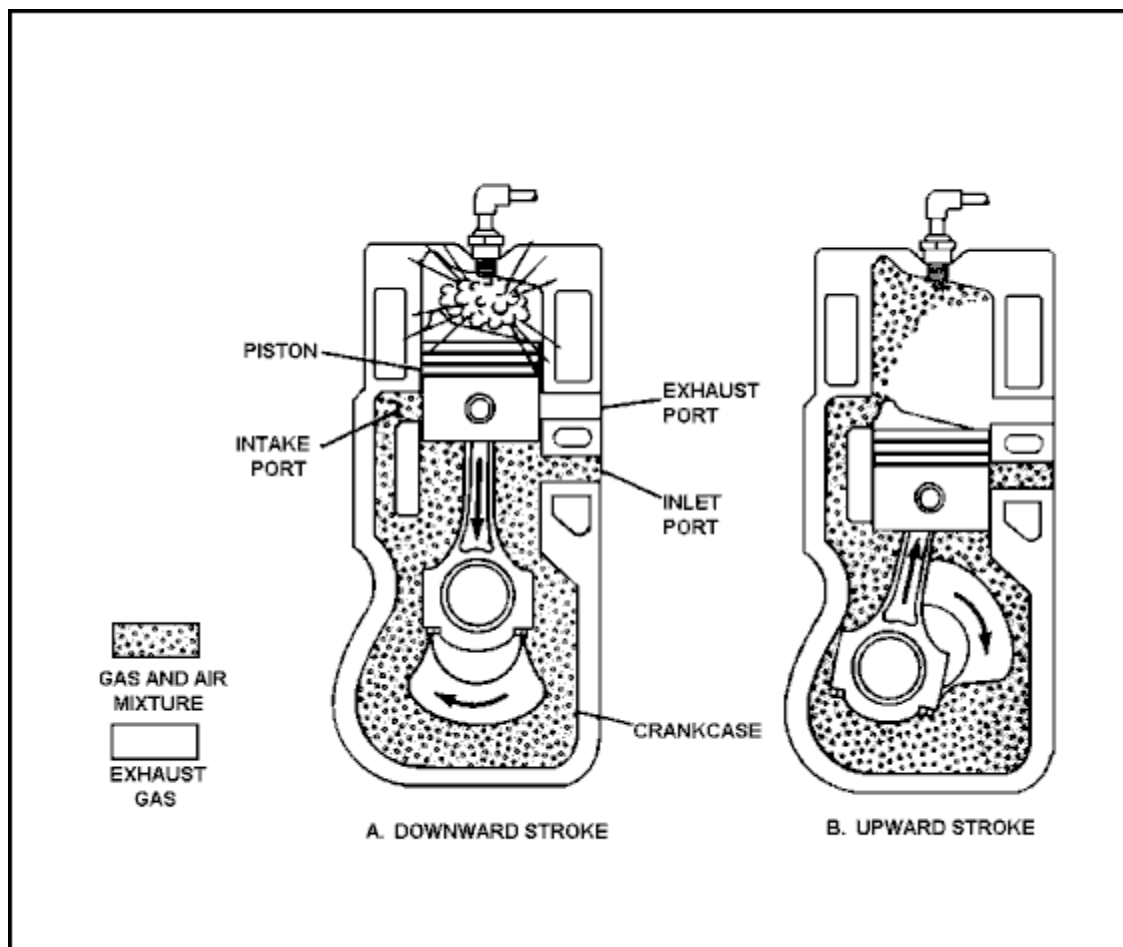


FIGURE 16. THE TWO-STROKE CYCLE.

When the piston reaches the top of its stroke, it has compressed the fuel-air mixture in the cylinder and filled the crankcase with a fresh mixture. Note that this has taken place in half a turn of the crankshaft.

The ignition system produces a spark at the spark plug gap igniting the fuel-air mixture in the cylinder, and the piston moves downward on the power stroke. As the piston moves downward, it decreases the space in the crankcase which tries to push the mixture out of the crankcase through the intake valve. The valve closes, sealing the crankcase. The descending piston now compresses the mixture in the crankcase.

The piston first uncovers the exhaust port to end the power stroke and to allow gas pressures in the cylinder to escape. Then the intake port is uncovered. The compressed fuel-air mixture in the crankcase now flows into the cylinder through the open intake port. Because the mixture is under pressure, it pushes the remaining exhaust gases out through the exhaust port.

Notice that the piston head is shaped so it deflects the in flowing mixture upward, away from the exhaust port. This is to keep the fresh mixture from mixing with the exhaust gases and being lost out through the open exhaust port.

The cylinder is now full of a fuel-air mixture as we imagined at the beginning of the cycle. Take particular notice that the complete cycle of operation occurred in only one turn of the crankshaft and two piston strokes. The cycle is repeated again and again as the engine continues to run under its own power.

In an engine of this type, engine oil is generally mixed with the gasoline fuel. Then, as the gasoline, oil, and air mixture passes through the crankcase in vapor form, it lubricates engine parts.

Learning Event 2:

DESCRIBE COMPONENTS AND CONSTRUCTION OF MULTICYLINDER ENGINES

In an engine with more than one cylinder, the cycle of operation is the same at each cylinder. Adding more cylinders, however, does lead to smoother operation because other cylinders will be furnishing power between the power strokes of the first cylinder. For instance, in a four-cylinder, four-stroke-cycle engine there is one power stroke for each half turn of the crankshaft. If the engine has more than four cylinders, the power strokes will overlap. To understand the engine in greater detail, a study of its parts is necessary.

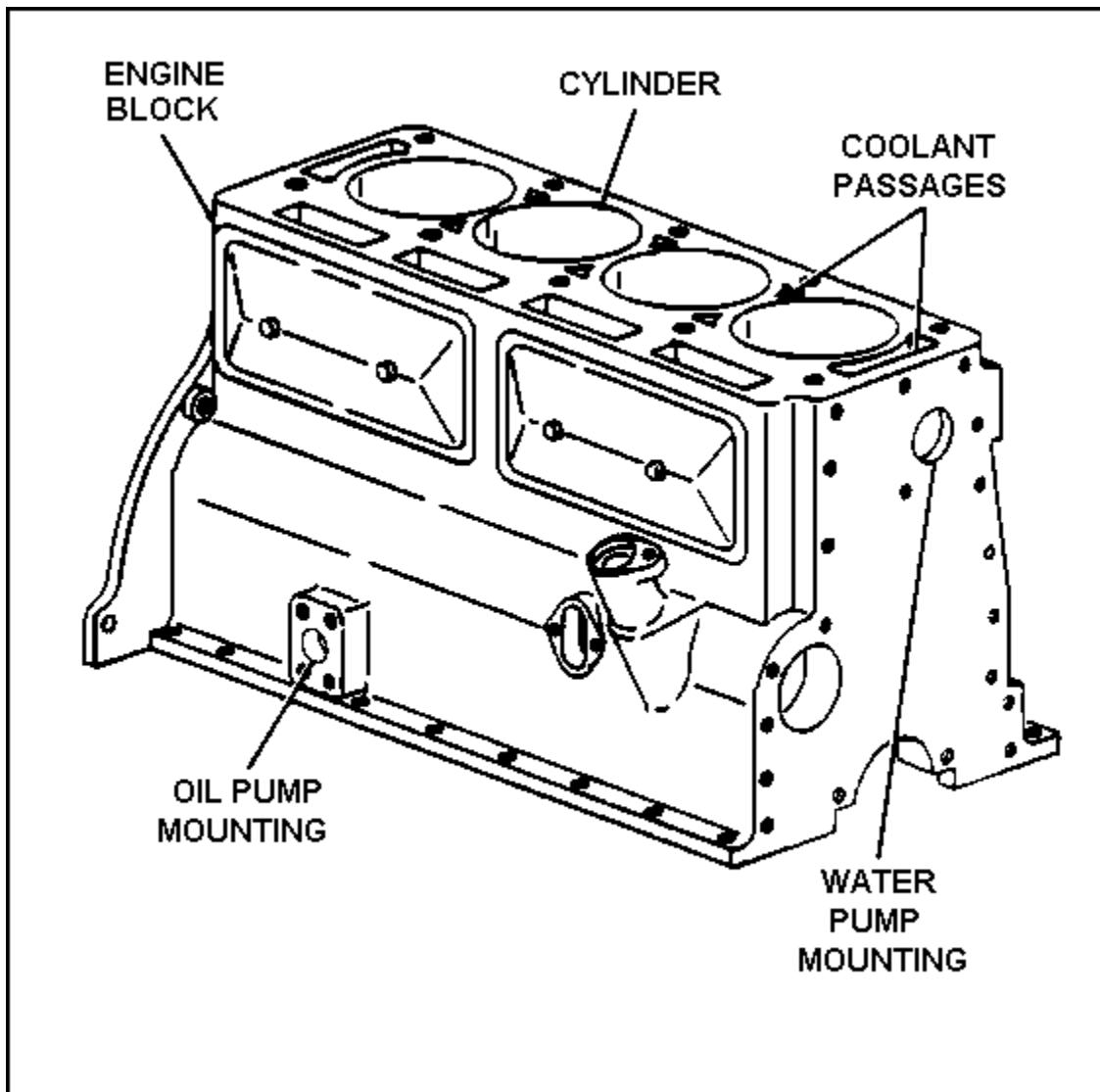


FIGURE 17. CYLINDER BLOCK.

Cylinder Block

The cylinders and the upper part of the crankcase are usually made together in one block of metal called the cylinder block. In L- and F-head engines, the block has valve seats and ports beside the cylinders. It also serves as a mounting foundation for the crankshaft and other engine parts.

The cylinders of the liquid-cooled engine have jackets all around them to hold the cooling liquid. These jackets are made with, and are a part of, the cylinder block. Passages in the top of the block allow the coolant to pass between the block and the cylinder head.

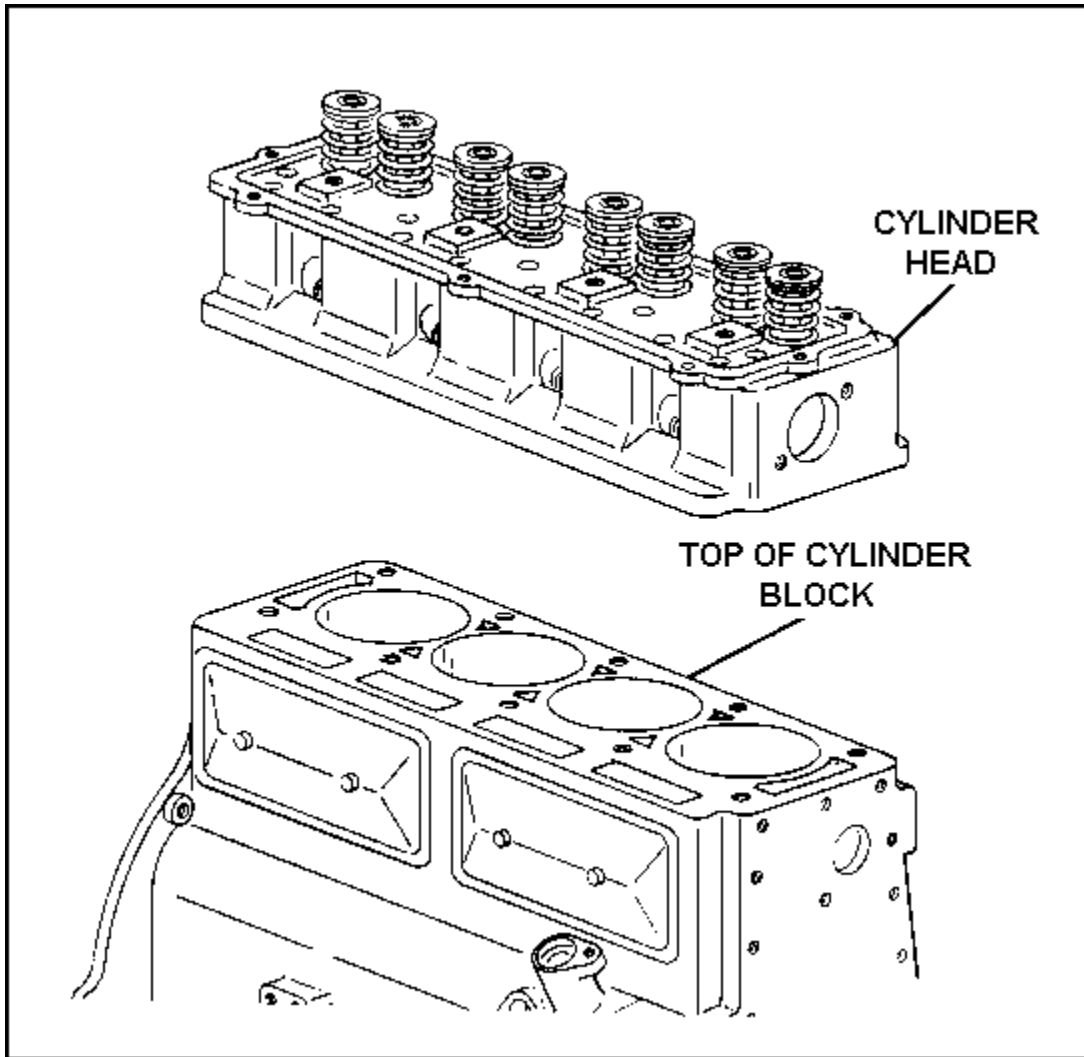


FIGURE 18. CYLINDER HEAD.

Cylinder Head

The cylinder head contains the upper half of the combustion chambers and is bolted to the top of the cylinder block. It contains coolant passages that align with the coolant passage in the cylinder block. The head also has a threaded hole in each combustion chamber for spark plugs to be screwed into.

Lesson 1/Learning Event 1

A metal or a metal-asbestos gasket is used between the head and the block to prevent the leakage of coolant and cylinder pressure. Holes are cut in the gasket that align with the cylinders, bolt holes, and coolant passages.

I- and F-head engine cylinder heads have valves and valve operating mechanisms mounted on them. These heads also have passages so lubricating oil can flow between the crankcase and the valve mechanism. A rocker armor valve cover is bolted to the top of the cylinder head. This prevents the leakage of oil and keeps dirt out of the valve mechanism.

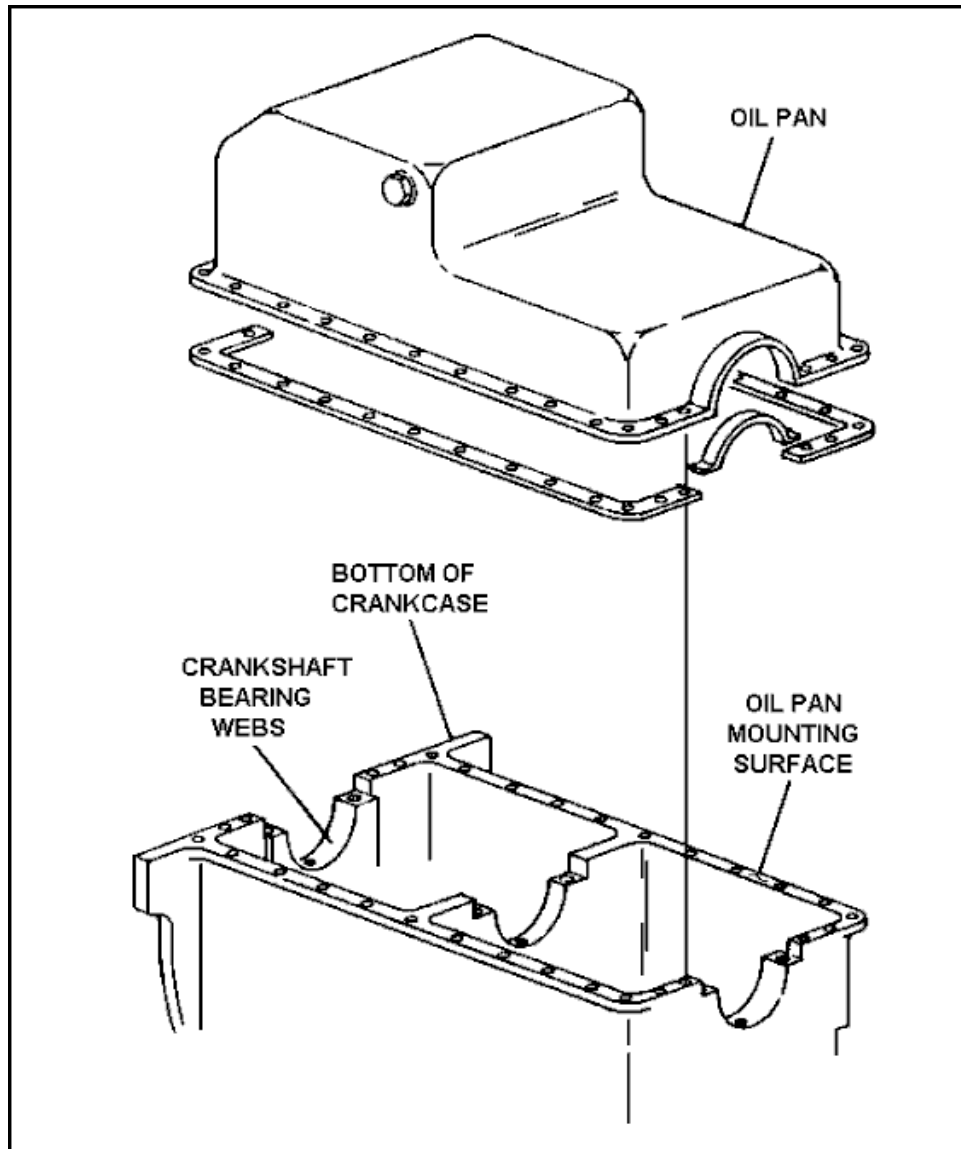


FIGURE 19. CRANKCASE.

Crankcase

The crankcase is the part of the engine that supports and encloses the crankshaft and holds the lubricating oil. As you know, the upper part of the crankcase is a part of the cylinder block. It supports the crankshaft in bearings that are called the main bearings.

The lower part of the crankcase holds the oil and is called the oil pan. It is usually made of sheet metal and is bolted to the bottom of the cylinder block. A gasket is used between the block and pan to prevent oil leaks. A threaded plug in the bottom of the oil pan allows the lubricating oil to be drained without removing the pan.

The crankcase sometimes provides the mounting points that support the entire engine in the vehicle frame. Rubber mounts are usually located between the crankcase brackets and vehicle frame. This is to insulate the frame and body from engine vibrations and noise.

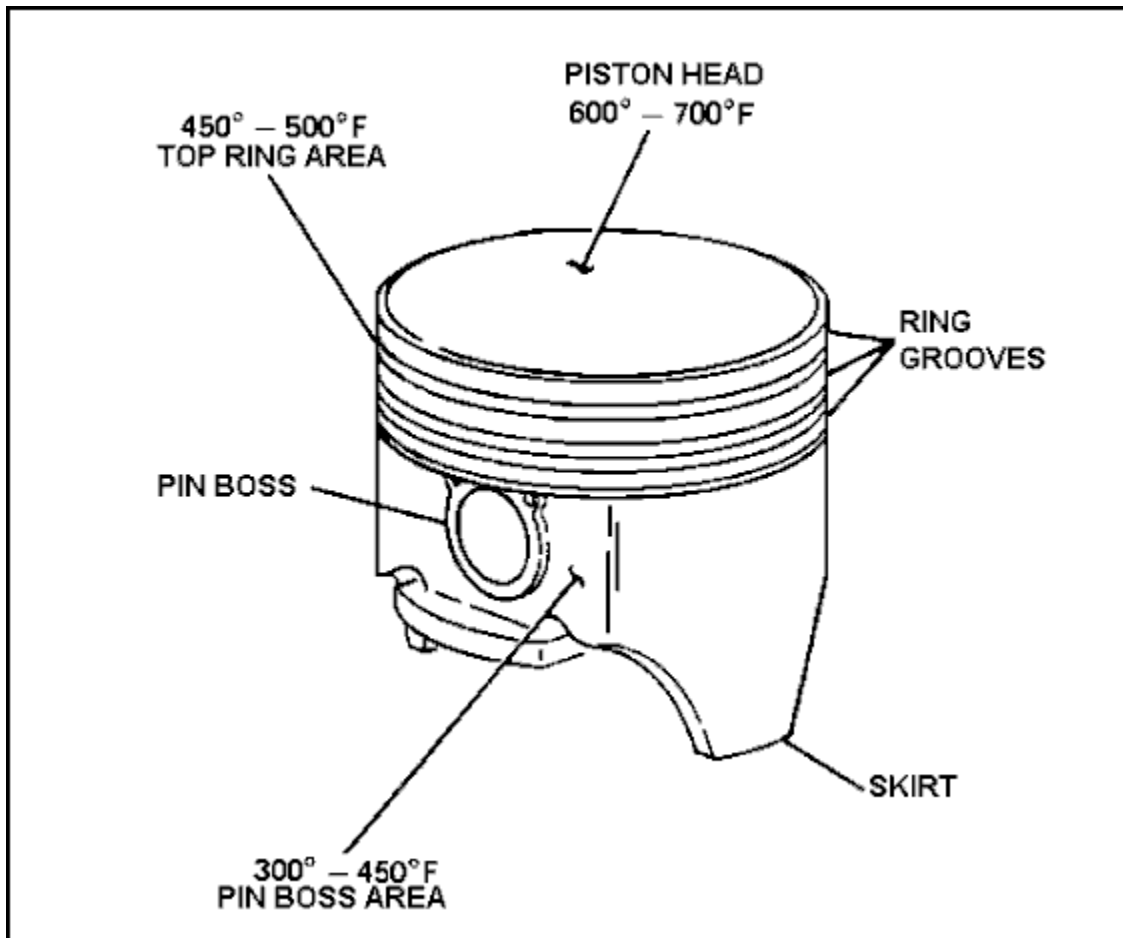


FIGURE 20. PISTON.

Pistons

The pistons in use today are made of metal that is lightweight but very strong. The pistons must come to a complete stop, and then start again in the opposite direction at the end of each stroke. Therefore, lightweight pistons are desired because they take less power away from the engine. The pistons must be strong to withstand the force created by the combustion of the fuel-air mixture.

Since the piston must be free to slide up and down inside the cylinder, there must be clearance between the piston and cylinder wall. There must not be too much clearance though or the piston skirt will slap against the wall. This would put excessive strain on the piston and prevent the piston rings from doing their job properly.

As metal warms up, it expands or gets bigger. Different kinds of metals expand different amounts for the same temperature change. Pistons expand more than the cylinders. Therefore, this presents a problem in keeping the piston to cylinder wall clearance proper as the engine temperature changes.

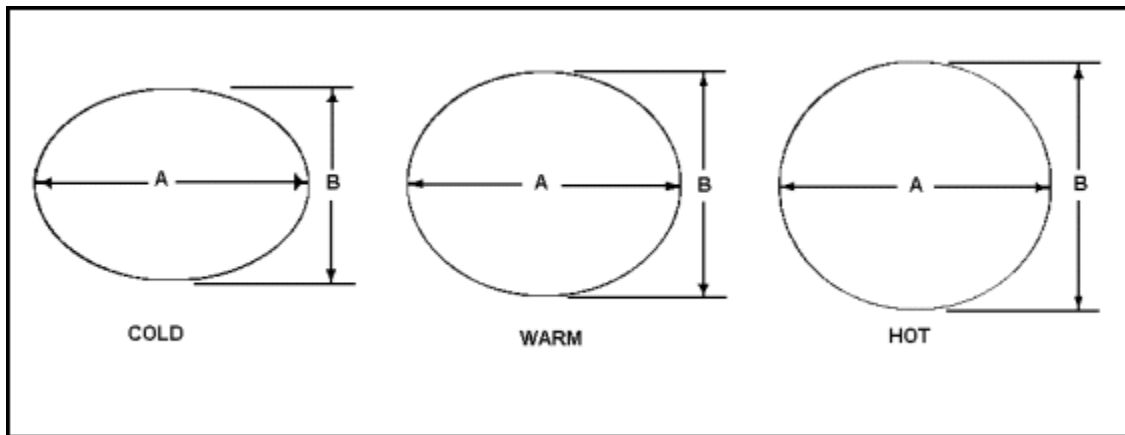


FIGURE 21. CAM-GROUND PISTON.

Builders of engines make pistons so their running clearances stay about the same regardless of temperature. One common way of doing this is to grind the piston skirt so it is elliptical or egg-shaped instead of round. When the engine is cold, the two high spots of the piston skirt fit close to the cylinder wall preventing piston slap. As the temperature rises, expansion causes the piston to become round instead of binding up in the cylinder. A piston shaped this way is called a cam-ground piston.

Piston Rings

The rings on pistons do more than prevent gases from leaking between the piston and cylinder wall. They also assist in cooling the piston and keep lubricant from entering the combustion chamber. They cool the piston by transmitting heat from the piston to the cylinder block. Two types of rings, compression and oil-regulating, are used.

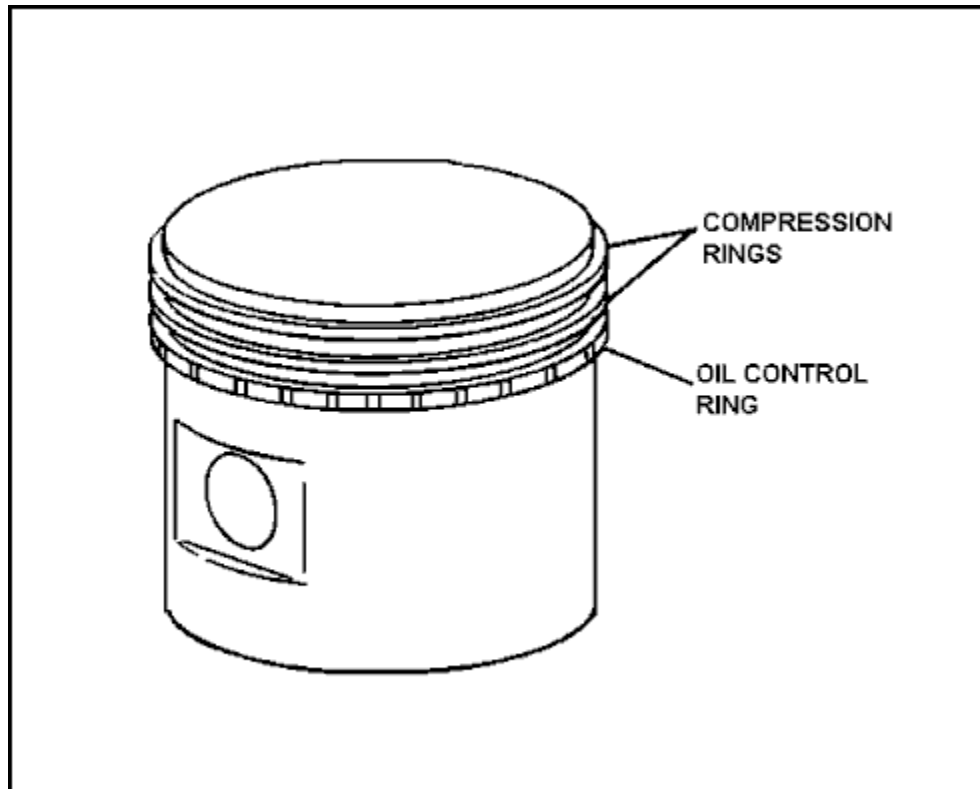


FIGURE 22. PISTON RINGS.

Compression Rings. The main job of the compression rings is to prevent pressure in the combustion chamber from leaking past the piston into the crankcase. Since the high pressures are created above the piston, compression rings are located in the top piston ring grooves. Generally, at least two compression rings are used.

Oil-Regulating or Oil-Control Rings. When an engine is running, a large amount of oil is being sprayed and splashed on the cylinder walls and pistons. This oil is needed for cooling and lubricating purposes, but if it gets into the combustion chamber, mechanical problems will develop. Oil that gets into the combustion chamber will be burned and passed out the exhaust.

system as blue smoke. Burning the oil will lower the oil supply in the oil pan and cause a buildup of damaging carbon inside the combustion chambers. Oil-regulating rings are placed in the bottom piston ring grooves to scrape oil off the cylinder walls and return it to the crankcase. At least one--sometimes two--of these rings are used on each piston.

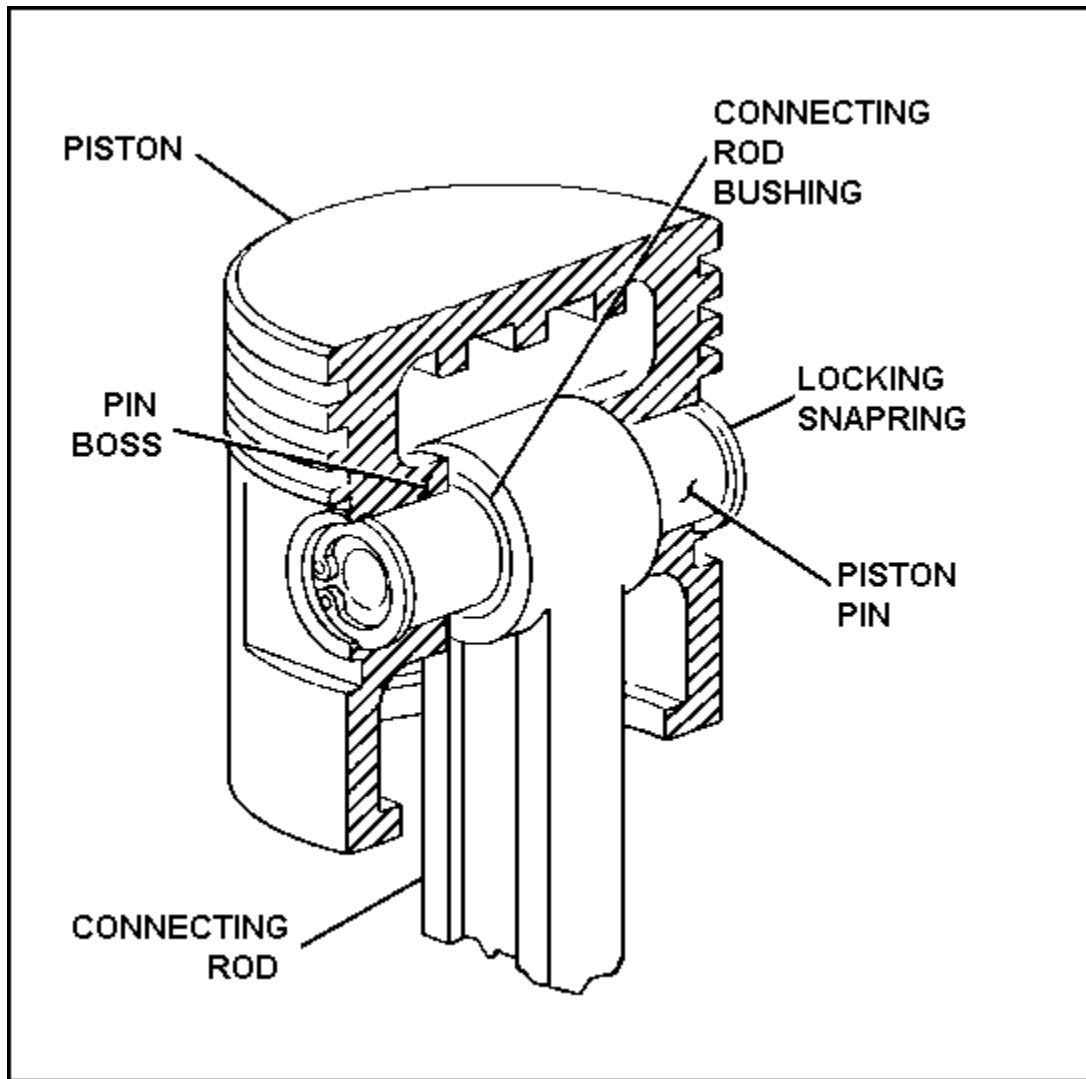


FIGURE 23. PISTON PIN.

Piston Pin

To reduce the weight of the pistons, the piston pins are made hollow. They are made of hard steel; therefore, their ends must not be allowed to touch the cylinders as this will score their walls. Also, the pins must fit in the pistons and connecting rods with the proper amount of operating clearance. Too little clearance will not allow the connecting rod to swing freely from the piston; too much clearance will cause a knocking noise when the piston changes its direction of travel.

Several different methods of securing a piston pin in the piston are used. Each method can be placed in one of three different classifications. These are anchored or fixed, semifloating, and full-floating pins.

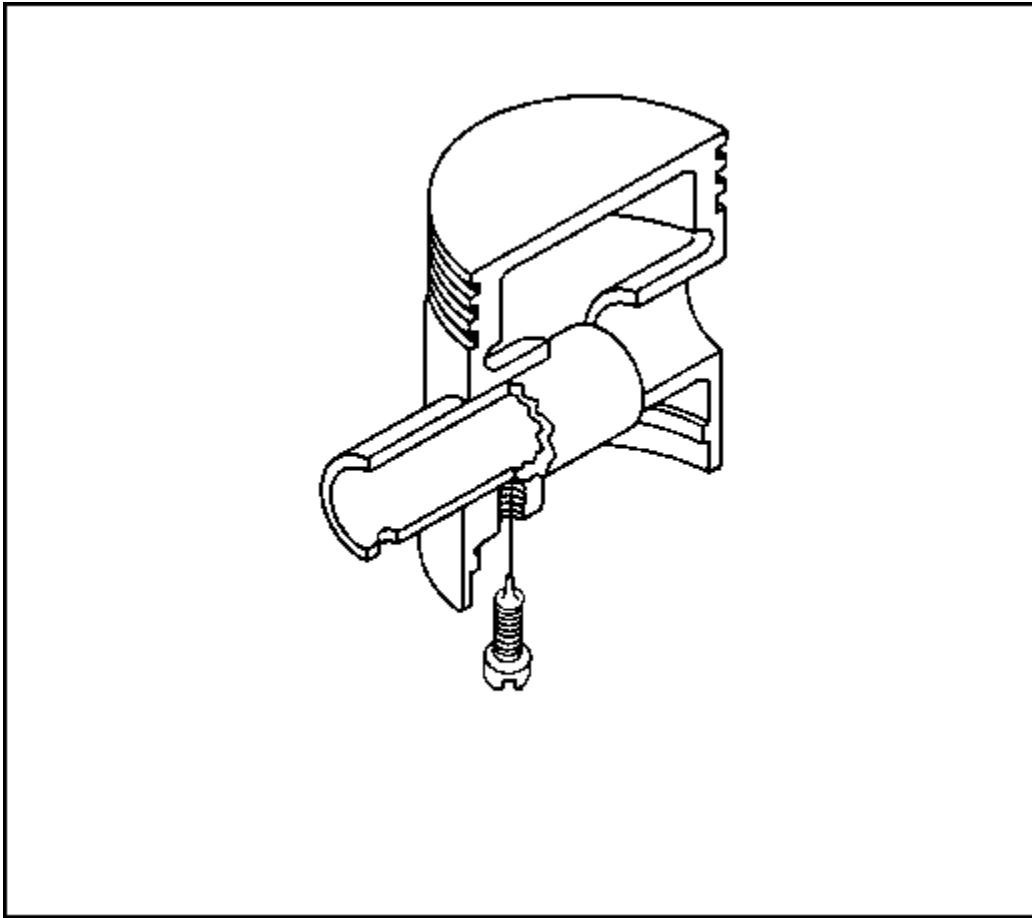


FIGURE 24. FIXED PIN.

Fixed Pin. The fixed pin is attached firmly to the piston, and the connecting rod is free to swing on the pin.

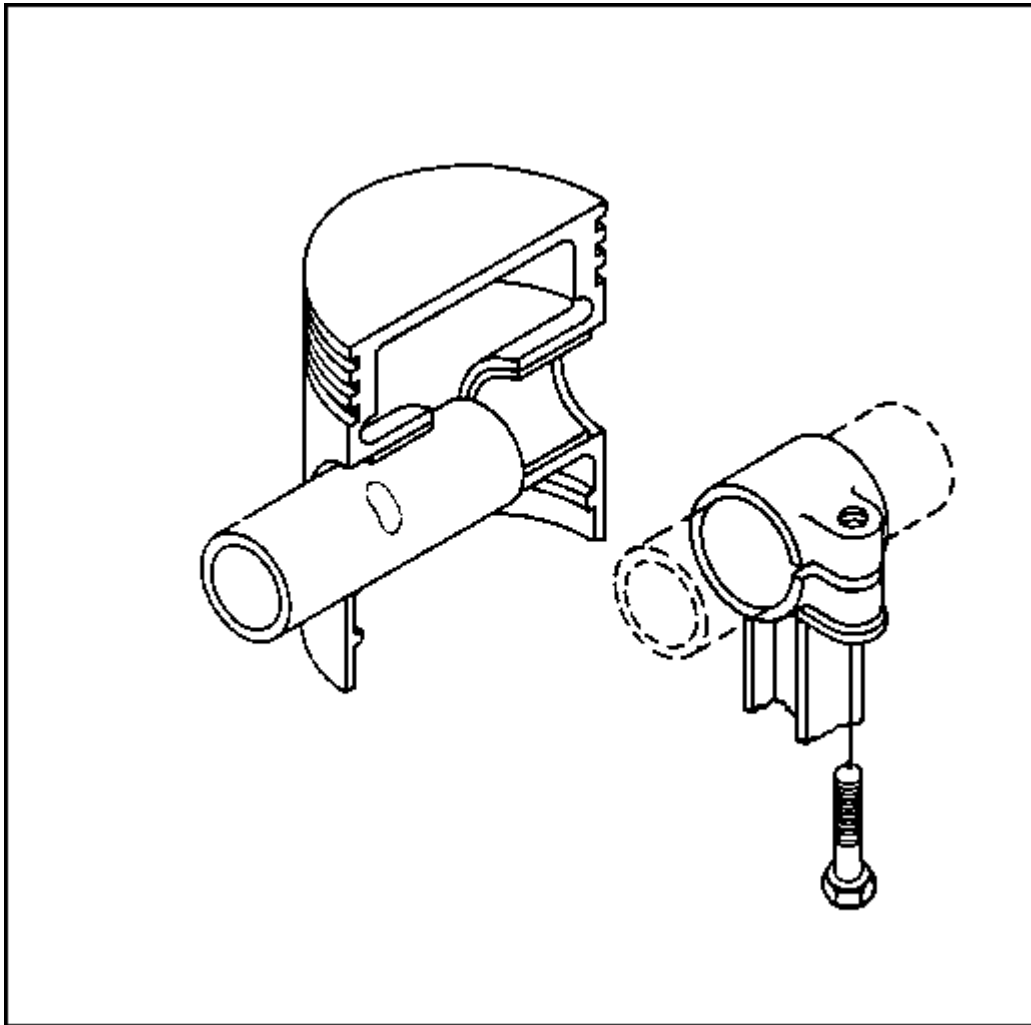


FIGURE 25. SEMIFLOATING PIN.

Semifloating Pin. The semifloating pin is anchored to the connecting rod and is free to turn in the piston.

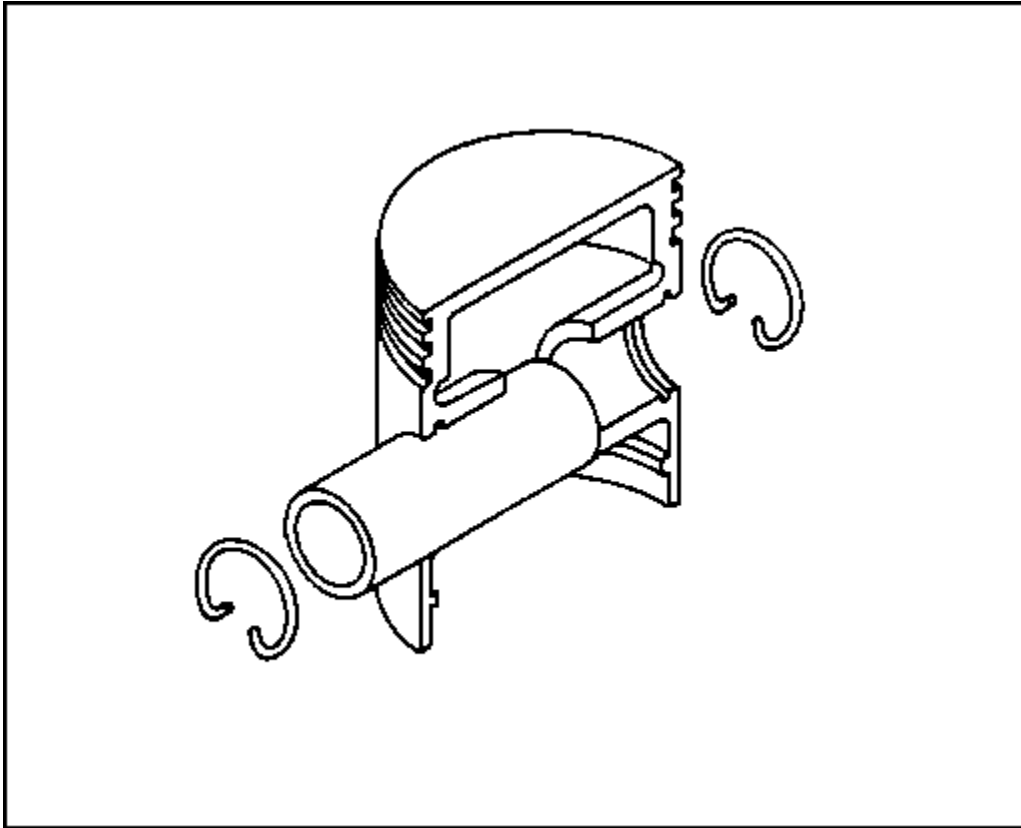


FIGURE 26. FULL-FLOATING PIN.

Full-Floating Pin. The full-floating pin is free to turn in both the piston and connecting rod. It is prevented from working out against the cylinder wall by plugs or snap rings.

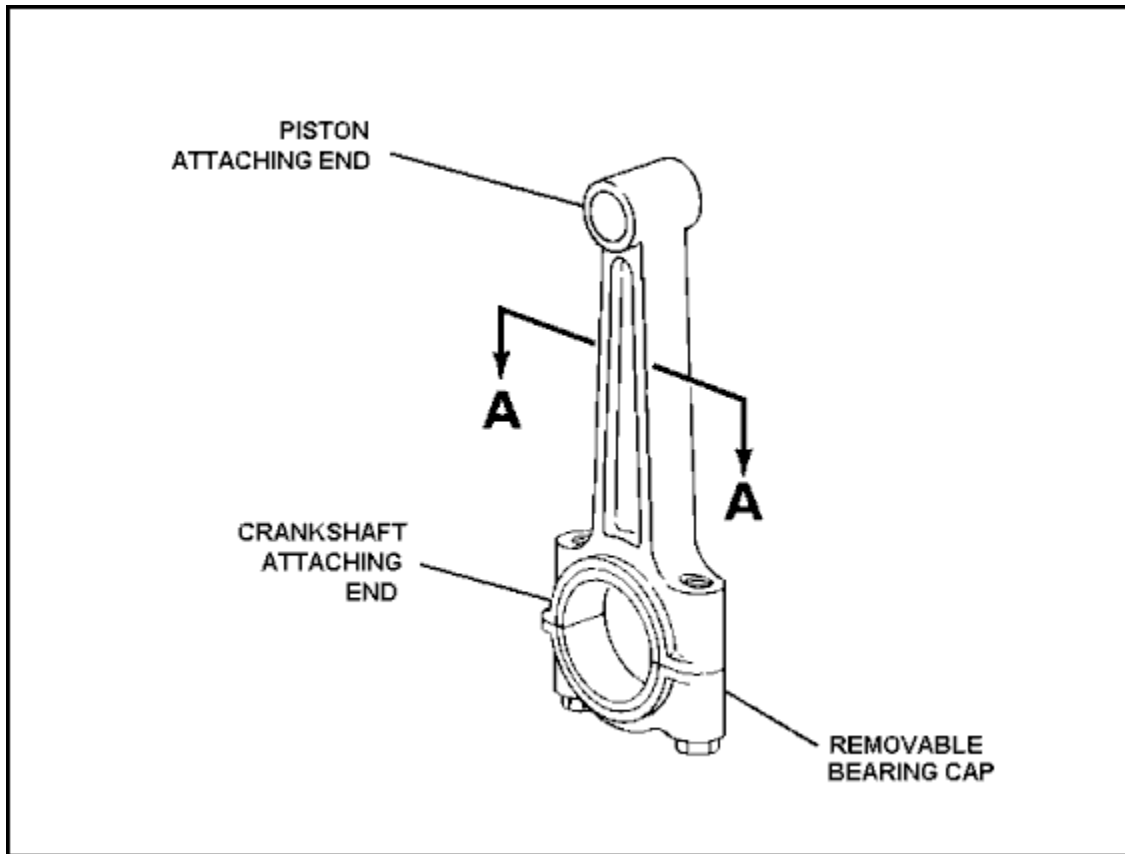


FIGURE 27. CONNECTING ROD.

Connecting Rods

Connecting rods that are used with fixed or full-floating pins generally have a bushing-type bearing pressed into the pin hole. The lower end is fitted with two-piece bearings that encircle machined bearing surfaces of the crankshaft throws. Connecting rod bearings with too much running clearance will cause a knocking noise and can result in a broken rod or a scarred crankshaft throw.

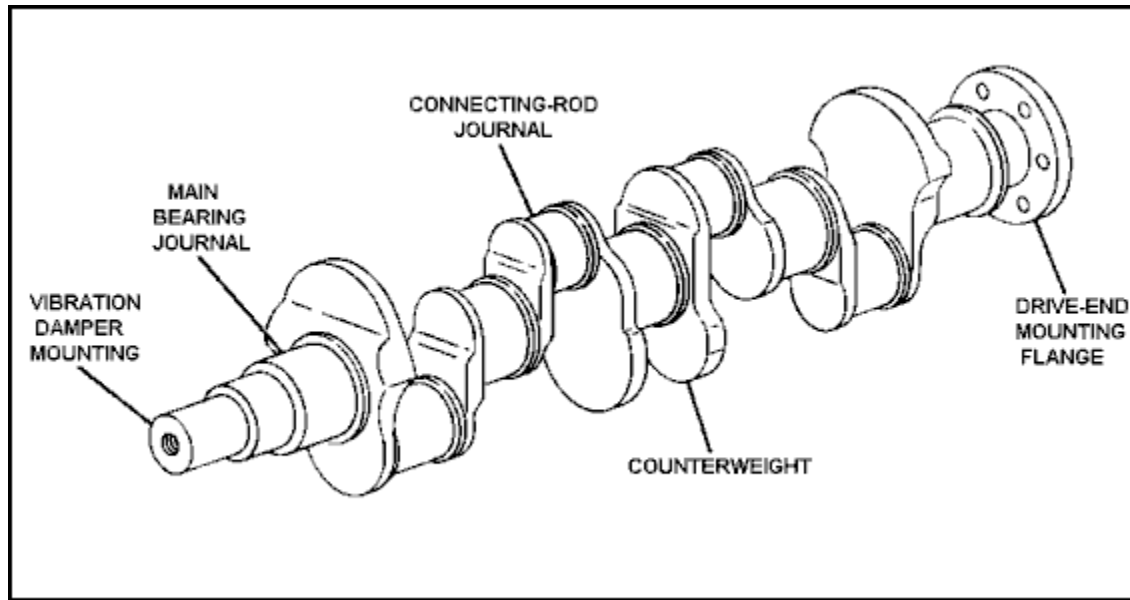


FIGURE 28. CRANKSHAFT.

Crankshaft

The crankshaft may well be called the backbone of the engine. It ties together the action of all the pistons--changing their back and forth motion into rotary motion and carrying the power to the flywheel.

In addition to having many throws, the crankshaft has several machined bearing surfaces for mounting it in the crankcase. Each mounting point in the crankcase is called a main bearing. The main bearings are made much like the connecting rod bearings with removable caps and two-piece bearing inserts. One of the main bearings has a lip or thrust surface on the sides of the bearing inserts. This is to control the end thrust or endwise movement of the crankshaft. Oil seals are used at each end of the shaft, where it sticks out of the crankcase, to prevent the leakage of lubricating oil.

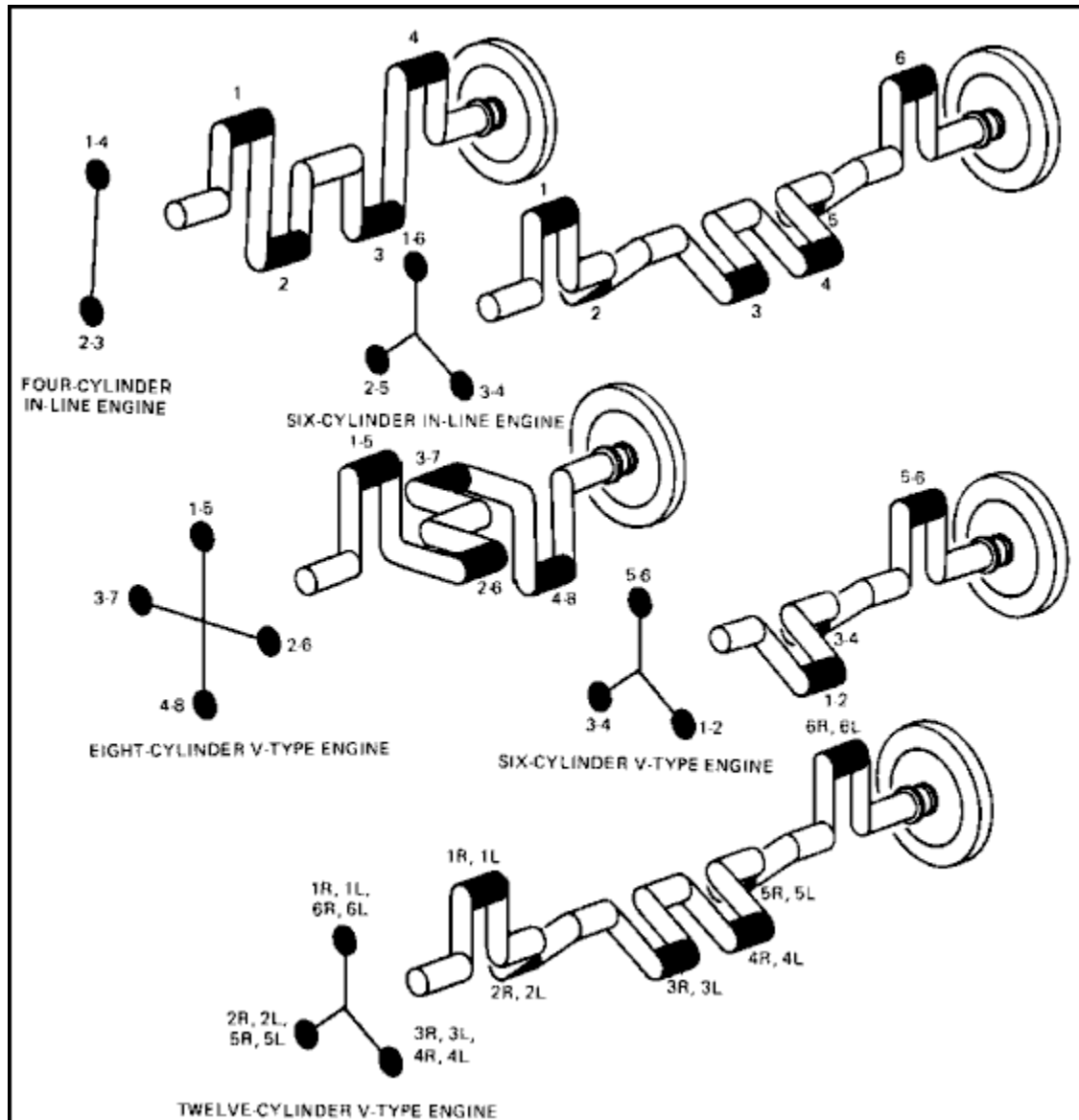


FIGURE 29. CRANKSHAFT THROW ARRANGEMENTS.

The throws are not all aligned with each other, but extend from the centerline of the crankshaft at different points. Their positions are arranged so the power strokes of the pistons occur regularly to provide a smooth flow of power. There are a number of different throw arrangements that can be used, but generally the ones pictured here are used.

As you can see, the order in which the cylinders produce power strokes is determined by the crankshaft throw arrangement. This order is called the firing order of an engine and is given by a group of numbers. For example, the firing order of a six cylinder engine is 153624. These numbers mean that the engine fires or produces power strokes beginning with cylinder No 1, then No 5, No 3, and so on.

Some crankshafts are quite long and tend to twist when some pistons are on their power strokes. This causes a shaking or vibrating of the shaft that is called torsional vibration. To understand how this can happen, think of the crankshaft as being made of rubber. When the front cylinder fires, it tries to turn the crankshaft very quickly. The heavy flywheel, which is bolted to the opposite end of the crankshaft, resists this sudden movement which causes the crankshaft to wind up or twist. When the power stroke ends, the crankshaft will unwind. The repeated winding and unwinding causes the torsional vibration.

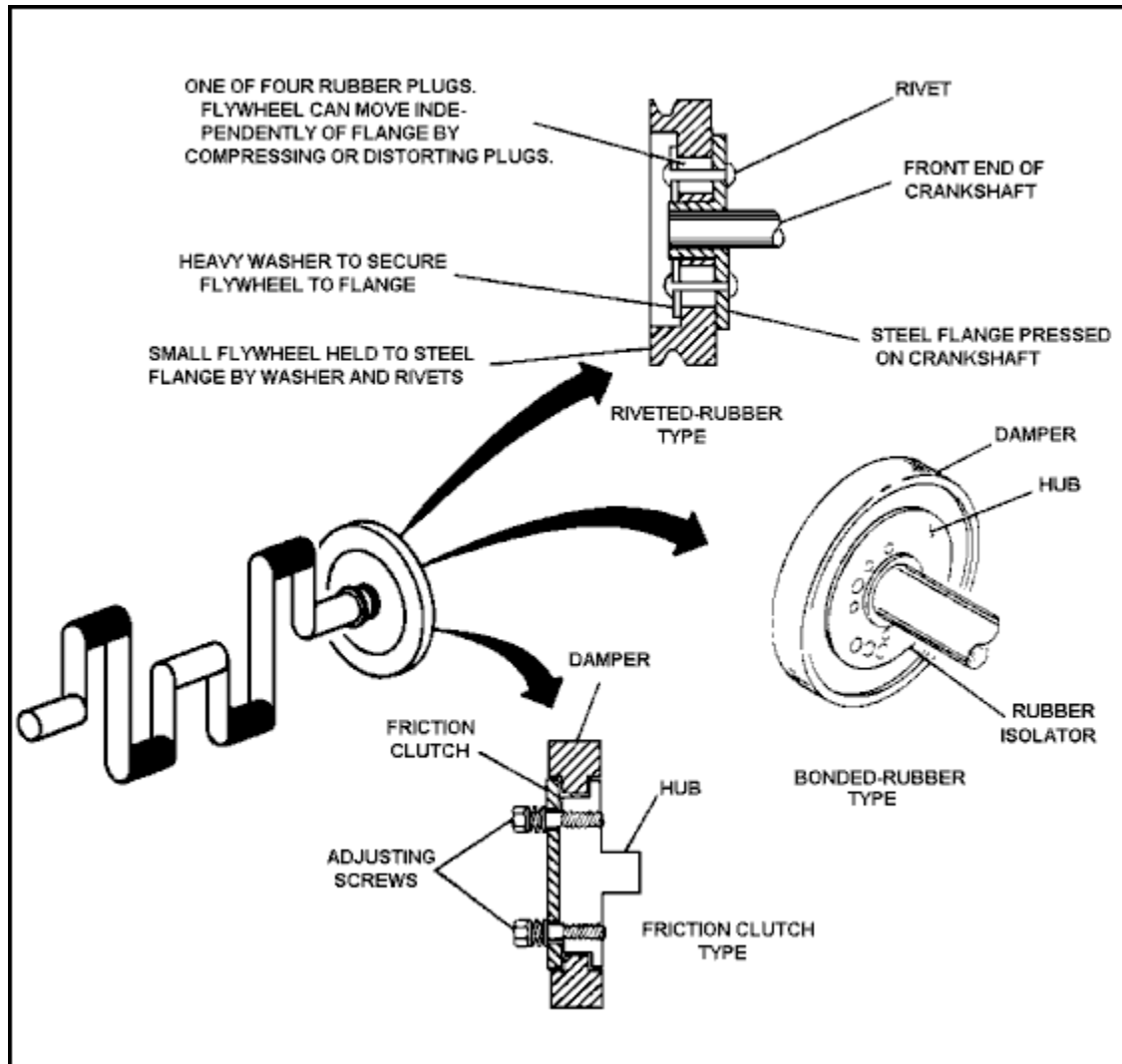


FIGURE 30. VIBRATION DAMPER.

To reduce or stop torsional vibration, a weighted wheel is placed on the front end of long crankshafts, opposite the flywheel. This wheel is referred to by such names as torsional balancer, vibration damper, and harmonic balancer. The damper or wheel is usually built in two pieces and connected by some flexible method like a friction clutch, rubber, or springs. Sometimes the two pieces separate or shift positions which may cause unusual noises or vibration.

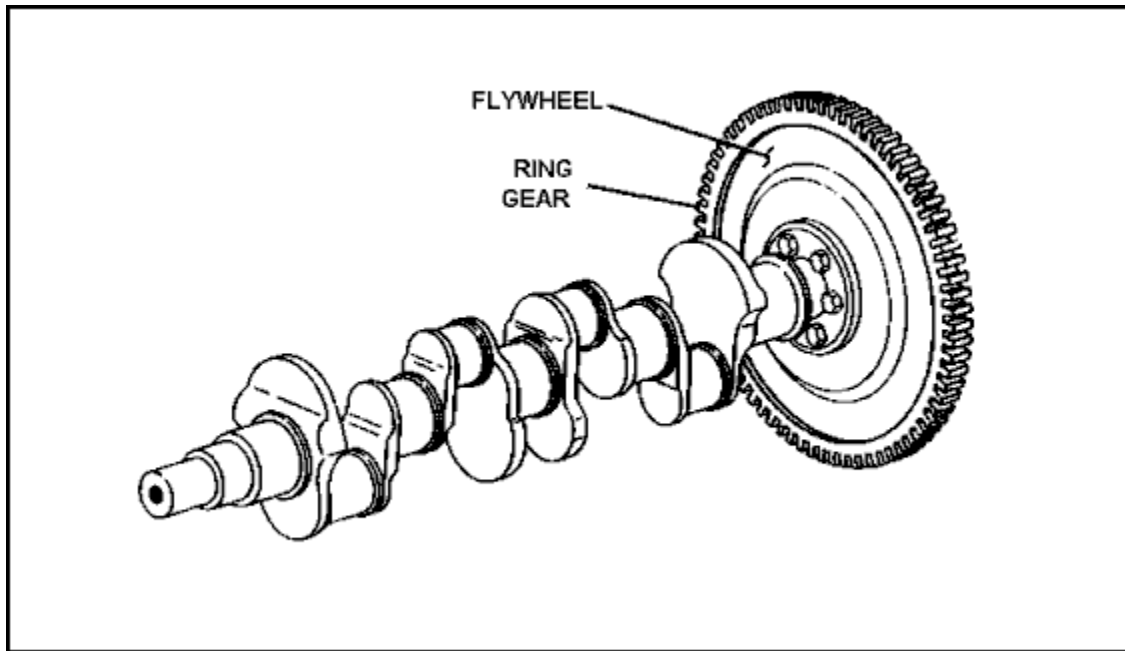


FIGURE 31. FLYWHEEL.

Flywheel

As more cylinders are added to an engine, the size and weight of the flywheel is reduced. This is because the power strokes are closer together and in some cases overlapping. Therefore, the weight of the flywheel is not needed as much to smooth out the crankshaft rotations.

However, the flywheels of engines serve other purposes in addition to causing the engine to run smoother. A ring gear is usually installed around its outer edge to mesh with a starter motor gear for cranking. The rear side of the flywheel is machined so the clutch or other parts may be fastened to it for driving the vehicle. A flywheel housing with a bottom cover or pan is bolted to the rear of the cylinder block to house the flywheel and the related drive parts.

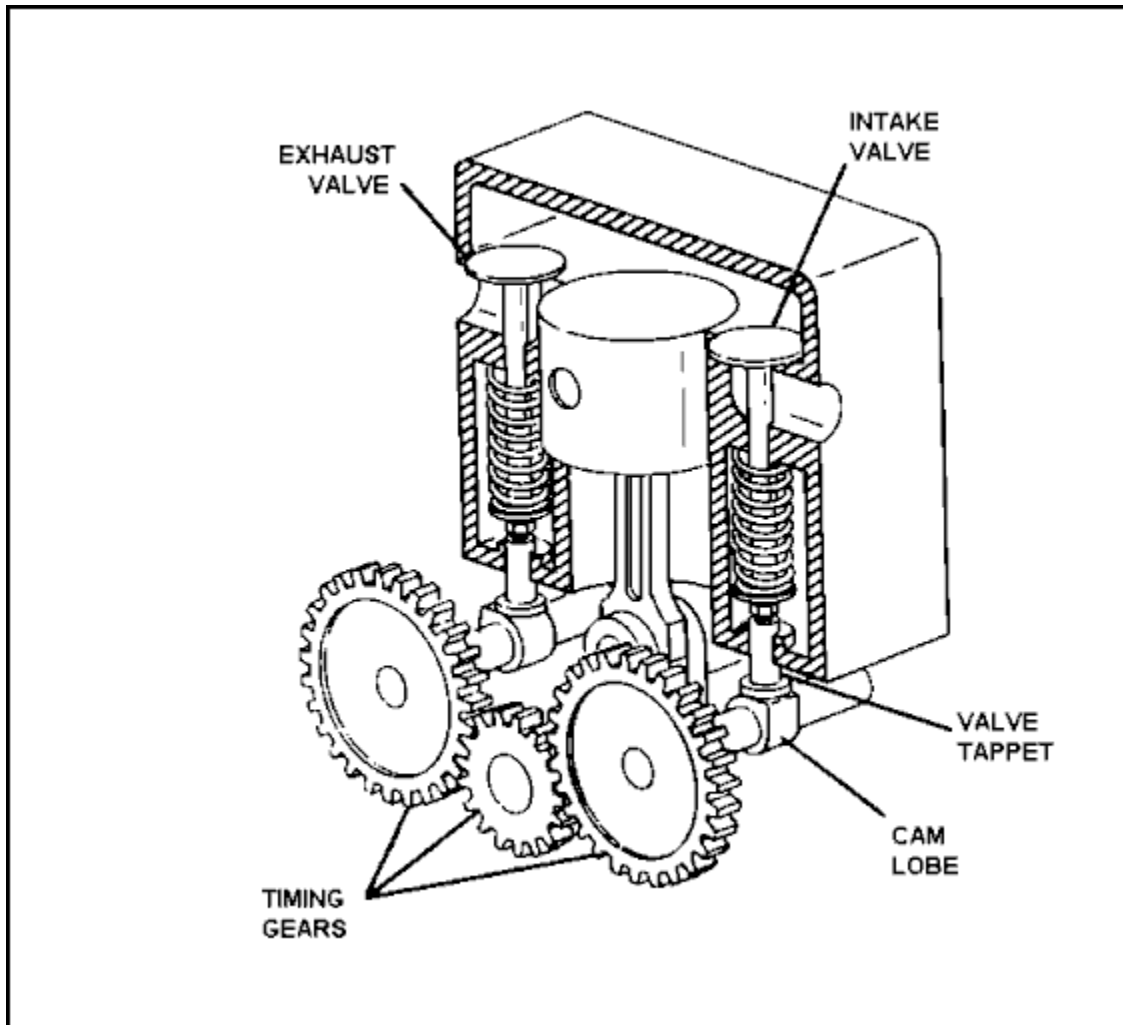


FIGURE 32. VALVES AND OPERATING MECHANISM.

Valves and Operating Mechanism

Every cylinder of a four-stroke-cycle engine has intake and exhaust valves. The intake ports from the intake valves are usually connected to one common pipe called a manifold. The manifold then leads to a mixing point that supplies the fuel-air mixture. Likewise, the ports leading away from the exhaust valves are connected to a common manifold for carrying exhaust gases away from the engine. V-type engines generally have two exhaust manifolds, one for each row of cylinders.

The camshaft extends the full length of the engine and has a cam for each valve, except in a few cases where one cam is used to operate more than one valve. The location of the camshaft, tappets, and other valve operating parts depends on the design of the engine they are used in.

In the in-line, L-head engine, the valve mechanism is located in the cylinder block. An adjusting screw is threaded into the top of the tappet to allow an adjustment of the operating clearance between the tappet and the valve stem. One or two covers with gaskets are bolted to the side of the cylinder block to cover the mechanism, protecting it from dirt and preventing oil leakage.

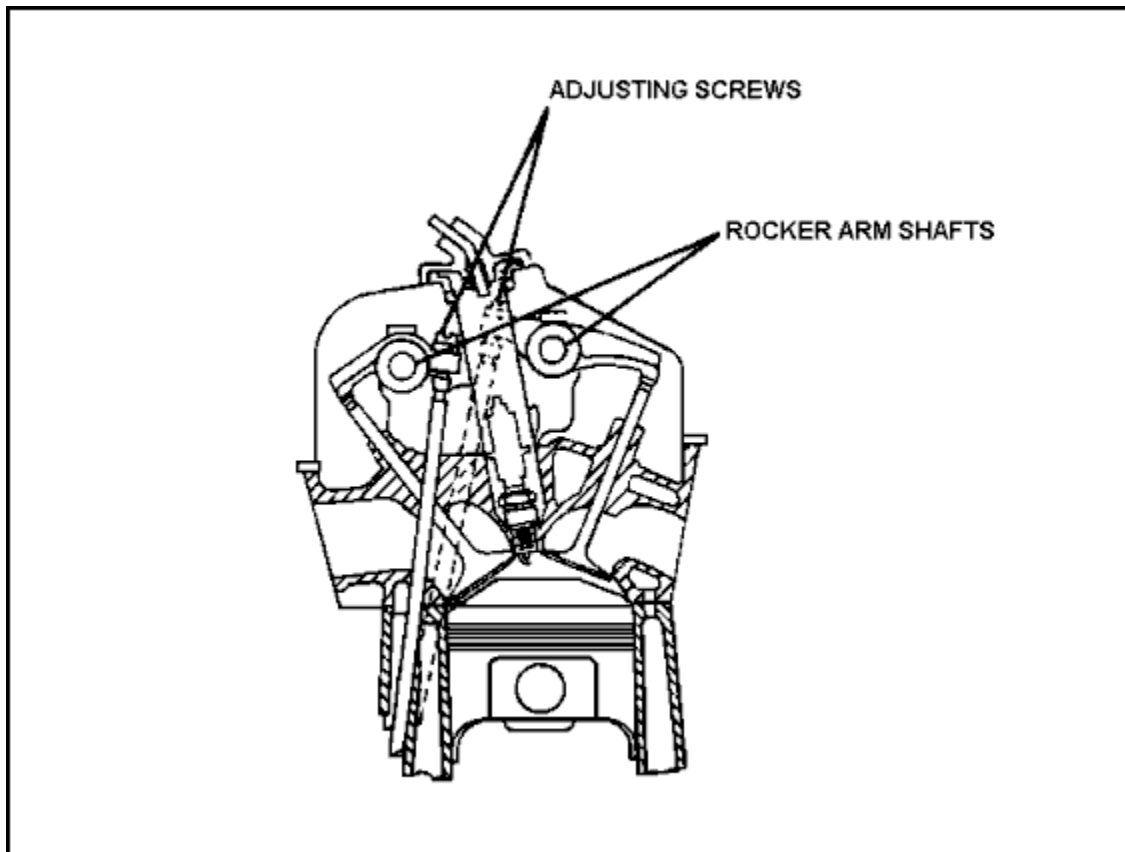


FIGURE 33. OVERHEAD VALVES.

The valves of the in-line, overhead valve (I-head) engine may be operated by either one of two different methods. In one method the camshaft and tappets are located in the cylinder block. Rocker arms that pivot on a shaft are located on the head. The valves are forced open when the rocker arms pivot. Tappet movements are transferred to the rocker arms through a pushrod

which rests on top of the tappet and extends up to one end of the rocker arm. Notice that in this system the valve clearance adjusting screw is located at the pushrod end of the rocker arm. A cover, bolted to the top of the cylinder head, covers the rocker arms.

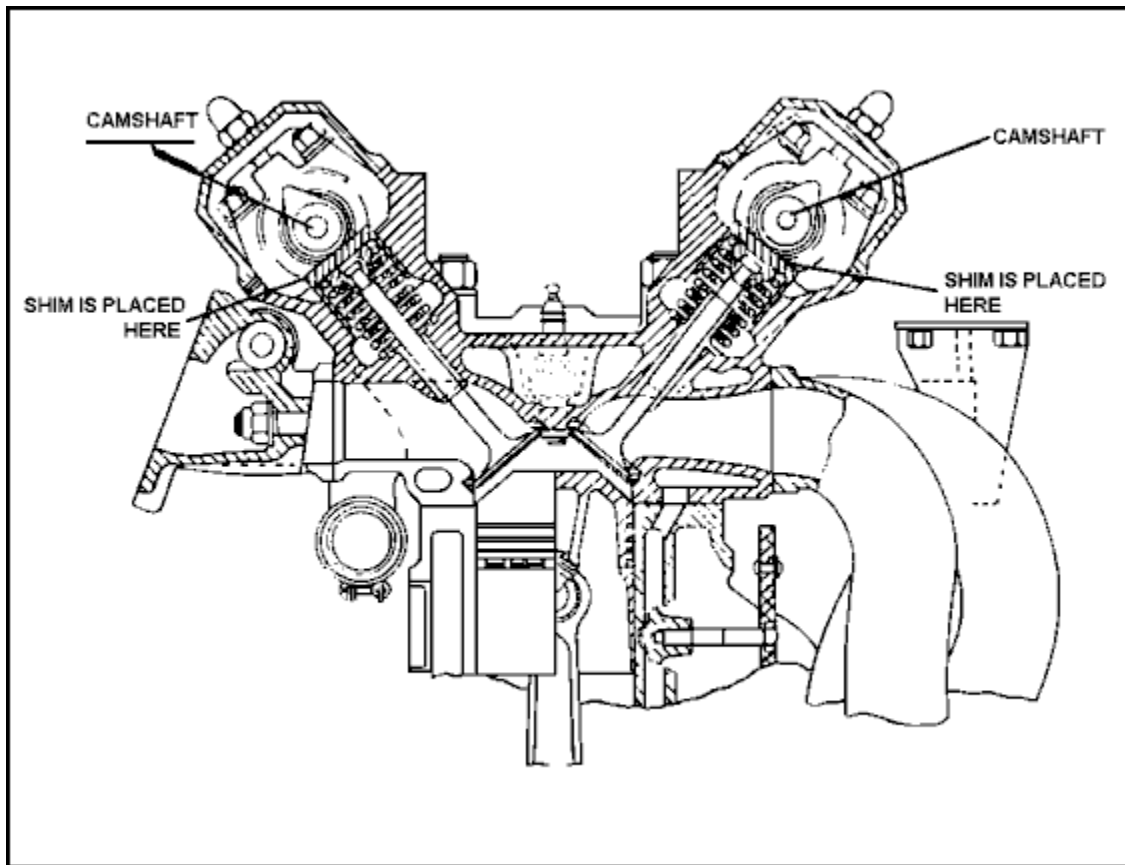


FIGURE 34. OVERHEAD CAM.

In the other method of operating the valves of the overhead valve engine, the camshaft is located on the cylinder head. This engine may be called an overhead cam engine. In technical manuals, it may even be shortened to read OHC engine. Rocker arms that pivot on studs are the only link between the valves and cams. Valve clearance is adjusted by inserting shims between the cam lobe and the lifter.

Lesson 1/Learning Event 1

The F-head engine has its camshaft in the cylinder block. For the valves located in the block, it uses a mechanism like the L-head engine. Rocker arms and pushrods are used on the valves in the head as with the overhead valve engine.

On V-type and horizontal-opposed engines, one camshaft is generally located in the center of the engine and operates the valves on both rows of cylinders. Of course, if the overhead cam method is used, a camshaft is needed on each row of cylinders.

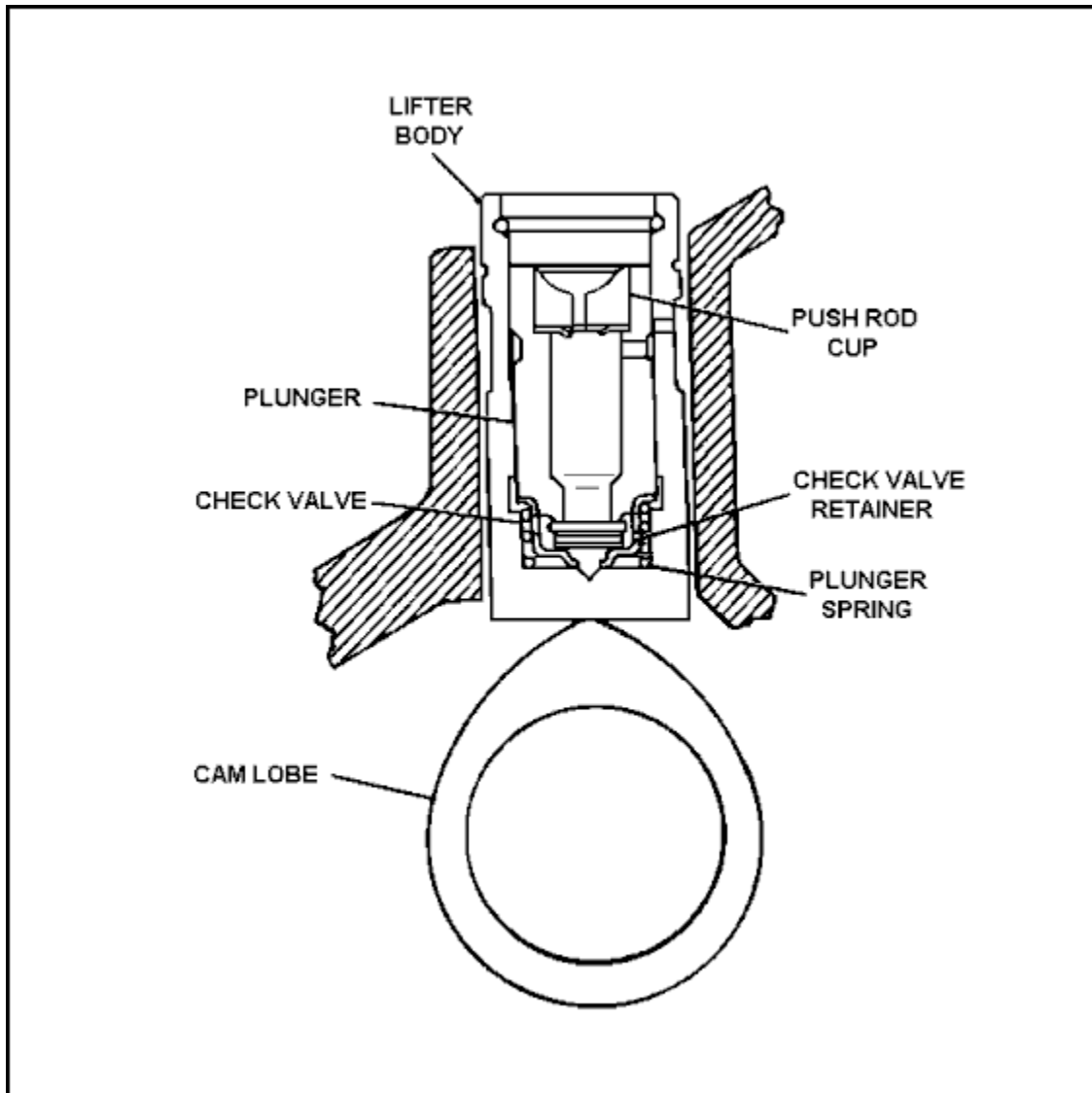


FIGURE 35. HYDRAULIC VALVE TAPPET.

Hydraulic valve tappets are used on many engines. These tappets make minor valve clearance adjustments automatically each time a valve closes. This way, all the tappet noise is stopped because the engine is operated without any valve stem to tappet clearance.

Basically, a hydraulic valve tappet is made up of a cylinder fitted with a plunger or piston and a ball-check valve. Oil under pressure is forced through the ball-check valve into the cylinder below the plunger when the tappet is on the base circle of the cam. This raises the plunger which, in effect, increases the tappet's length and removes all clearance in the valve linkage. When the lobe lifts the tappet, oil tries to flow out

of the chamber from under the plunger. This closes the ball check valve, and the trapped oil lifts the plunger opening the engine valve. When the lobe moves out from under the tappet, any slight loss of oil from under the plunger is replaced by oil pressure from the lubricating system.

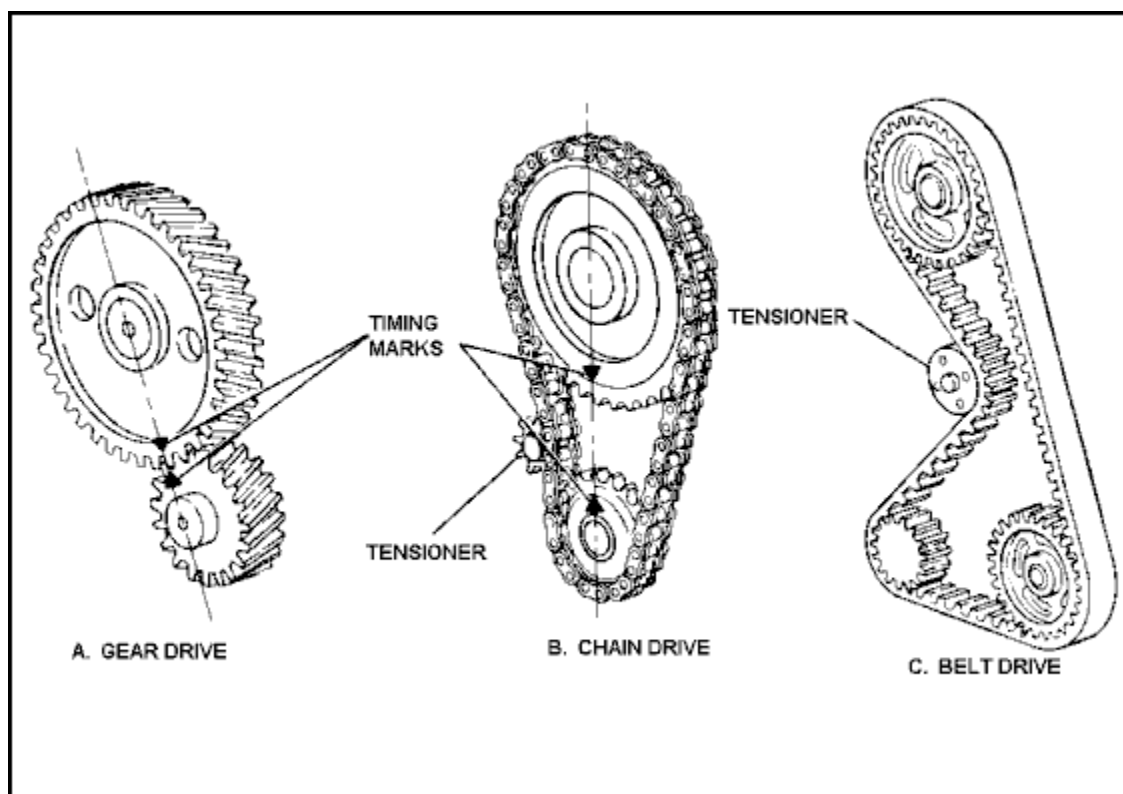


FIGURE 36. CAMSHAFT DRIVES.

There are two common methods of turning the camshafts of multi-cylinder engines in wheeled vehicles. One is with gears as you studied on the basic one-cylinder engine. In the other method, two sprockets and a timing chain or belt, something like a bicycle drive, are used. A timing chain or belt is most likely to be used when the crankshaft and camshaft are not very close together

PRACTICE EXERCISE

1. The upper part of the combustion chamber is formed by the
 - a. oil pan.
 - b. cylinder head.
 - c. piston head.
2. In a four-stroke-cycle engine, both valves are closed when the piston is on which stroke?
 - a. Intake
 - b. Compression
 - c. Exhaust
3. What directs the airflow around the cylinders of an air-cooled engine?
 - a. Fan
 - b. Fins
 - c. Baffles
4. The bottom ring on a piston is used to
 - a. remove lubricant from the cylinder wall.
 - b. prevent compression leakage.
 - c. deposit a thin film of oil between the piston and cylinder.
5. An OHC engine is an engine in which the
 - a. cylinders are horizontal-opposed.
 - b. valve mechanism includes pushrods.
 - c. camshaft is mounted on the cylinder head.

ANSWERS TO PRACTICE EXERCISE 1

1. b (page 29)
2. b (page 20)
3. c (page 3)
4. a (page 35)
5. c (page 47)

LESSON 2

FUNDAMENTALS OF COMPRESSION-IGNITION ENGINES

TASK

Describe the fundamentals of compression-ignition engines.

CONDITIONS

Given information about the construction and principles of operation of the two- and four-stroke-cycle compression-ignition engines and the different types of compression-ignition engines.

STANDARDS

Solve 70 percent of the multiple-choice test items covering fundamentals of compression-ignition engines.

REFERENCES

TM 9-8000

Learning Event 1:

DESCRIBE PRINCIPLES OF OPERATION AND CONSTRUCTION OF FOUR-STROKE-CYCLE ENGINES

The Army is presently using two types of straight diesel fuel engines. They are the two- and four-stroke-cycle diesel engines. These engines are of many different sizes and shapes. Some are in-line engines, like those found in the 2 1/2- and 5-ton vehicles, while others have V-type cylinder arrangements, like those found in the high mobility multipurpose wheeled vehicle (HMMWV) and the commercial utility cargo vehicle (CUCV). Common in-line types generally have four or six cylinders. The V-type usually have six or eight cylinders.

FOUR-STROKE-CYCLE OPERATION

The four-stroke-cycle diesel engine is constructed about the same as the four-stroke-cycle gasoline spark-ignited engine. The working parts of a diesel engine are made heavier than the gasoline spark-ignited engine. This is because the diesel engine has much higher cylinder pressures. Early diesel engines were made too heavy for use in trucks and buses. These heavy diesel engines ran at slow speeds and were used for locomotives, ships (marine), and power-generating stations.

As time progressed, new metals were developed that were stronger for their weight, and industry soon found it could build a lighter diesel engine. This lighter diesel engine could run at speeds high enough to work well in the automotive field.

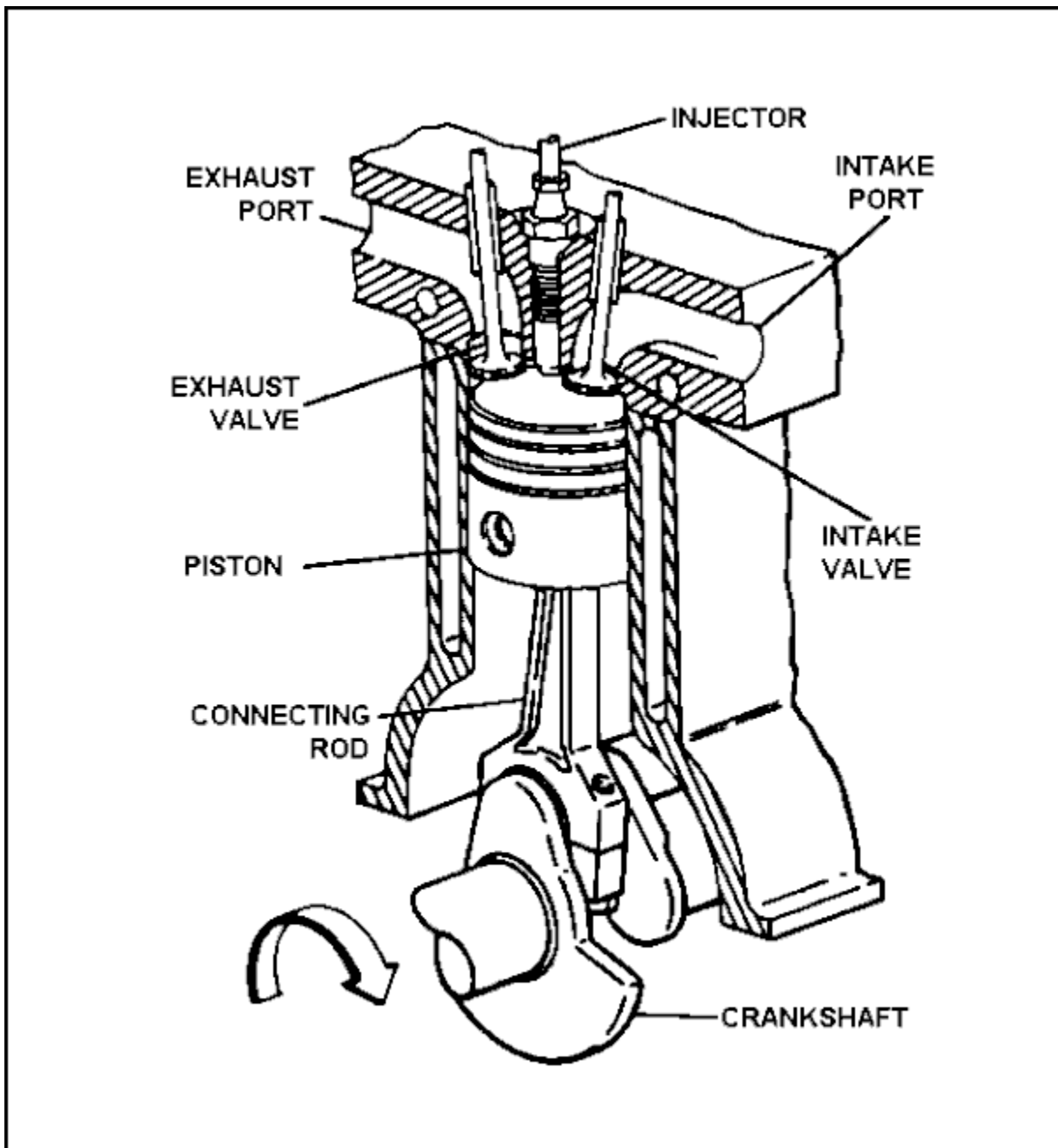


FIGURE 37. FOUR-STROKE-CYCLE DIESEL ENGINE.

The intake and exhaust systems of the four-stroke-cycle diesel engines are similar to those of gasoline engines. One big difference is that diesel engines do not have carburetors which are found in the intake system of gasoline engines. All present four-stroke-cycle diesel engines have at least one intake and one exhaust valve per cylinder, but some may have two exhaust valves and two intake valves. Most diesel engines have intake and exhaust manifolds with one inlet or outlet port per cylinder. Many compression-ignition engines use a supercharger, which is an air blower located in the intake system. It increases the horsepower output of the engine.

Many four-stroke-cycle diesel engines use the turbosupercharger. The turbosupercharger is driven by exhaust gases, thereby using some of the energy that is normally wasted. An example would be the M915-series vehicles.

A turbosupercharger consists of two impellers mounted on the same shaft. The compressor impeller is on one end of the shaft and the turbine impeller on the other. Each impeller works or spins in separate sections of the housing, with seals between to prevent leakage from one housing to the other. The impellers have a series of straight or curved vanes that act much like a fan. The turbine impeller and housing is mounted in the engine exhaust system and is driven by the pressure from the escaping exhaust gases. The compressor impeller is mounted in the air intake system and turns with the turbine, forcing air into the cylinders.

The blower increases normal air pressure and aids in forcing air into the cylinder and the burned gases from the cylinder. It is lubricated by the engine lubrication system.

Most high-speed diesel engines use the full-force oil feed system. An oil pump mounted in the crankcase is driven by gears and shafts. The pump picks up oil from the sump (oil pan) and forces it under pressure through drilled passages to all the working parts of the engine.

Most compression-ignition engines use an oil cooler. The oil cooler is a series of tubes mounted in a water passage of the engine cooling system. As the hot lubricating oil passes through these tubes, the heat is transferred into the cooling water.

Compression-ignition engines have fuel injection systems. Although many types of fuel injection systems are used, they must all perform the same functions. These functions are first, to put the fuel under very high pressure (or to pressurize); second, meter or measure an exact amount of fuel for delivery; and third, to inject this fuel into the combustion chamber at the proper time.

Most compression-ignition engines use a governor with the fuel injection pump. The governor controls the maximum (top) engine speed and aids in maintaining a constant operating speed. The operating speeds and power output of the engine are controlled by changing the amount of fuel that is injected into the combustion chamber.

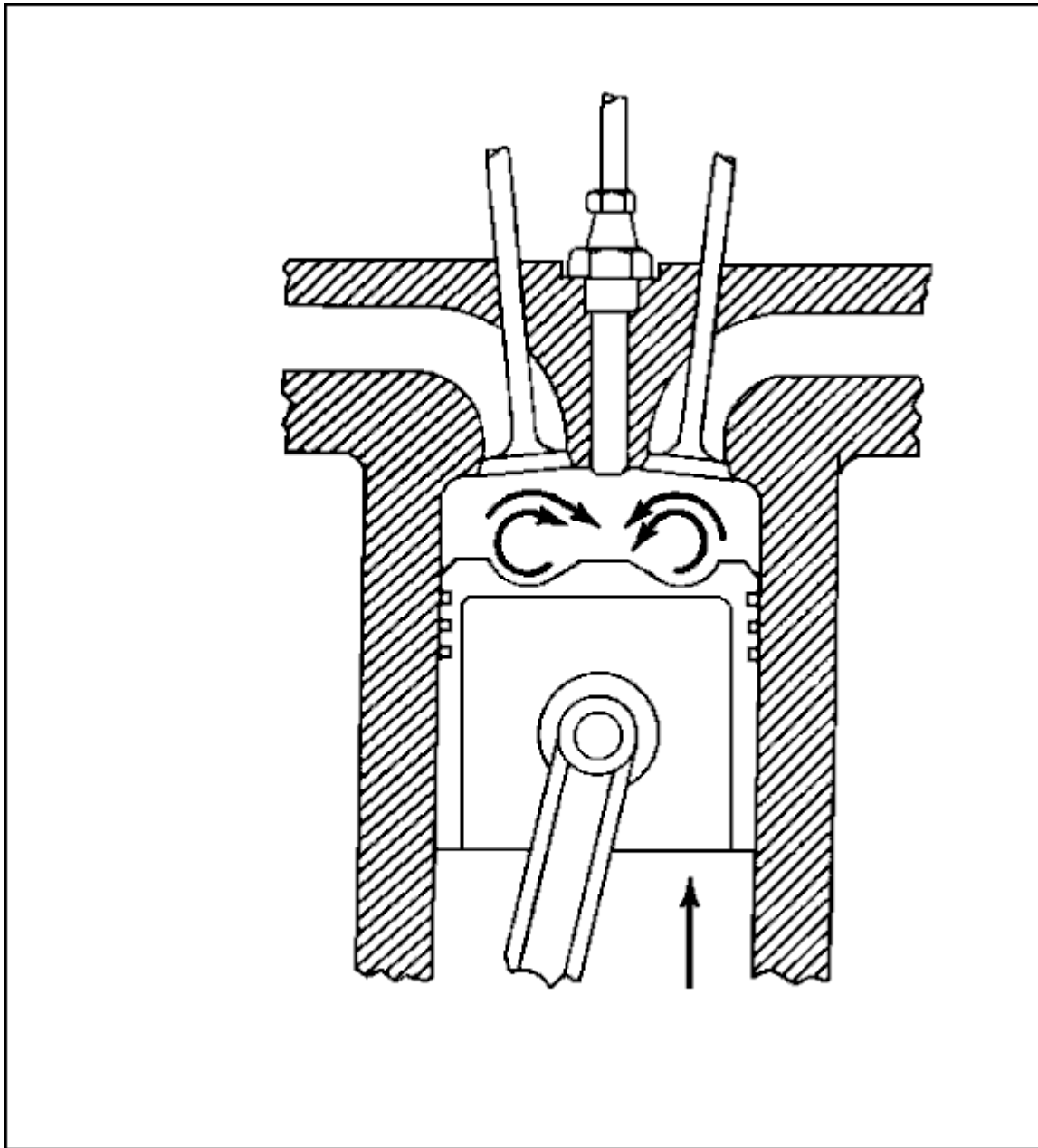


FIGURE 38. OPEN-TYPE COMBUSTION CHAMBER.

The shapes of the combustion chambers in compression-ignition engines have changed as time has passed. At first, it was thought the open-type chamber could only be used in the large, slow-speed engines. In the open-type chamber, fuel is injected directly into the cylinder itself.

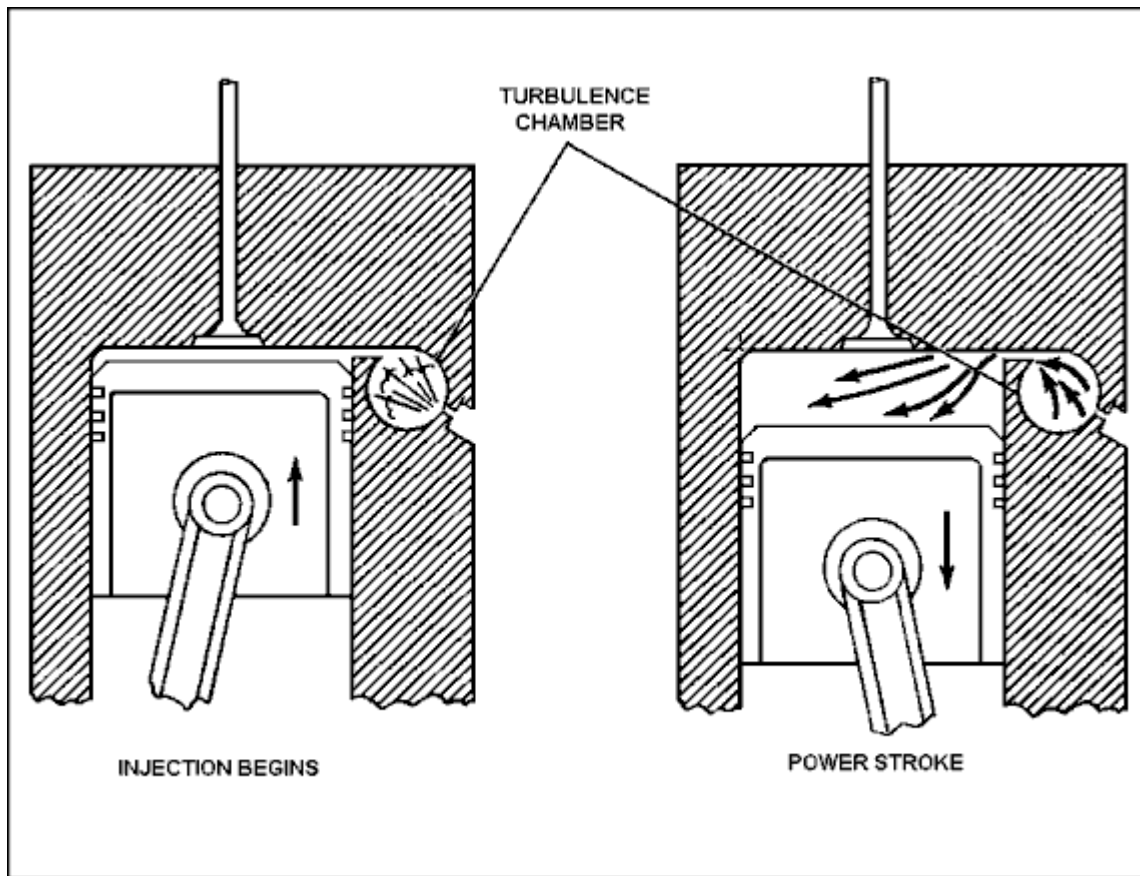


FIGURE 39. TURBULENCE CHAMBER.

The turbulence chamber (Lanova-divided type) is used in smaller, high-speed engines.

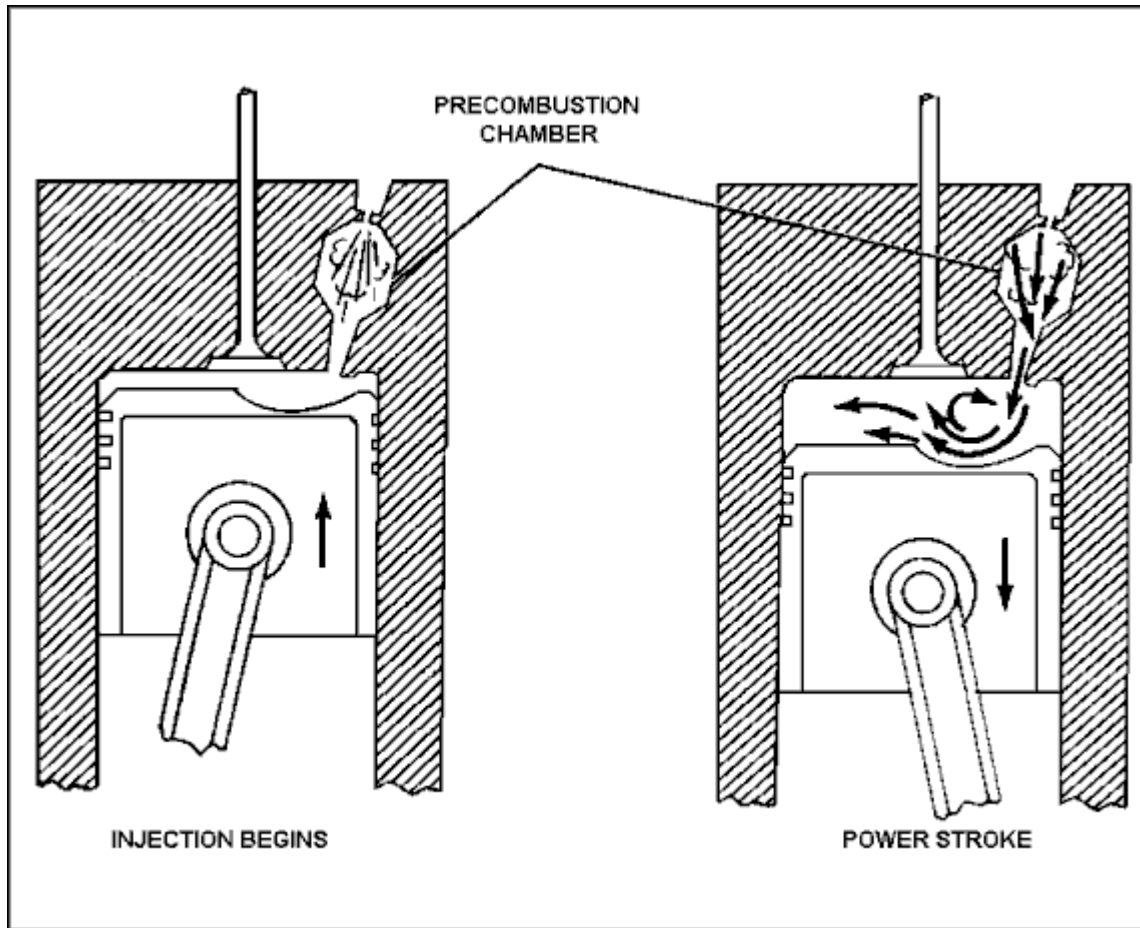


FIGURE 40. PRECOMBUSTION CHAMBER.

The precombustion type of chamber is also used in the smaller, high-speed engines.

These chambers are thought to have features that improved the burning of fuel at high engine speeds. Fuel is injected into a smaller ignition chamber to improve burning of fuel. Later, it was learned that as the fuel injectors were improved and engines were built with higher compressions, the open-type combustion chamber worked well at all engine speeds. The open chamber is now used in many military high-speed diesels. A few high-speed diesels, such as the HMMWV and the CUCV, still use other types of chambers.

Most of the present high-speed compression-ignition engines use a cold-weather starting aid. This may be a heating element located in the combustion chamber or in the intake manifold. The starting aid located in the intake manifold preheats the air before it enters the engine cylinder. The combustion chamber heating element directly aids in igniting the fuel-air mixture.

Let's go through the operations of a four-stroke cycle of a diesel compression-ignition engine. By comparing the diesel cycle with the gasoline cycle you will learn just how the four-stroke-cycle (diesel) works.

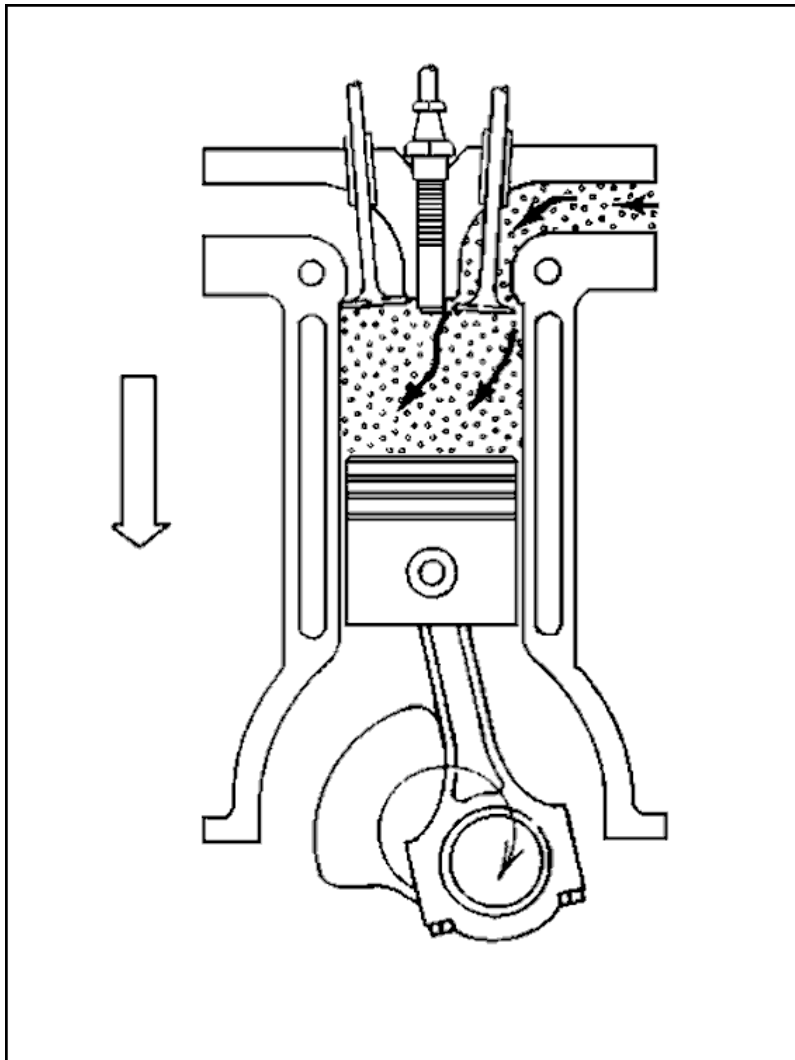


IMAGE: FIGURE 41. INTAKE STROKE.

During the intake stroke (downward movement of the piston), the intake valve is open and air enters the cylinder around the intake valve. With no carburetor and throttle valve, the cylinder fills with air whether the engine is idling or running wide open.

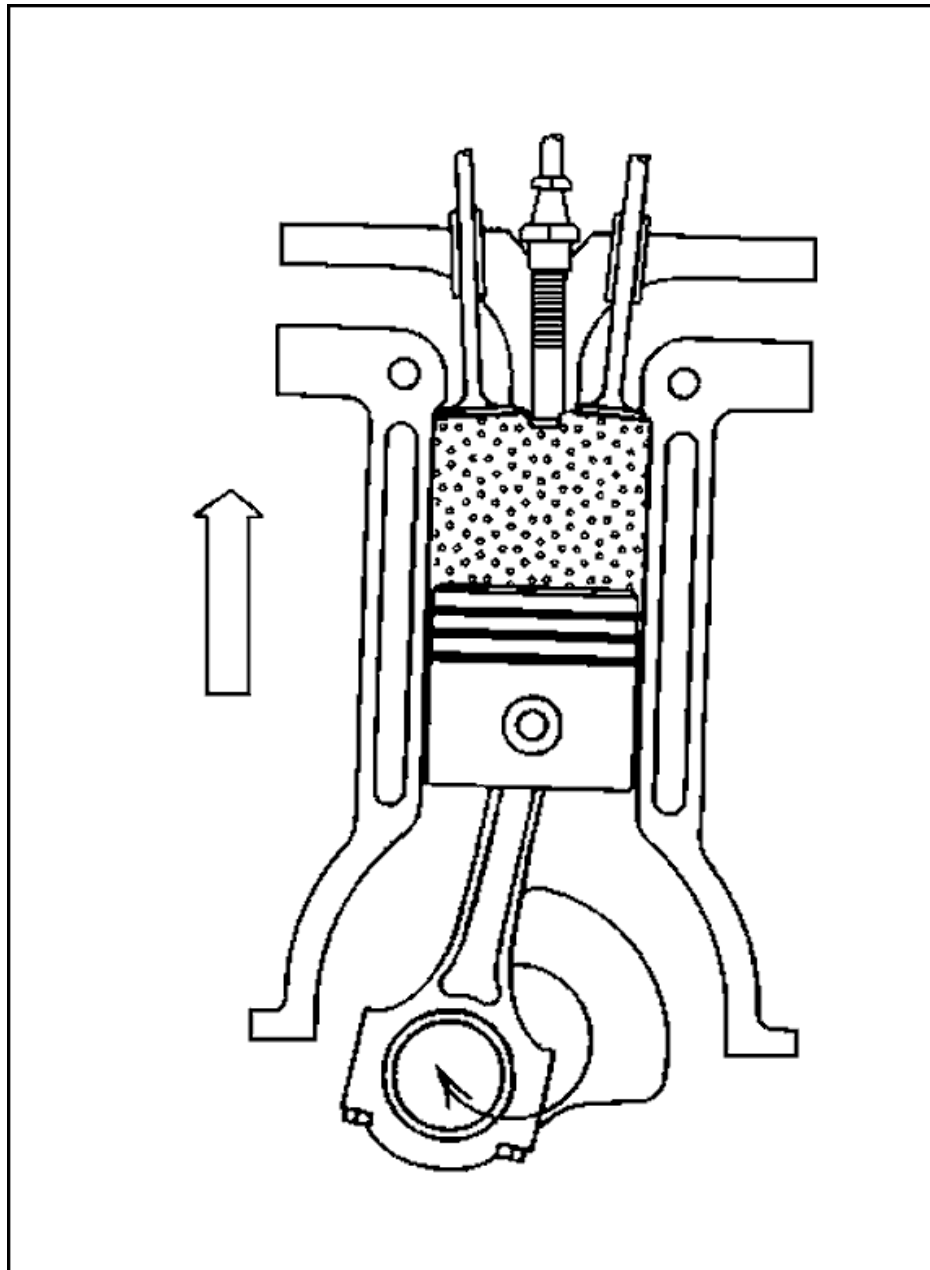


FIGURE 42. COMPRESSION STROKE.

During the compression stroke, the piston moves up with both valves closed. This upward movement squeezes the air into a very small area. This is a much smaller area than is used in the same size gasoline spark-ignited engine. Squeezing the air causes it to get hot, reaching a temperature of 800°F to 1,000° at about 500 PSI. Just before the piston reaches the end, or top, of the compression stroke, fuel is injected into the hot air in the combustion chamber by the injector nozzle. The fuel is ignited by the hot air and then burns.

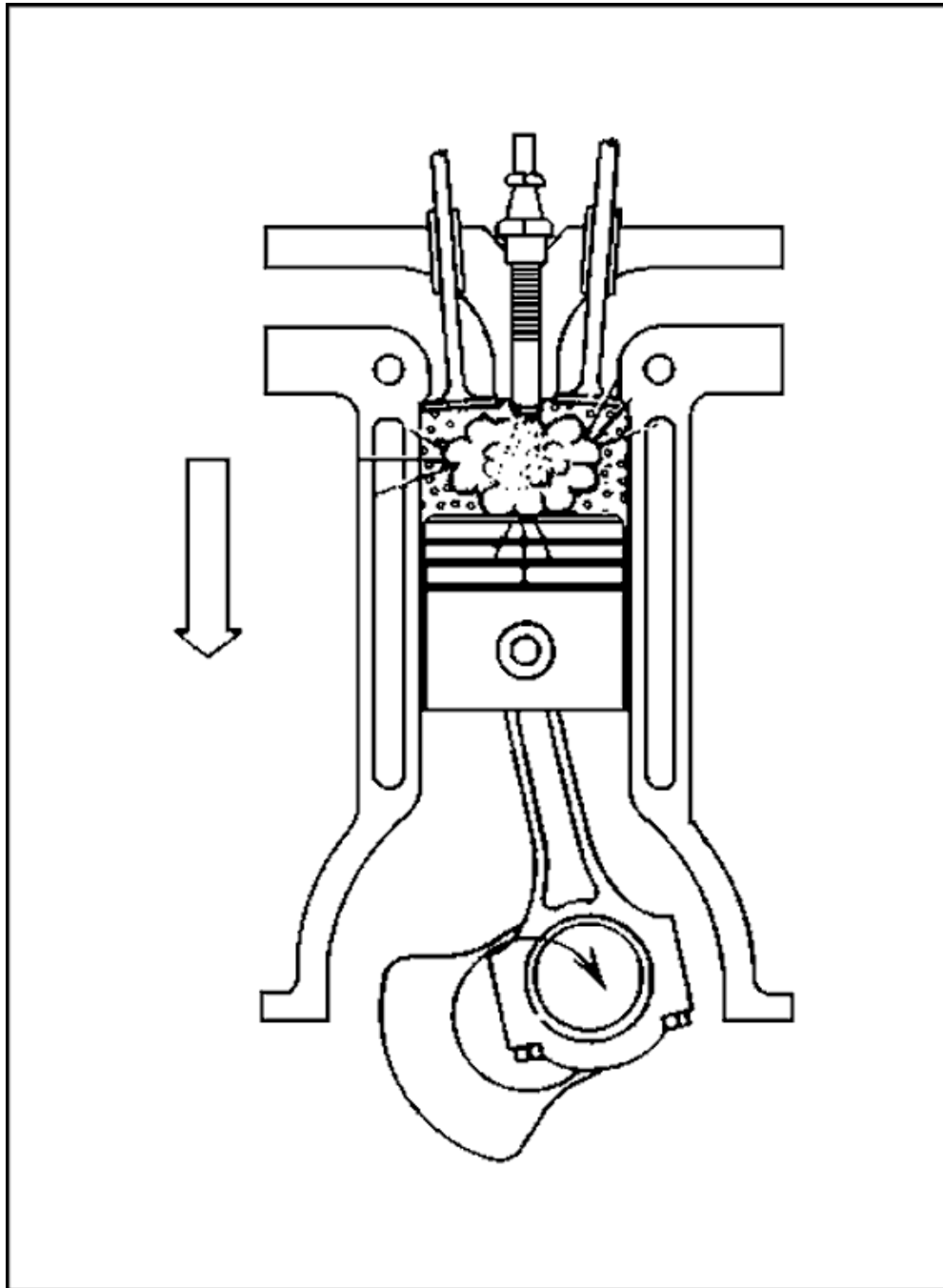


IMAGE: FIGURE 43. POWER STROKE.

As the piston starts down on the power stroke, the burning fuel is now producing extreme heat. The heat expands the gases in the cylinder which pushes down on the piston with great force. Just before the piston reaches the bottom of the power stroke, the exhaust valve opens. The burned gases in the cylinder, still under some pressure, start to rush out by the open exhaust valve.

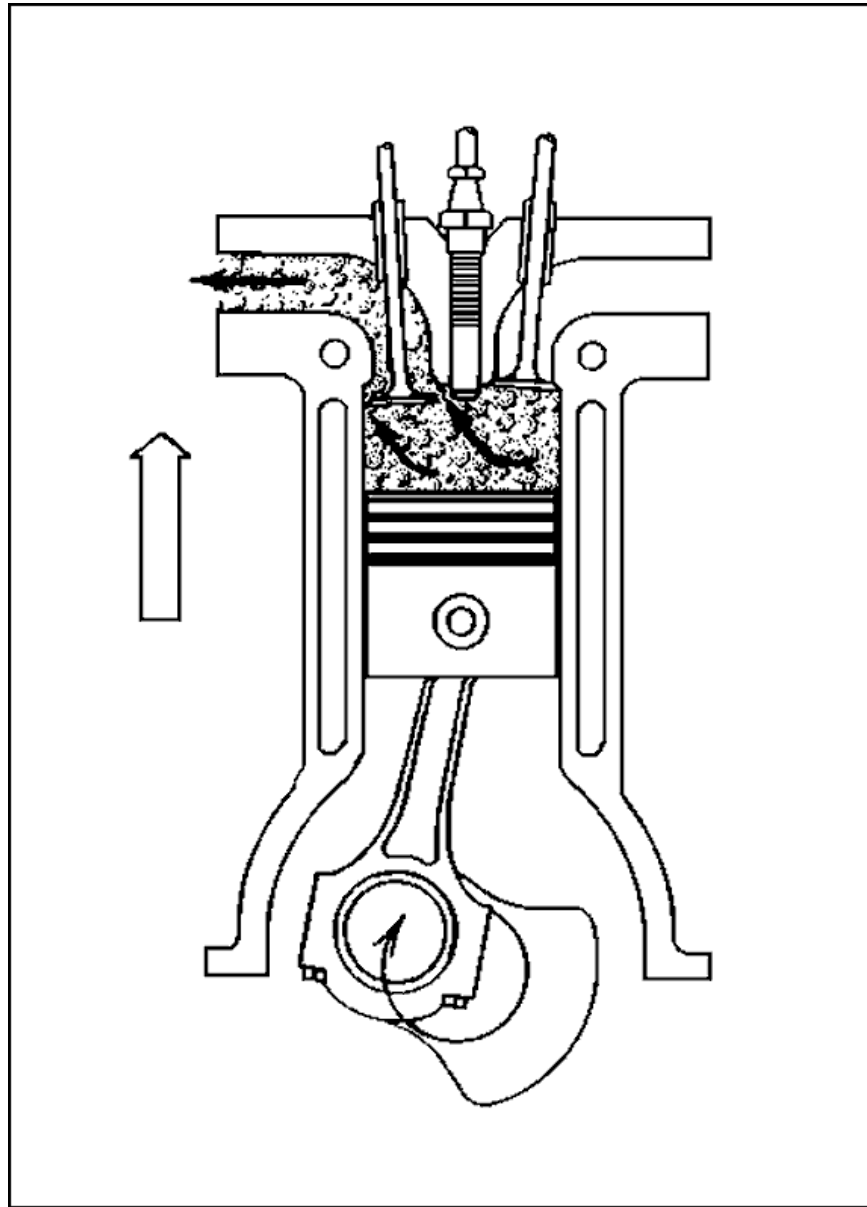


IMAGE: FIGURE 44. EXHAUST STROKE.

Thanks to the flywheel, the crankshaft starts the piston moving up on the exhaust stroke. The upward movement of the piston pushes the burned gases out through the open exhaust valve. Just before the piston reaches the top of the stroke, the intake valve opens and clean air rushes in. This forces any burned gases left out through the exhaust valve. This is called scavenging the cylinder. The exhaust valve closes and the piston is then pulled back down by the crankshaft and flywheel, and the intake stroke starts the cycle once again.

MULTIFUEL ENGINE

Today's mechanized field army requires many vehicles to move its personnel and equipment. Most of these vehicles operate on either gasoline or diesel fuel.

In the early 1960s, an engine was introduced that would run on various available fuels with no adjustments needed. These fuels included regular gasoline, aviation kerosene, compression-ignition fuel (CITE), and diesel fuels.

This engine is used in some of the Army's wheeled vehicles. It is called the multifuel engine. This engine has proven to be very valuable to military operations due to the many fuels the engine will operate on. About 71 percent of a barrel of crude oil can be used in the multifuel engine, but only 54 percent of the same barrel of crude oil could be used in both the gasoline and diesel engines combined.

The present multifuel engine used in wheeled vehicles is a six-cylinder, in-line, valve-in-head engine. It is also a liquid-cooled, compression-ignited type of engine. It operates on the four-stroke-cycle principle.

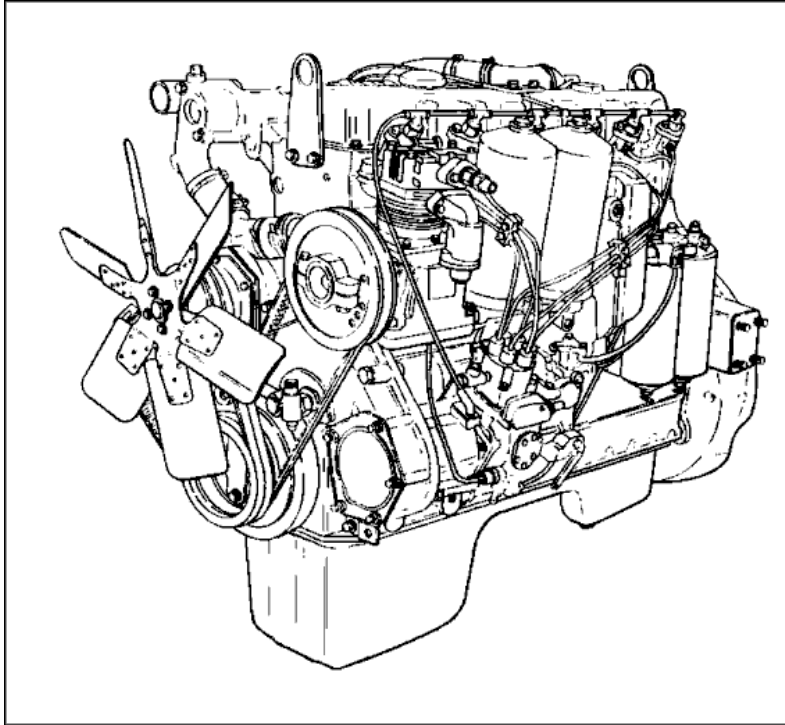


IMAGE: FIGURE 45. MULTIFUEL ENGINE.

The engine uses a multifuel combustion system. The term "multifuel" means many fuels, and combustion means burning. Together the words "multifuel combustion system" would then mean a system that burns many fuels. Combustion, in the automotive engine field, means controlled burning.

The multifuel engine is presently used in 2 1/2-ton and some 5-ton wheeled vehicles. These wheeled vehicles use a turbocharged (forced air intake) engine. Both engines are the same size, but the turbocharged engine produces more power. With the exception of the air intake systems, both engines operate on the same principles.

Basically, the multifuel engine is made the same as most four-stroke-cycle diesel engines. The major difference is the design of the air intake and combustion chamber. A ball-shaped combustion chamber pocket is located in the top of the piston to permit burning of various fuels.

Let's take a closer look at a typical multifuel engine. Each letter and number contained in the identification number of the engine has a specific meaning. For example, for the LDS 465-1A engine used in the 5-ton truck, "L" means liquid-cooled, "D" means diesel, and "S" means supercharged. The 465 is the model number of the engine, and the 1A means a change has been made in the basic engine model.

Now let's take a look at the operating principles. First, on the intake stroke, air is drawn through the open intake valve. The intake passages in the intake manifold and valve port openings are made so they cause the air to swirl or spin around in the cylinder as it enters. The air swirls with such force that it will continue to do so for sometime.

On the compression stroke the piston moves up, and both valves are closed, as in other engines. The air swirl continues throughout this stroke and also throughout the next.

As the piston nears the top of the intake stroke, fuel is injected by the fuel injector nozzle. It is injected onto the walls of the combustion chamber pocket in the piston head. A small amount of this injected fuel turns to vapor and starts to burn due to the extreme heat of compressed air. About 95 percent of the fuel settles in the lower part of the combustion chamber pocket. Oil spraying on the bottom of the piston head cools the combustion chamber pocket walls so all the fuel will not burn immediately

After the first amount of fuel is ignited, the piston is being forced down on the power stroke. The sweeping action of the swirling air keeps lifting some of the fuel up out of the combustion chamber pocket. As the fuel is lifted up into the burning fuel in the center of the combustion chamber, it also starts to burn. The pressure from the burning expanding gases pushes down on the piston. The original 5 percent of fuel that was first ignited is now acting as a spark plug igniting the remainder of the fuel charge. The slow, steady sweeping of fuel from the pocket in the piston head during the power stroke produces a long, effective power stroke. This steady burning of fuel, especially when using gasoline, eliminates a detonation knock.

Just before the bottom of the power stroke the exhaust valve opens. The piston then passes BDC and starts up on the exhaust stroke, pushing the exhaust gases out the open exhaust valve. Just before the piston reaches TDC on the exhaust stroke, the intake valve opens and both valves are open. If the engine uses a turbosupercharger, the turbosupercharger forces clean fresh air past the intake valve into the cylinder. The clean air clears the cylinder of any remaining exhaust gases by pushing it out the open exhaust valve. This is called scavenging the cylinder.

When the piston passes TDC and starts down on the intake stroke, the exhaust valve closes. This starts the four-stroke-cycle over again. You can now see that the difference between the multifuel engine and most straight diesel engines is the combustion process of controlled slow burning of the fuel. This allows the engine to operate on many fuels with no adjustment needed.

Learning Event 2:

DESCRIBE PRINCIPLES OF OPERATION AND CONSTRUCTION OF TWOSTROKE-CYCLE ENGINES

TWO-STROKE-CYCLE OPERATION

The same basic rules hold true for the two-stroke-cycle engine, whether it is a compression-ignition or a spark-ignition type of engine. Because two-stroke-cycle compression-ignition engines have ONE power stroke for each turn, they produce twice as many power strokes as the four-stroke-cycle engine, and the flywheel can still be lighter. Let's find out how the two-stroke-cycle diesel engine is different from the four-stroke-cycle diesel engine that was just discussed.

The same events of intake, compression, power, and exhaust take place in all compression-ignition engines. On the four-stroke-cycle engine, all four events occur during four strokes of a piston and two turns of the crankshaft. In the two-stroke-cycle engine, all four events occur during two strokes of a piston and in one turn of the crankshaft. To make this possible, the engine must be built a little different from the four-stroke-cycle type of engine.

The present military two-stroke-cycle diesel engine, such as that used in the M911 tractor truck, does not have any intake valves. Instead, it has inlet ports about halfway down the cylinder sleeve. There is no intake stroke in the two-stroke-cycle diesel engine to draw air into the cylinder. A Roots-type air blower is used to pump air into the cylinder. The up and down movement of the piston opens and closes the inlet ports causing them to function as inlet valves. The engine has exhaust valves located in the cylinder head. The exhaust valves are operated by a camshaft, tappets, pushrods, and rocker arms like most other engines. But, the operating principles of this engine are different from most other engines. Let's find out how it operates.

The Roots-type blower is made with two rotors with lobes that mesh and work together as a pump to pack air into the engine.

The blower housing mounts the two rotors and driving gears. Air is drawn in through openings on one side of the housing and is exhausted through holes on the opposite side. The blower is driven from the engine crankshaft by gears and shafts. On in-line engines, the blower is bolted to the side of the cylinder block. It is mounted on the top between the cylinder banks of the V-type engine.

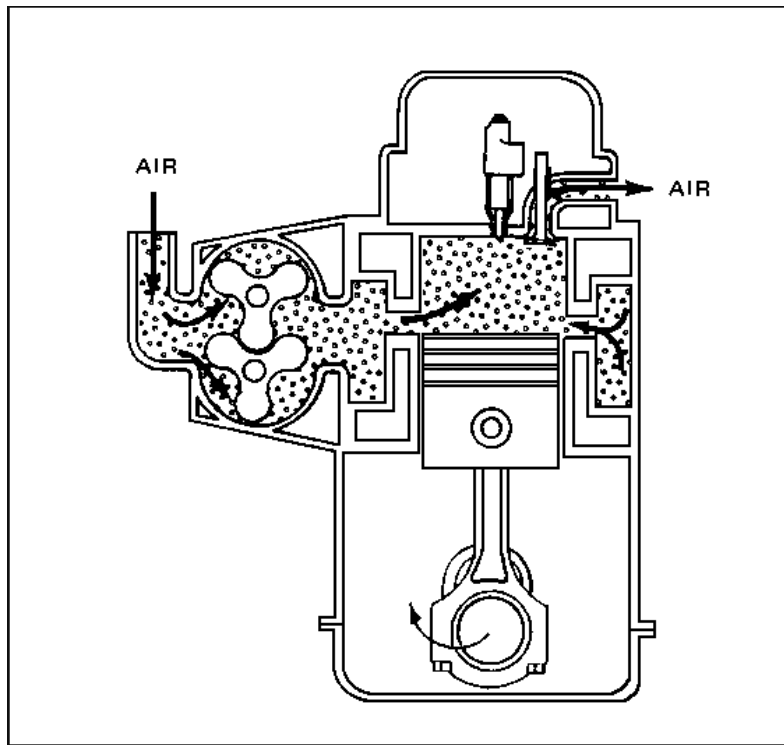


FIGURE 46. SCAVENGING (INTAKE) STROKE.

When the crankshaft moves the piston all the way down, it uncovers the inlet ports. The Roots-type blower forces fresh clean air through the ports and into the cylinder. At this time the exhaust valves are open and part of the clean air passes through the exhaust valves, clearing any exhaust gases that may be left in the cylinder from the last cycle of operation. This is called scavenging the cylinder, just like the four-stroke-cycle diesel engine. But it is different in that the intake phase of the two-stroke-cycle diesel takes place during the scavenging of the cylinder.

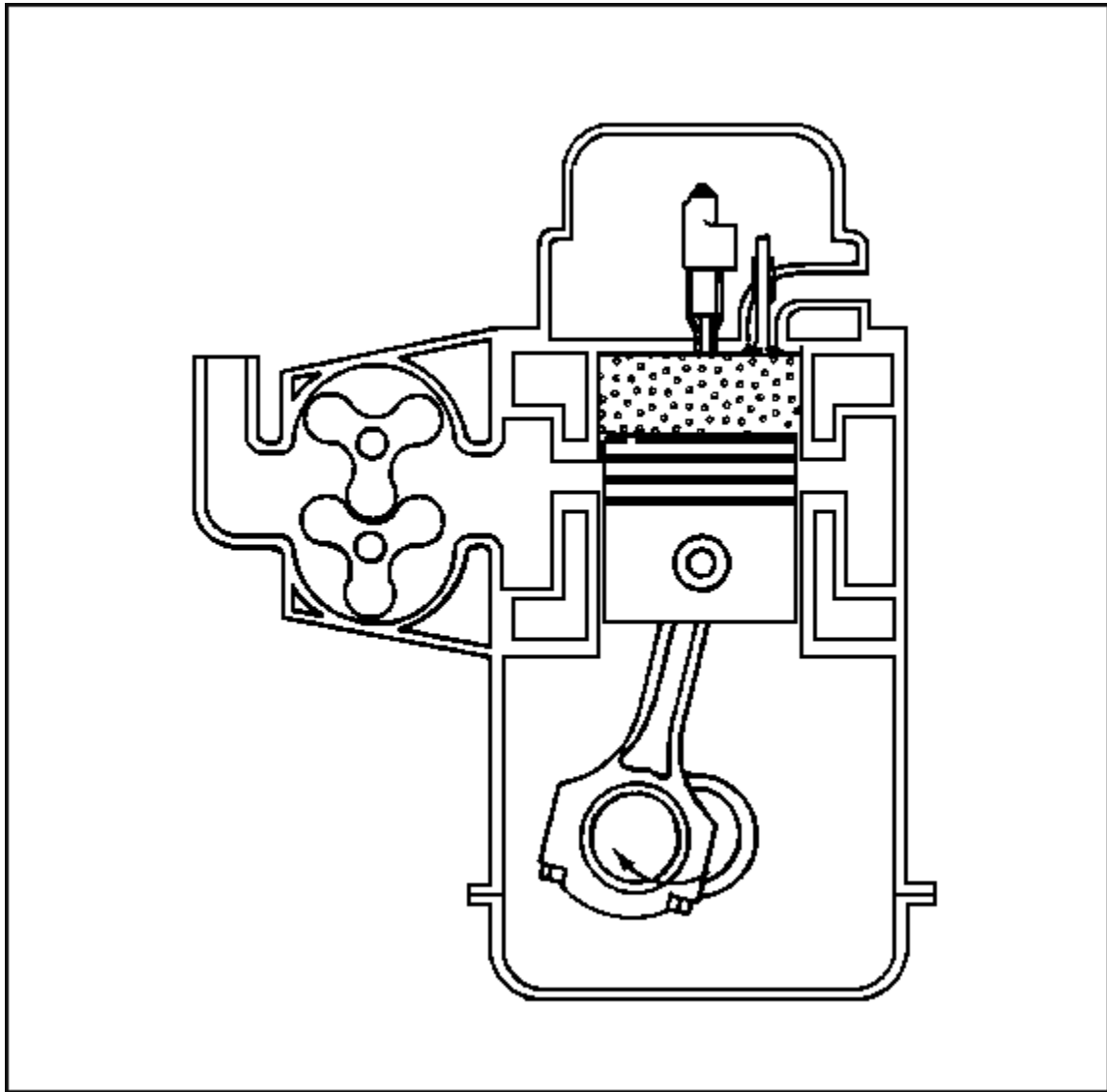


FIGURE 47. COMPRESSION STROKE.

The crankshaft next starts the piston up on the compression stroke. The two-stroke-cycle diesel engine compresses or squeezes the air, just as the four-stroke-cycle diesel engine does, to very high pressure. To compress the air to very high pressure, the engine must have a high compression ratio. Compression ratio means how much LESS space there is above the piston when it is all the way up than when it is all the way down. If there is eight times more space above the piston when it is all the way down, then the compression ratio is eight to one or 8:1. This means that when the piston moves all the way up, it will have squeezed the air into a space that is eight times smaller. Many gasoline engines use the 8:1 compression ratio. Most compression-ignition engines have from 15 to 22:1 compression ratios. The more air is compressed, the hotter it gets.

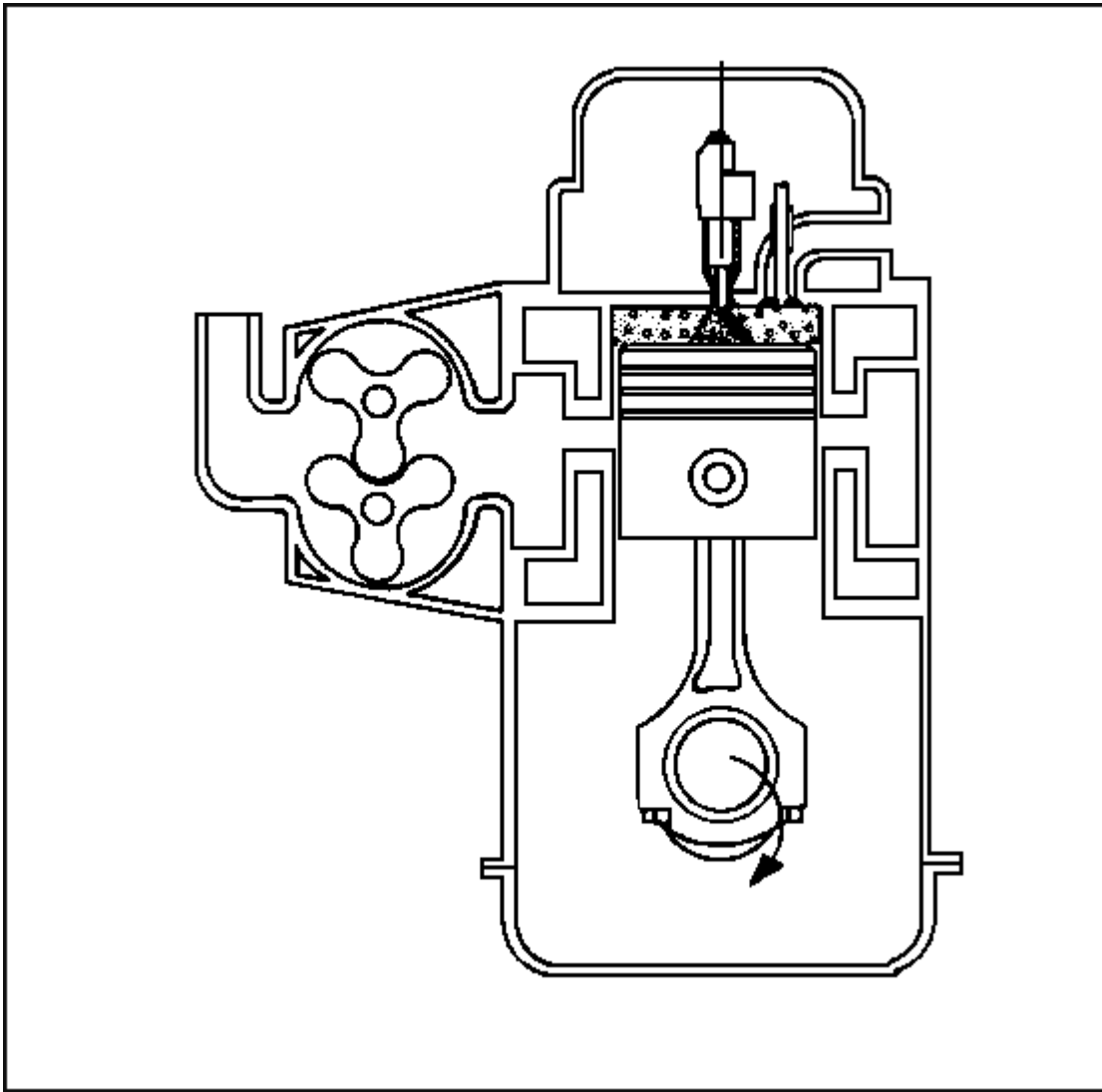


FIGURE 48. POWER STROKE.

Just before the piston reaches the end of its compression stroke, fuel is injected into the compressed hot air. This fuel ignites, and the piston starts down on its second stroke, the power stroke. Just as in the four-stroke-cycle diesel, the expanding gases push down on the piston with great force. All compression-ignition engines have long power strokes due to the slow and steady burning of diesel fuel.

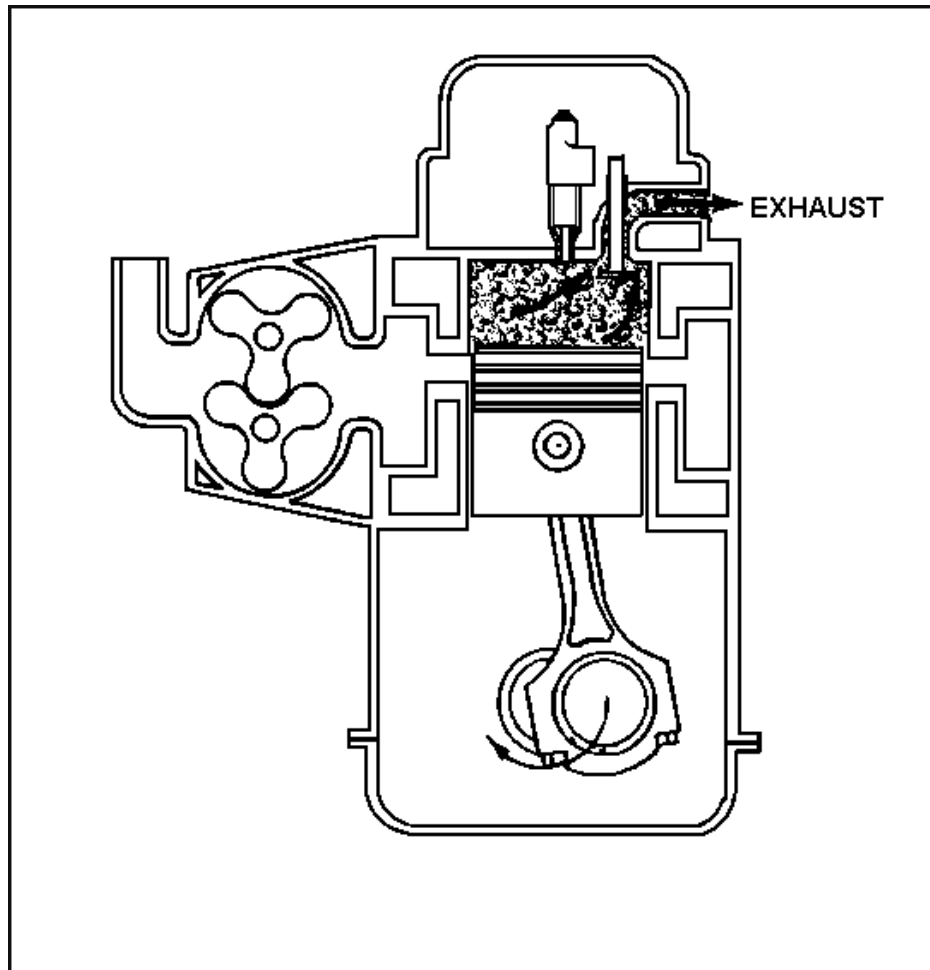


FIGURE 49. EXHAUST STROKE.

About halfway down on the power stroke, the exhaust valves open and some of the gases rush out through the open valves. The piston continues down until the inlet ports are uncovered. The air blower then forces clean air in, clearing the rest of the exhaust gases from the cylinder. The piston then starts back up first covering the intake ports and, then, as the exhaust valves close, starts the compression once again. As you can see, all four events--intake, compression, power, and exhaust--take place during two strokes of the piston and one turn of the crankshaft in this engine.

In this lesson, you learned there are two types of compression-ignition engines. They are the straight diesel and the multifuel types. You were also instructed on their operation and basic parts.

Now review the lesson once more; then take the practice exercise and grade yourself. If you have any problem on the exercise, reread the lesson.

PRACTICE EXERCISE

1. What are the two types of straight diesel engines presently used by the Army?
 - a. Two- and four-stroke cycle
 - b. Compression-ignition and spark-ignition
 - c. Multifuel and compression-ignition

2. Which cylinder arrangement is used in the present military four-stroke-cycle diesel engines?
 - a In-line and V-type
 - b In-line only
 - c V-type only

3. Superchargers are used on compression-ignition engines to
 - a. decrease the combustion chamber temperature.
 - b. decrease detonation knock.
 - c. increase the engine horsepower.

4. What percentage of a barrel of crude oil can be used in the multifuel engine?
 - a. 100
 - b. 71
 - c. 54

5. The combustion chambers of the multifuel engine are designed to stop detonation knock by
 - a. scavenging the cylinders.
 - b. steady burning of the fuel.
 - c. supercharging the air intake.

ANSWERS TO PRACTICE EXERCISE 2

1. a. (page 53)
2. a. (page 53)
3. c. (page 55)
4. b. (page 64)
5. b. (page 67)

LESSON 3 ENGINE INSPECTION

TASK

Describe the inspecting, testing, and troubleshooting procedures for engines.

CONDITIONS

Given information about procedures for inspection of the engine and use of test equipment.

STANDARDS

Solve 70 percent of the multiple-choice test items covering engine inspection and testing.

REFERENCES

TM 9-8000

Learning Event 1:

DESCRIBE VISUAL AND OPERATIONAL INSPECTION TECHNIQUES

When you need to repair your automobile, lawnmower, shotgun, or anything else, your first thought is probably the cost. This is good thinking. Why should you spend more money repairing an item than the item is really worth? The same is true with military equipment. How can we be sure of the repair cost of an item? Well, it is very simple. First, you must decide what is wrong and then what parts need repairing or replacing. Time is also something else that must be taken into account; your time is surely worth something. All of these points add up to the cost of repairing an item. Then, you must compare the value of the item to the cost of repair and decide whether to repair the item or buy a new one. Of course, the availability of repair parts and the time involved will also affect your decision. We do this sort of thinking all our lives and being in the military service does not change things very much.

How do we arrive at the right decision when it comes to a vehicle engine? By performing an inspection of the engine. By this means, we can locate the trouble and decide what parts are needed and how long it should take to do the job, and only by this means can any of us be good mechanics.

There are ways for us to inspect an engine, or anything else, that will ensure we do a good job. If you are like most people, when you think of an inspection the first thing you imagine is inspecting by the use of your eyes. Really there are other means that ensure a complete job is being done. They are touching, smelling, and hearing. All these methods coupled together will guarantee a complete job of any inspection.

When inspecting an engine or a vehicle, the inspector must use a system that permits little or no chance for faults to go undetected. Mechanics do not perform inspections in exactly the same manner. Moreover, each mechanic will vary slightly the system used on different types of vehicles to make it suit the arrangement of the vehicle itself. After you have inspected a few vehicles, you will, no doubt, develop some ideas of your own on how to go about an inspection. The inspection of any piece of automotive equipment is the first and most important step in maintenance operations. Therefore, you must develop your own system soon. In the meantime, you can inspect engines using the procedures outlined in this lesson.

RECORD ALL FAULTS

It is important that all the things that need to be repaired, replaced, or adjusted be written down so they are not forgotten. A record of them must be made on DA Form 2404 (Equipment Inspection and Maintenance Worksheet). Entries on the form can be made by the mechanic while performing the inspection.

VISUAL INSPECTION

Look the engine over first before you attempt to operate it. Here are some things you should look for.

Oil Leaks

When you look for oil leaks, start on one side or at any given point on the engine. Then work completely around, under, and over the entire engine. Make sure you do not miss a spot where oil may leak.

Oil leaks are most likely to appear where gaskets and oil lines connect to or touch other parts. Some places to pay particular attention to are the valve covers, oil pressure sending units and safety switches, oil filter mountings, all oil lines, and the crankcase oil pan. Keep in mind there is no place on an engine where oil is supposed to leak.

You may ask, "Why should I be so concerned with oil leaks?" Well, the loss of oil cuts down on how far you can travel with a vehicle before you have to stop for maintenance or service. Another reason is that dirt will stick to oil and when oil and dirt cover an engine, the engine will overheat. An oil and dirt mixture will burn, so it also gives fire a place to start. Therefore, you must be thorough; make sure all oil leaks are seen and recorded, and then begin inspecting for other faults.

Oil Level

Before inspecting something other than oil, be sure you check the oil level in the crankcase. Usually, the main reason anyone checks the oil level with the dipstick is to find out if there is too little or too much oil in the crankcase. But, when inspecting an engine, there are other reasons too.

Suppose that the oil level is too high and has a milky appearance. The dipstick may also be rusty or show drops of water. All of these things are caused by water getting into and mixing with the oil, making it unfit for use. This means that you will have to find out how the water got into the crankcase, which may be through a leaking head gasket or a cracked engine block or head.

On other occasions, you may find that the oil on the dipstick looks very dark and feels like it has sand in it. This could be caused by the oil not being changed regularly and may indicate more serious trouble, such as excessive wear of engine parts.

Coolant Leaks

Looking for coolant leaks is like checking for oil leaks; make sure all points are covered. In fact, you can combine these two checks and look for both coolant and oil leaks as you move around the engine. Be sure to include the radiator and all connecting hoses when looking for coolant leaks.

Most of the time, coolant leaking onto hot engine parts, such as the cylinder block, can be detected by rusty colored streaks in the area of the leak. The coolant runs onto the parts and, due to the heat, it boils away leaving a rusty stain. Be sure to look for stains like this where the head and the block join. Sometimes this is the only way a head gasket leak is discovered.

Some coolant leaks will only show up when the engine is running or after it has been warmed up. When the engine is running and warm, the coolant is under pressure and may be forced out through small holes where it may not leak otherwise. You must be very careful when inspecting an engine that is running to prevent injuring yourself on the fan, belts, or other moving parts.

Accessories

Check the mounting of all accessories for loose, cracked, and missing hardware, such as brackets, nuts, bolts, and washers. Just normal operation, not to mention driving over rough roads, will cause nuts and bolts to loosen and often fall completely off the vehicle. Make sure a note is made of all loose and missing bolts and nuts so they are taken care of before they cause more damage.

Engine Block

During all phases of engine inspection, look for signs of overheating, such as holes in the engine block, cracks in the block, and leaking water jacket plugs. Any of these items can either cause the engine to be unsuitable for repair or indicate more damage that you cannot see. Bent or damaged parts attached to the engine indicate that a closer inspection of the engine block is required. For instance, mounting pads or bolt holes may be damaged.

Engine Starting

Does the engine start within the first few seconds of cranking? The vehicle batteries can only operate the starter system for short time before they run down. Also, cranking the engine for long periods will overheat the starter motor causing damage to it. If the engine is too hard to start, an engine tune-up may be needed. Then again, the cause may be the engine is cranking too slow due to a faulty starter system or batteries that are partially discharged. On the other hand, the piston rings may be worn or the valves may be leaking so the compression pressures are too low.

Oil Pressure

Once the engine starts, check the reading on the oil pressure gage right away. If the oil pressure gage does not show pressure immediately, stop the engine and determine the cause before going any farther. Operating the engine without oil pressure will ruin it in just a short time.

When the engine is cold and is first started, the oil pressure will be high because the oil is thick and does not flow easily. Then, as the engine and oil warm up, the oil gets thinner and the pressure gets lower. The normal oil pressure for each engine is listed in the technical manuals for the particular vehicle and for the particular type of oil being used. The oil pressure specifications listed always pertain to readings that are obtained with the engine at operating temperature. Make notes of oil pressure readings that do not agree with the specifications in the proper technical manual.

Do not be too hasty in deciding the cause of faults if the oil pressure reading is not correct. The lubrication system may be all right and the gage could be at fault. Look for simple things first, such as a loose wire, components not grounded properly, and missing nuts and bolts. Little things are the problem more often than major ones.

Noises

Particular attention should be paid to unusual operating noises when the engine is cold and first started, as this is when they are most likely to occur. Most noises, especially engine knocks, are caused by excessive clearance between parts that work together. As the engine warms up, parts expand, reducing operating clearances and noises. Here are some of the noises that you are expected to recognize as being uncommon.

A piston (wrist) pin knock. Loose piston pins will generally knock louder when the engine is not operating under a load. A piston pin knock is sometimes mistaken for a connecting rod knock although the pin knock is not as loud. If it is possible to adjust the exhaust valve so that it stays open all the time, the pin knock will double up so it makes twice the number of sounds.

The connecting rod knock is caused by excessive clearance between the connecting rod bearing inserts and the bearing surface of the crankshaft throw. It makes a loud, sharp knock while the engine is running at a constant speed without a load. You can detect the faulty connecting rod bearing by disconnecting and connecting the spark plug leads one at a time. When you disconnect the lead from the cylinder with the loose rod bearing, the knock will go away or at least change a great deal.

Loose main bearings on the crankshaft cause a heavy, dull, thud type noise which is usually worse with the engine loaded. Loose connecting rod bearings or main bearings will usually cause low oil pressure. This low pressure will be more noticeable at slow engine speeds. This is because the oil pressure leaks off past the loose bearing, and at slow engine speeds, the oil pump turns too slow to pump enough oil to maintain the proper pressure. At higher speeds, enough oil is pumped to overcome the leak and build up the oil pressure. If we have a sharp knock or a dull thud sound and the oil pressure is low, the connecting rods or main bearings are worn.

A piston slap usually sounds off only when the engine is on a pull. Like the connecting rod, disconnecting the spark plug wire to the affected cylinder will generally stop the knock. Pistons have been known to knock quite loud when the engine is cold, then the noise completely disappears after the engine warms up.

Water pumps sometimes make noises that are hard to locate. It may make a grinding noise, may sound like marbles rolling around in a tin can, or may be a high-pitch whistle. One way to find out if a noise is caused by the water pump is to remove the water pump (fan) drive belt. But you must keep in mind that the same belt may drive other parts, such as the generator, which could be the noise maker. If this is the case, lay your hand on the components and feel for the vibration that is making the noise. If the parts are hard to reach, use a metal bar or a stick for a sounding bar. To do this, place one end of the sounding bar against the suspected noise maker and touch the opposite end of the bar to your ear.

If the operating clearance between the valve stem and its operating linkage is too great, there will be a tapping noise each time the valve opens. The noise remains the same regardless of the load on the engine. But the tapping will get faster and louder as engine speed increases. This noise can be easily stopped in a few minutes, in most cases, by an adjustment. Can

you imagine how much the unnecessary cost would be if you or someone else were to mistake valve noise as being a loose rod or main bearing? This is why a mechanic with a lot of experience will sometimes get other mechanics to listen to a noise in an engine. Then they talk it over before deciding what the trouble is. Any noise that the engine does not normally make should be investigated. Find out where the unusual noise is coming from. Then by using your knowledge of the construction and operation of the engine and referring to technical manuals, decide what is causing the noise.

Engine Temperature

By the time you have run an engine long enough to check it out for noises and pressure leaks in the coolant and lubrication systems, the engine should be warmed up to its normal operating temperature. Check the temperature gage reading; then look in the maintenance manual to see what the normal operating temperature is for the engine you are working on. Generally, 180°F will be the normal operating temperature for military vehicles.

If the temperature gage pointer is at the very bottom or top of the scale, either the gage or wiring is probably bad. If you suspect that a gage is faulty, check its reading with an antifreeze hydrometer. This instrument is normally used to check the strength of the antifreeze solution in the cooling system. But, it also has a thermometer to indicate the temperature of the coolant. By filling the hydrometer with coolant from the radiator, the coolant temperature will be shown on the thermometer. Compare this reading with the temperature gage reading. Any big difference in reading will indicate that the temperature gage is not reading correctly.

When you remove the radiator cap to use the hydrometer, be very careful. The coolant expands as the engine warms up, so pressure builds up in the cooling system. Removing the radiator cap lets the pressure escape. If the engine happens to be very hot, boiling water and steam can fly out past the cap and scald you seriously.

On the other hand, if the engine is warm and no pressure escapes when the radiator cap is released, there is probably a leak somewhere in the cooling system. If you found no water leaks, the pressure may have leaked above the water level. One place it can do this is through either one of two valves in the radiator cap. Both valves are held closed by a spring. One relieves the system of excess pressure, while the other valves allow outside air to enter the radiator after the engine is stopped and the water cools off.

If the engine actually gets too hot, it could be caused by some internal problem, such as a thermostat or a leaky head gasket, but you should look for more simple faults first. For instance, is there anything that reduces the amount of airflow between the radiator fins? These fins collect heat from the water passing through the radiator, then air cools the fins. So, inspect the radiator core for bent fins or being stopped up with leaves or brush. Anything that reduces airflow must be corrected before doing a lot of other repair work in an attempt to correct overheating problems.

Road Test

If the condition of the vehicle will allow you to operate it on the road, a road test should be performed. Some of the questions about engine operation that a road test should answer are: does the engine develop full power? Does it accelerate properly? Are there any unusual noises as the engine is operated under different load conditions? Does it run smoothly? Does it smoke excessively?

Exhaust

The color of the smoke coming out the exhaust can be a clue to the cause of some engine troubles. Have the driver speed up and slow down the engine while you watch the exhaust. If the engine is running normally and is at operating temperature, the exhaust should be clear or a hazy gray. It may be white if the engine is cold. The color of the smoke may be slightly black as the engine is speeded up, but, when run at a steady speed, the blackness should disappear.

If the blackness does not go away, the fuel is not burning properly. The trouble could be in the air intake system or carburetor. The vehicle should go to your support maintenance if the problem exists after you have checked all of the things you should check, such as the air cleaner.

If the smoke has a blue color, oil is reaching the combustion chamber. This could be caused by bad rings, worn intake valve guides, or oil leaking through the head gasket. In any case, the vehicle should go to your support maintenance for more checks.

If the engine is warmed up and the exhaust smoke is white, water is getting into the combustion chamber. This could be caused by a leaking head gasket or a cracked head or engine block. This is also a job for your support maintenance.

The exhaust can also provide a clue if one or more cylinders are not firing. Place your hand about 3 inches from the end of the tail pipe and in line with the exhaust gases as they leave the pipe. The pressure of the gases against your hand should be almost steady, with a slight increase every time a cylinder fires. If a cylinder fails to fire, you can notice it by a drop in the pressure against your hand.

Learning Event 2:

DESCRIBE SPARK-IGNITION ENGINE TESTING PROCEDURES

Thus far, we have been discussing what we should look or listen for when inspecting an engine. Suppose that during the inspection you find one or more things wrong with the engine. Now what do you do?

What you will do depends on a number of things. Some of these are: Just what is your job? Are you just to inspect? Are you also supposed to repair and adjust? What did you find wrong and should there be more checks made to confirm your findings? What tools and equipment do you have? All these things and many others will determine what you will do.

During this part of the lesson, we are going to assume you have the time, tools, and equipment that you need. Also, we are going to try to forget that many of you will be working in mud up to your ankles or snow up to your knees and perhaps with the enemy just a short distance away. All of this will have an effect on what you do and how you go about it.

The testing procedures we will be discussing apply only to spark-ignition engines. Most compression-ignition engine problems can only be tested at intermediate support maintenance, so we will not cover them here.

COMPRESSION TESTING

Suppose during the inspection of an M151 1/4-ton truck, you find the engine does not develop as much power as it should. The engine may need to be replaced, but it could also be a lot of other things too. More tests should be made to find out for sure. Most often the problem is in the fuel or ignition system. Since the tests on these systems are covered in the lessons on fuel and ignition, we will consider tests on the engine alone here. Engine problems that could cause a lack of power are worn rings, leaking valves, and head gasket leaks. Measuring the amount of pressure the cylinders build up on the compression strokes will tell us if these items are bad.

Before making a compression test, run the engine until it is at normal operating temperature. Ensure the batteries are fully charged and the starter system is in good working order. Make the test while cranking the engine. If it does not crank as fast as it should, the compression reading will be low. Next, blow

the dirt from around the spark plugs with compressed air and remove the spark plugs. Now, ensure that the choke is pushed all the way in and pull the throttle all the way out. This is so the pistons can draw in a full charge of air on each intake stroke.

Obtain a compression gage from the toolroom and make the compression test. To do this, insert the rubber tip on the compression gage into the spark plug hole of the No 1 cylinder. Press the gage in firmly to ensure it seals the spark plug hole, and have someone else crank the engine with the starter. Record the highest reading the gage reaches. Release the pressure trapped in the gage by pressing a relief valve on the gage, so the gage pointer returns to zero. Repeat this test on each cylinder. Each cylinder should reach its highest reading in about the same number of crankshaft turns.

Compare the compression pressure of the cylinders. Normal readings of the M151-series vehicle should be 85 PSI or higher. There should not be more than 25 PSI between the lowest and highest cylinder. If the readings are within the above specifications, the trouble is somewhere else.

Low compression readings of the same amount on two cylinders that are side by side, say No 2 and 3, indicate a leaking head gasket. The head gasket would be allowing the compression pressure to leak from one cylinder to the other. This may be caused by improperly tightened cylinder head bolts. Torque the head bolts to 60 to 65 lb-ft, being sure to tighten them in the recommended sequence (order). Keep in mind that the operating clearance of the valves must be adjusted on an M151 truck engine after the head bolts have been retightened. After adjusting the valves, check the compression pressure again. If the pressure is still low on the two cylinders, the head gasket is probably faulty and should be replaced.

If the rings are worn or the valves leak, the compression reading may be low on all or any number of cylinders. To determine which is at fault, put about a half ounce of engine oil in the bad cylinder on top of the piston. Retest the compression. If the rings are worn, the oil makes them seal better and a higher compression reading is obtained. If the reading remains about the same, the valves are probably leaking. In the event of leaky valves, their operating clearance should be adjusted and the compression retested. If they were adjusted too tight, this may correct the problem.

INTAKE MANIFOLD PRESSURE (VACUUM) TEST

Knowing the compression of engine cylinders is very useful in determining engine condition, but this is not the only test you can make for this purpose. You can also measure the amount of suction or vacuum that the cylinders have on the intake stroke. On compression-ignition engines, this is not your job, so we will look only at the spark-ignition engine.

Actually, a vacuum measurement is still a measurement of pressure, but the pressure is less than the normal air pressure that is all around us. Instead of being measured in pounds of pressure per square inch, as compression is, the vacuum is measured in inches of mercury.

The term "inches of mercury" refers to the distance that mercury in a U-shaped tube moves when a vacuum is applied to one end of a tube. For example, if the mercury rises 10 inches, the value of the vacuum is 10 inches of mercury.

Vacuum Gage

The vacuum gage that you will be using has a scale and a needle pointer like the compression gage. Each mark on the scale stands for 1 inch of mercury. Most gages will also read a small amount of pressure for checking fuel pump pressure. (This test is covered in another lesson.) The vacuum gage is issued to your unit as a kit and comes with adapters and hoses so it can be attached to any engine.

Connecting the Gage

The vacuum reading is obtained by connecting the vacuum gage to the intake manifold and then operating the engine. Recall that the intake manifold is a common pipe that connects to all of the cylinders. Almost all engines contain some sort of a plug or connection in the intake manifold. Remove the plug or fitting and replace it with a suitable adapter from the vacuum gage kit and connect the vacuum gage.

Vacuum Readings

Start the engine. When it has run long enough to reach operating temperature, look at the vacuum reading. Normal vacuum readings will vary between different engine models, so be sure to check the proper technical manual for the exact normal readings. Specifications given in the technical manual are for sea-level operations. At higher elevations, the gage readings are lowered about 1 inch of mercury for every 1,000 feet of increase in altitude. For example, Denver, Colorado, is about 5,000 feet above sea level. So the vacuum reading obtained on a vehicle at Denver will be about 5 inches less than a reading obtained on the same vehicle at sea level.

The normal reading for most engines is about 20 inches of mercury with the engine at idle speed. A steady reading in this range indicates that the engine is running as it should at this speed.

As a further check for normal engine operation, open and close the throttle quickly. If the engine is running as it should, the reading will drop to about 2 inches at wide open throttle. Then it will quickly go to about 25 inches when you close the throttle and the engine is slowing down. (The black needle on the gage (in the illustration) indicates the normal reading and the white needle indicates the needle travel.)

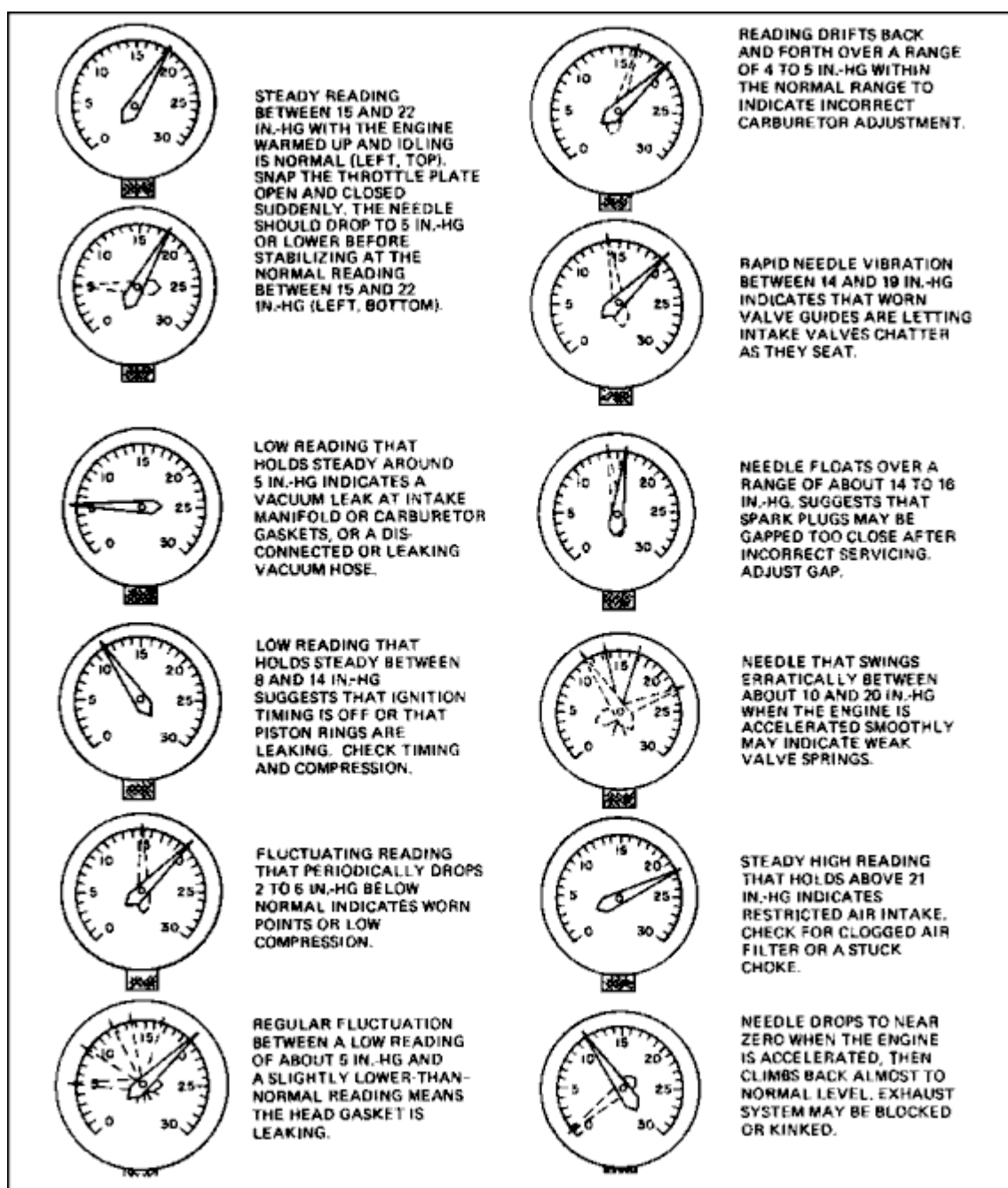


FIGURE 50. VACUUM GAGE READINGS.

Now for some of the readings you will get if the engine is NOT running properly. Sometimes the same readings that are caused by engine faults can also be caused by troubles in the engine ignition or fuel system. Therefore, we will mention all the troubles here, but we will only go into detail on faults in the engine.

If the reading is a little low and the needle floats slowly back and forth from about 12 to 16 inches, the fuel-air mixture is not correct. This is usually caused by an improperly adjusted carburetor which is covered in later lessons.

A plugged or partly plugged exhaust system will result in a normal reading when the engine is first started. But, the reading will drop off as the engine runs. How quickly the reading drops will depend on how badly the exhaust system is plugged.

A steady but below normal reading indicates a fault that affects all of the cylinders. Just how low the reading is will depend on how bad the fault is. Some of the possible faults are incorrect ignition or valve timing, a leak in the intake manifold or carburetor mounting gaskets, and uniform piston ring leakage.

If all the piston rings are leaking enough to lower the reading, the compression will also be low and blue smoke will be coming out of the exhaust. The blue smoke is caused by oil leaking from the crankcase past the rings and into the combustion chamber.

If the valve timing is incorrect, the low vacuum reading would also be accompanied by low-compression readings. If an engine uses timing gears, the valves will not get out of time once the engine has been put together properly. However, if it uses a chain and sprockets to drive the camshaft, it is possible for a worn chain to slip over one or two teeth on a sprocket. This will upset the relative position of the crankshaft and camshaft and change the valve timing.

Suppose that the gage needle repeatedly drops back about 3 to 6 inches and then returns to normal. The needle movement is regular and seems to be timed with the engine speed. This reading indicates a condition that is affecting one or more, but not all, cylinders. Problems that can cause this are an ignition miss and a leaky valve or head gasket. If the needle just drops back once in a while, the trouble is probably a sticky valve or an ignition problem.

You can locate the cylinder or cylinders that are affected by disconnecting and connecting the spark plug leads one at a time while watching the gage. When you disconnect a lead and the action of the needle is not affected, you know that this is the affected cylinder.

Lesson 3/Learning Event 2

If you suspect leaky valves or a head gasket, perform a compression check. These procedures are explained in spark-ignition compression testing.

If the gage bounces back and forth very fast, the valve stems are probably loose in the valve guides.

If the needle bounces back and forth at high engine speeds but reads normal at idle, the valve springs are probably weak.

PRACTICE EXERCISE

1. What is indicated if the engine oil level is too high and the oil has a milky appearance?
 - a. Oil of the wrong viscosity
 - b. Fuel leaking into the oil
 - c. Water leaking into the oil

2. An engine knock that goes away when the proper spark plug lead is disconnected is most likely caused by a loose
 - a. rod bearing.
 - b. main bearing.
 - c. throwout bearing.

3. Which parts have too much operating clearance if the engine knocks and the oil pressure is low?
 - a. Piston pins
 - b. Valve guides
 - c. Bearings

4. Loose main bearings in the engine will make the MOST noise when the engine is
 - a. hot.
 - b. cold.
 - c. under load.

5. What should be done first if an engine overheats?
 - a. Check the operation of the thermostat
 - b. Check the airflow through the radiator cores
 - c. Flush the radiator

ANSWERS TO PRACTICE EXERCISE 3

1. c (page 77)
2. a (page 80)
3. c (page 80)
4. c (page 80)
5. b (page 82)

LESSON 4

ENGINE LUBRICATION SYSTEMS

TASK

Describe the principles of engine lubrication and crankcase ventilation systems.

CONDITIONS

Given information about principles of operation and maintenance of engine lubrication and crankcase ventilation systems.

STANDARDS

Solve 70 percent of the multiple-choice test items covering engine lubrication and crankcase ventilation systems.

REFERENCES

TM 9-8000

Learning Event 1:

DESCRIBE PRINCIPLES OF OPERATION AND COMPONENTS OF LUBRICATION SYSTEMS

The lubrication and ventilation systems used on modern internal combustion engines are excellent examples of good engineering design. The lubrication system must be designed so it will deliver a large amount of oil to some of the parts while providing mere drops to other parts in the engine. Too much oil in some places can cause as much trouble as too little. If, for example, the lubrication system delivered as much oil to the cylinder walls as it does to the main bearings, the rings could not wipe off the excess oil fast enough. Some of the excess oil would get by the rings into the combustion chamber where it would foul up the spark plugs, gum up the chamber with carbon, and burn during the power stroke to be lost through the exhaust pipe. Too much oil in the wrong places will also cause oil seals to fail and valves to stick.

The crankcase ventilation system (also known as the breathing system) plays an important part in the life of an engine. It has the responsibility of removing the vapors that form in the crankcase. If not removed, these vapors form sludge when mixed with the engine oil and destroy the lubricating qualities of the oil.

What are these vapors and where do they come from? Well, part of the vapors are plain water which collects on the walls of the crankcase the same way water forms on the outside of a glass of iced tea. As you know, when the air containing water vapors strikes the cold outside of an iced tea glass, the vapors condense and form drops of water on the glass. The same thing happens in an engine. When the engine is running, the air in the crankcase starts to heat up. When the heated air strikes the cooler sides of the oil pan and crankcase, the moisture in the air condenses and falls as drops of water into the engine oil.

Excess fuel from the combustion chamber can travel by the piston rings and collect in the crankcase oil along with the water. Even with an engine in good condition, some unburned fuel gets by the rings into the crankcase, especially during the time the engine is being cranked or is being operated while it is cold. The driver usually has the choke pulled out or is pumping the accelerator to supply the engine with more fuel. Much of the fuel that is not burned winds up in the crankcase where it dilutes the oil.

We cannot prevent the water and fuel from getting into the lubricating oil, but we can remove most of both of them through the crankcase ventilation system.

OPERATION OF LUBRICATION SYSTEMS

The lubrication system has the job of supplying all of the moving parts in an engine with oil. As you know, the oil helps to reduce friction, clean the moving parts, and cool them by carrying off part of the heat. In the case of the pistons and rings, the oil helps to seal off the combustion chamber and helps to prevent the burning gases from entering the crankcase.

There are four types of lubrication systems used in internal combustion engines. They are the splash, the combination splash and force feed, the force feed, and the full-force feed.

The splash, combination splash, and force-feed systems are no longer used in automotive engines in this country. They are, however, used in such things as lawnmower engines, outboard motors, and motorcycles, so we will discuss them briefly.

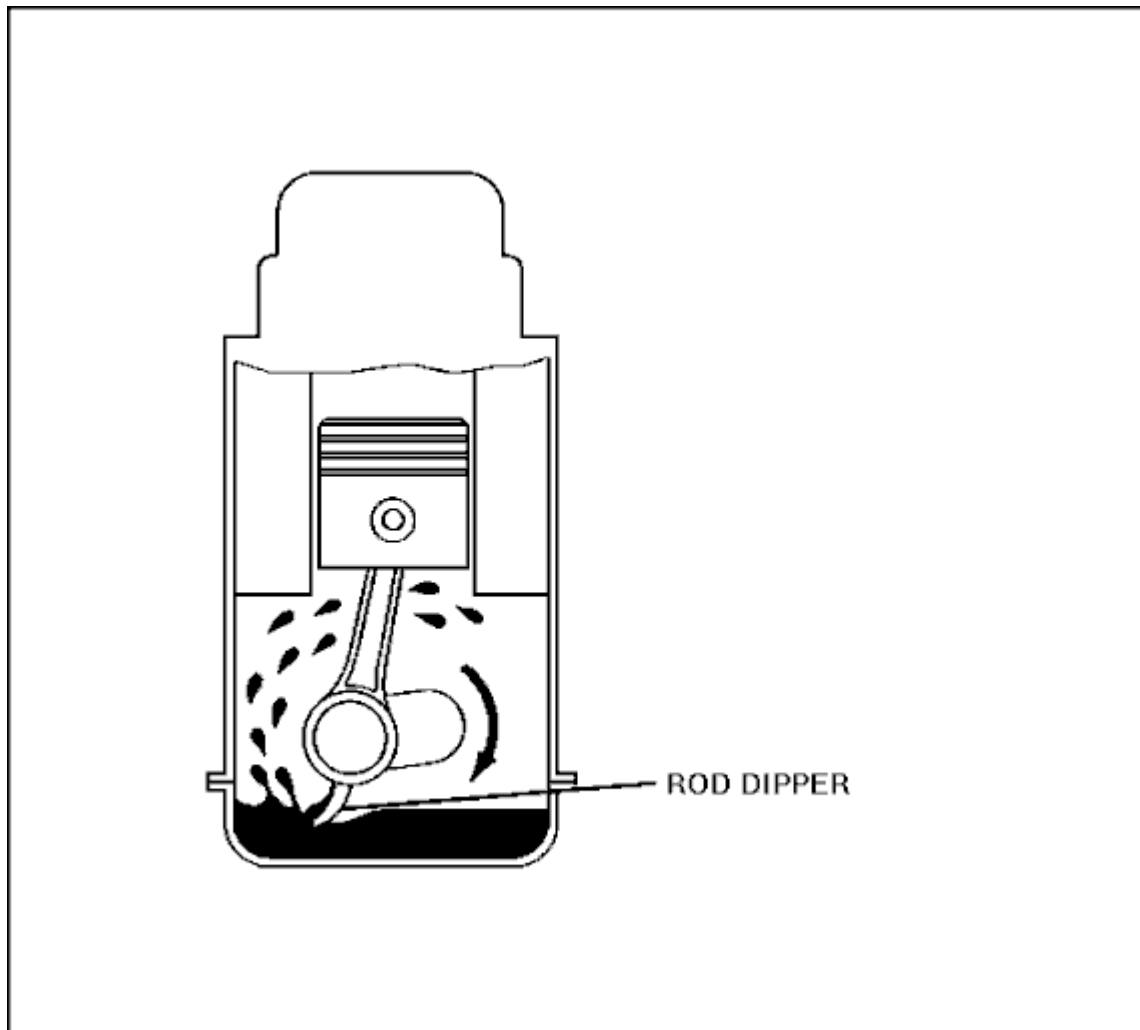


FIGURE 51. SPLASH-TYPE LUBRICATION SYSTEM.

Notice on the splash system there is a dipper on the bottom of the connecting rod. This dipper splashes the oil all over the inside of the engine. All of the moving parts are lubricated by the oil splashed on them by the dipper.

A variation of the splash system is used in the two-stroke-cycle engine. Here the lubricating oil is mixed with the gasoline in the fuel tank. During the compression stroke of the piston, the reed valve opens and a fresh charge of oil, fuel, and air enters the crankcase. The fuel, air, and oil moves through the intake port into the cylinder when the piston moves down on its power stroke. The oil in the fuel lubricates the moving parts. This method of lubricating the engine is very common on small two-stroke-cycle engines, especially those used on motorcycles and motorboats. This system is known as the vapor lubrication system.

The amount of oil mixed with the fuel in the two-stroke-cycle engine must be carefully controlled. Too little oil will cause rapid wear of the engine parts. Too much oil will cause carbon to form in the combustion chamber, foul up the spark plugs, and clog the exhaust ports. Spark plug fouling is a very common problem with this type of engine.

An advantage of this type of lubrication system is that the engine can be tilted or operated in any position. If the engine was operated on its side or in an upside down position, it would not last long. This is because the oil in the crankcase would flow away from the dipper and could not be splashed over all of the moving parts.

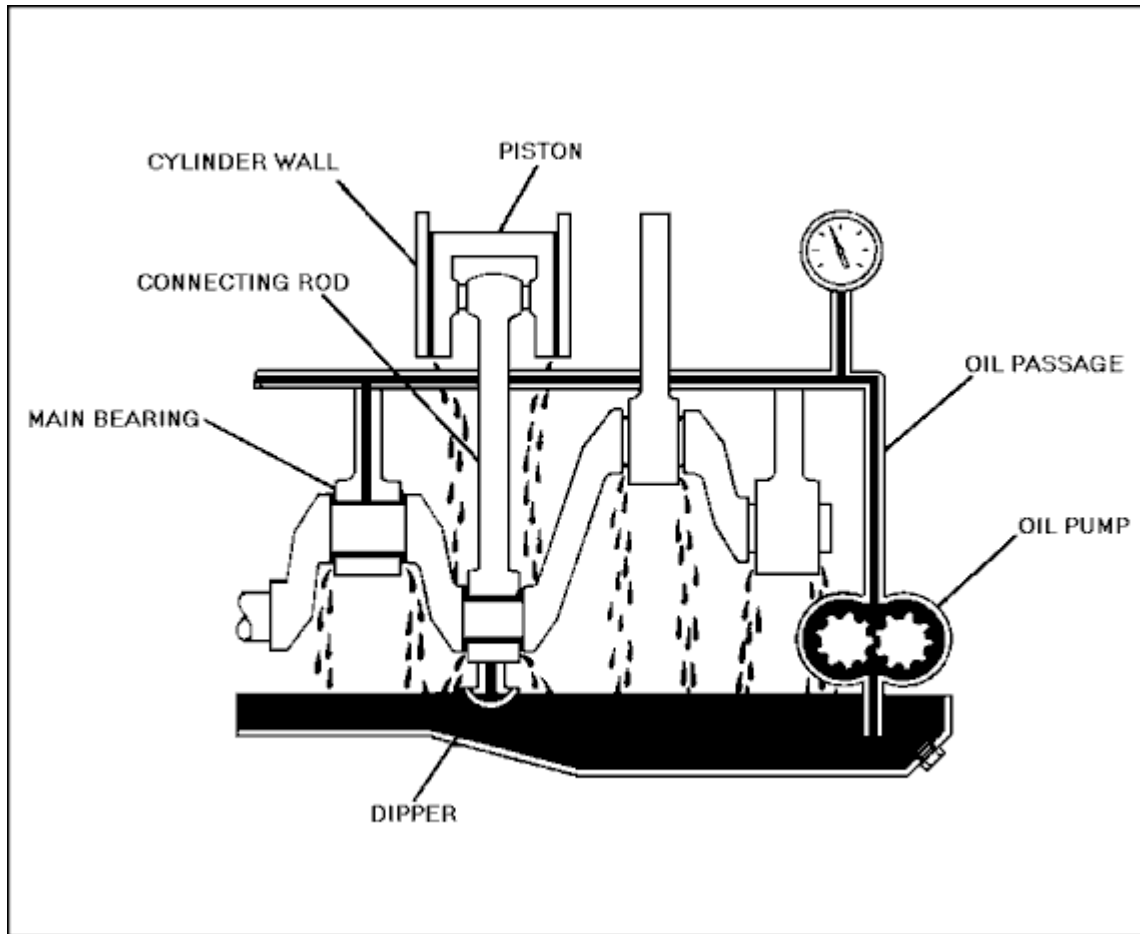


FIGURE 52. COMBINATION SPLASH AND FORCE-FEED LUBRICATION SYSTEM.

The combination splash and force-feed systems of engine lubrication were used on some American-made vehicles until the middle 1950s. An engine using this system still relies on dippers on the connecting rods to lubricate the connecting rod journals, the cylinder walls, and the pistons and rings. Other parts, such as the main bearings, valves, camshaft, and timing gears are lubricated by oil supplied by a pressure pump.

Compare the lubrication system shown with the one above. Notice the parts that have been added to provide oil under pressure to some parts of the engine. Item A is an oil pump. It is usually driven by a gear on the camshaft. The pump picks up the oil through a pickup tube in the engine oil pan B. Item C is the oil passage leading from the oil pump to the main bearings and to other engine parts that are supplied oil under pressure. Notice one oil passage leads to a small jet or nozzle that can spray the

oil directly into the dipper on the connecting rod and into the tray or trough directly below dipper D. With this arrangement, the dipper does not have to reach the oil in the pan. You can imagine what would happen if the oil level in the pan was a bit too low for the dipper to reach. With the oil spray jet, the connecting rod bearings and cylinder walls will be properly lubricated even if the oil level is low in the oil pan.

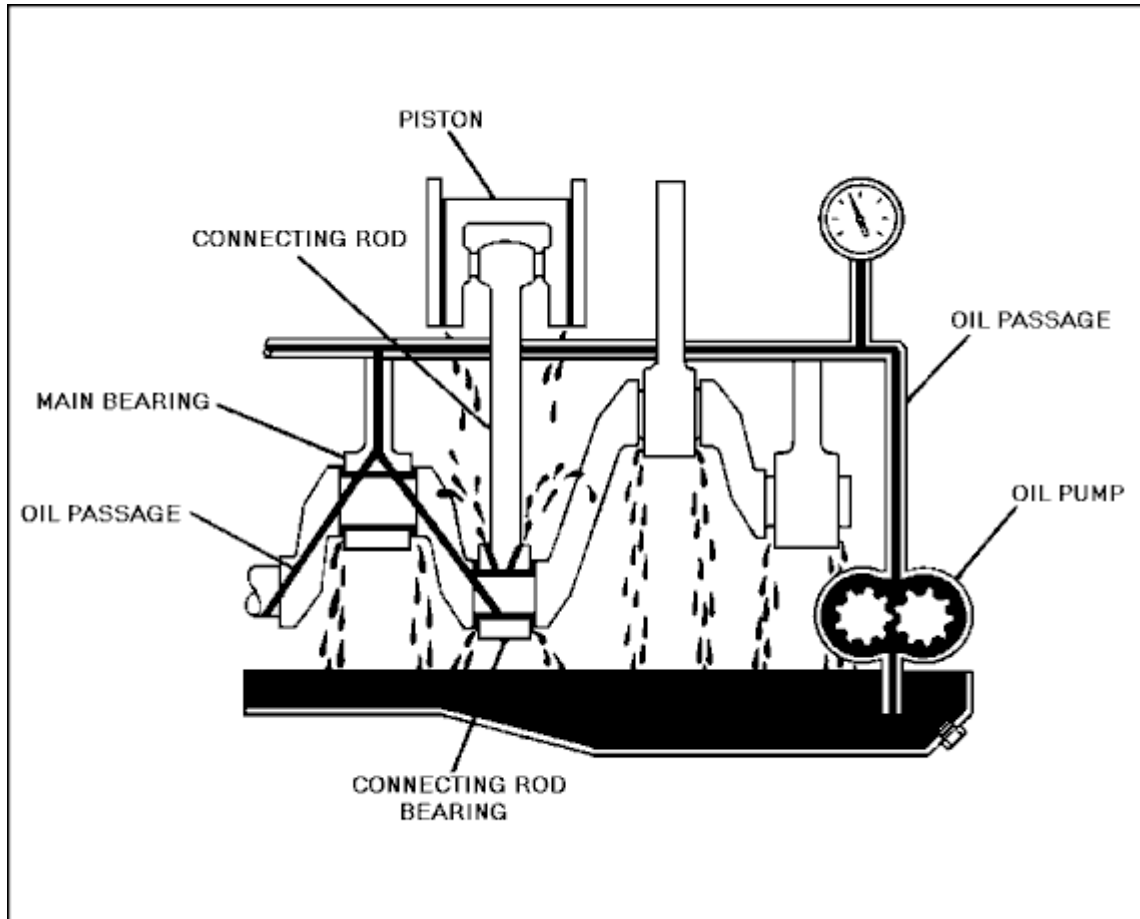


FIGURE 53. FORCE-FEED LUBRICATION SYSTEM.

Shown here is the force-feed lubrication system. Notice there are no dippers on the connecting rods. Instead, the crankshaft has drilled passageways leading from each of the main bearing journals to the connecting rod journals. Oil is delivered to the main bearing by the pump. Part of the oil travels through the drilled passageways to the connecting rod journals.

On some engines, the oil leaking out around the connecting rod bearings is thrown on the cylinder walls by the spinning crankshaft.

On other engines, a small squirt hole is drilled through the rod to spray oil on the piston and cylinder wall.

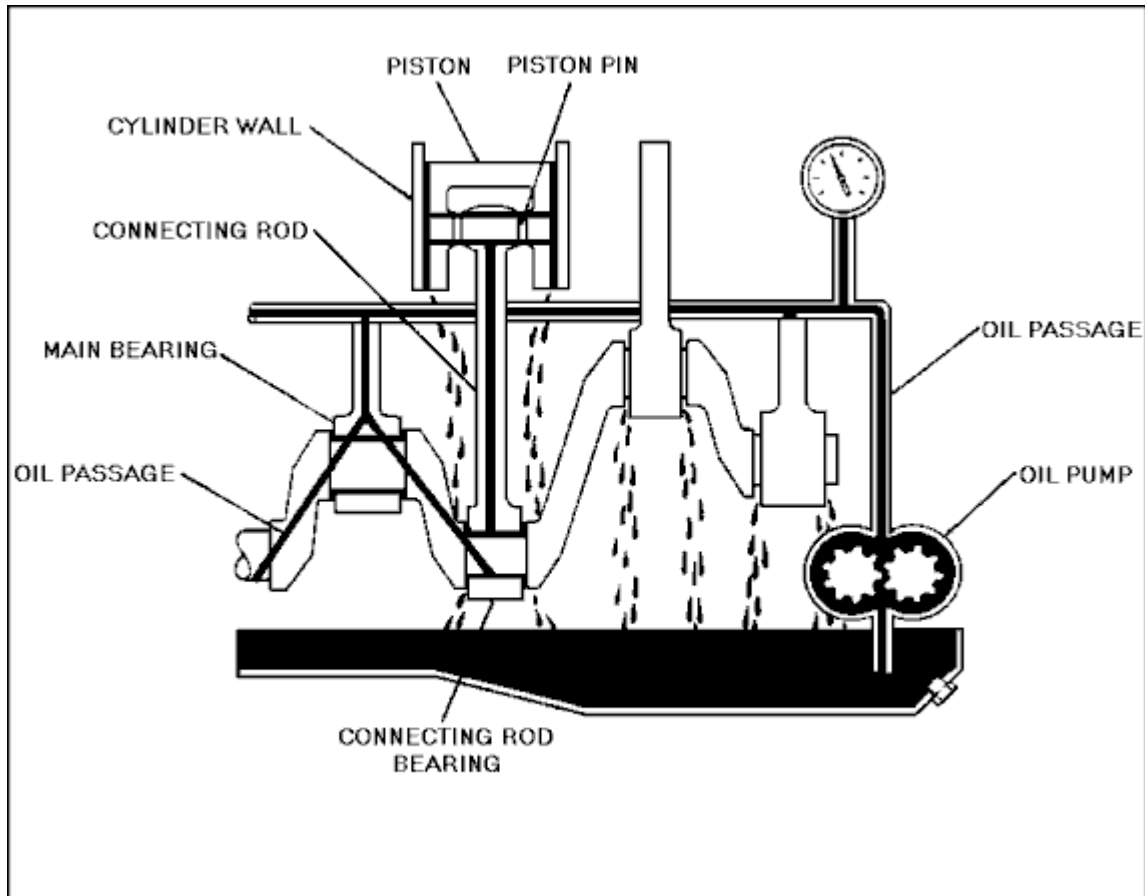


FIGURE 54. FULL-FORCE-FEED LUBRICATION SYSTEM.

The full-force-feed system is identical to the force-feed system except that the connecting rod is drilled to supply oil under pressure to the piston pin.

SUBASSEMBLIES OF THE LUBRICATION SYSTEM

Now let's examine the individual parts found in the lubrication system of an engine.

The reservoir for storing the oil is known as the oil pan. It is sometimes known as the crankcase cover because it does seal the bottom of the engine crankcase.

Most oil pans, especially on military wheeled vehicles, have a fairly deep section known as the sump. The sump serves several purposes.

- First, it increases the amount of oil the oil pan can hold.
- Second, it provides a pocket into which dirt, water, and metal particles can settle.
- Third, it reduces the amount of sloshing back and forth that the oil can do.
- Fourth, it houses the pickup screen for the oil pump and ensures the delivery of oil to the pump as long as there is any in the oil pan.
- Finally, the sump makes certain that oil will be available at the pickup screen when the vehicle is climbing or going down steep grades.

If the oil pan is shallow and has a flat bottom, all of the oil will run to the front or rear of the oil pan when the vehicle travels over steep grades. With the deep sump, part of the oil will always be present in the sump so the oil pump can pick it up.

Some oil pans also have baffle plates which help to reduce the amount of sloshing the oil can do as the vehicle travels over rough roads or cross-country. Excessive sloshing is undesirable because it tends to keep the dirt and water mixed with the oil instead of letting them settle to the bottom of the sump.

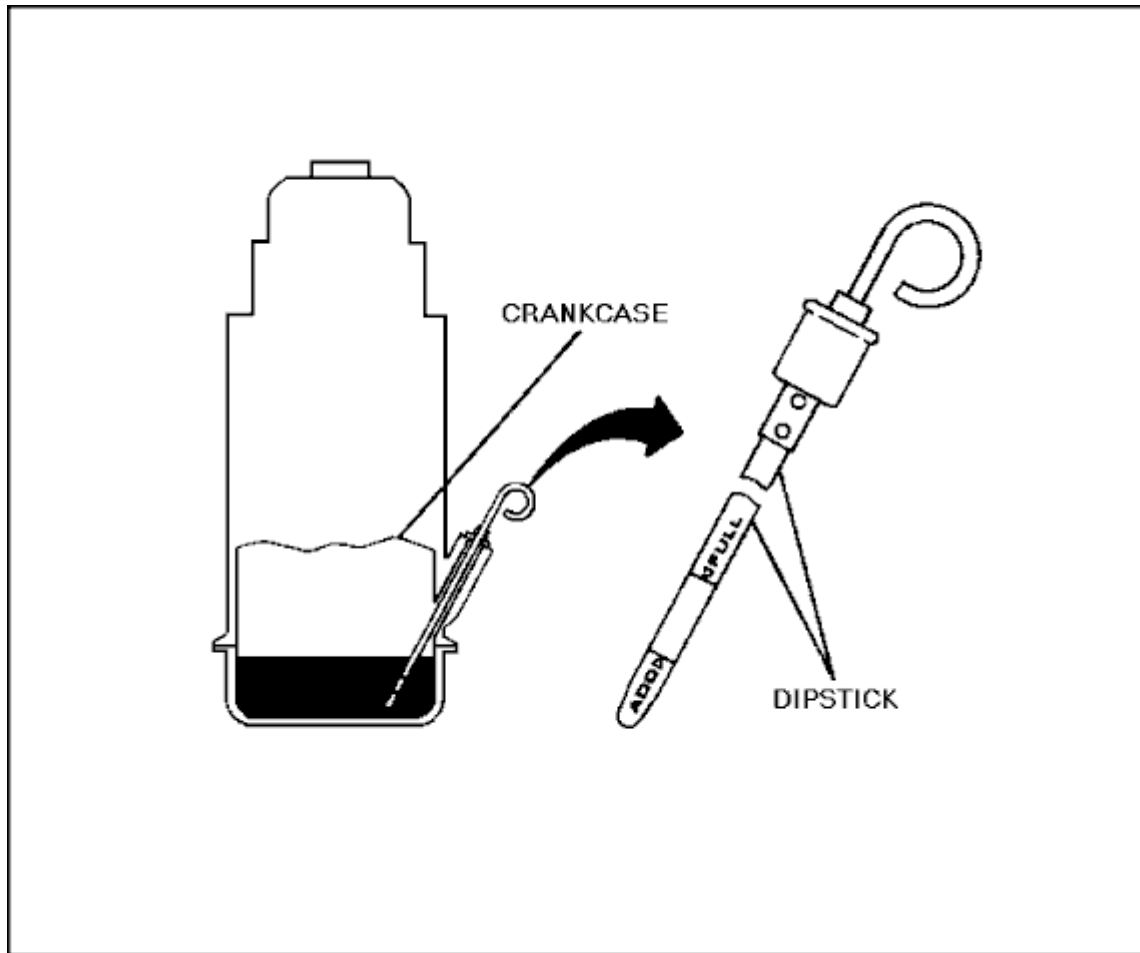


FIGURE 55. OIL LEVEL GAGE.

The oil level gage or dipstick is used to measure the level of the oil in the pan.

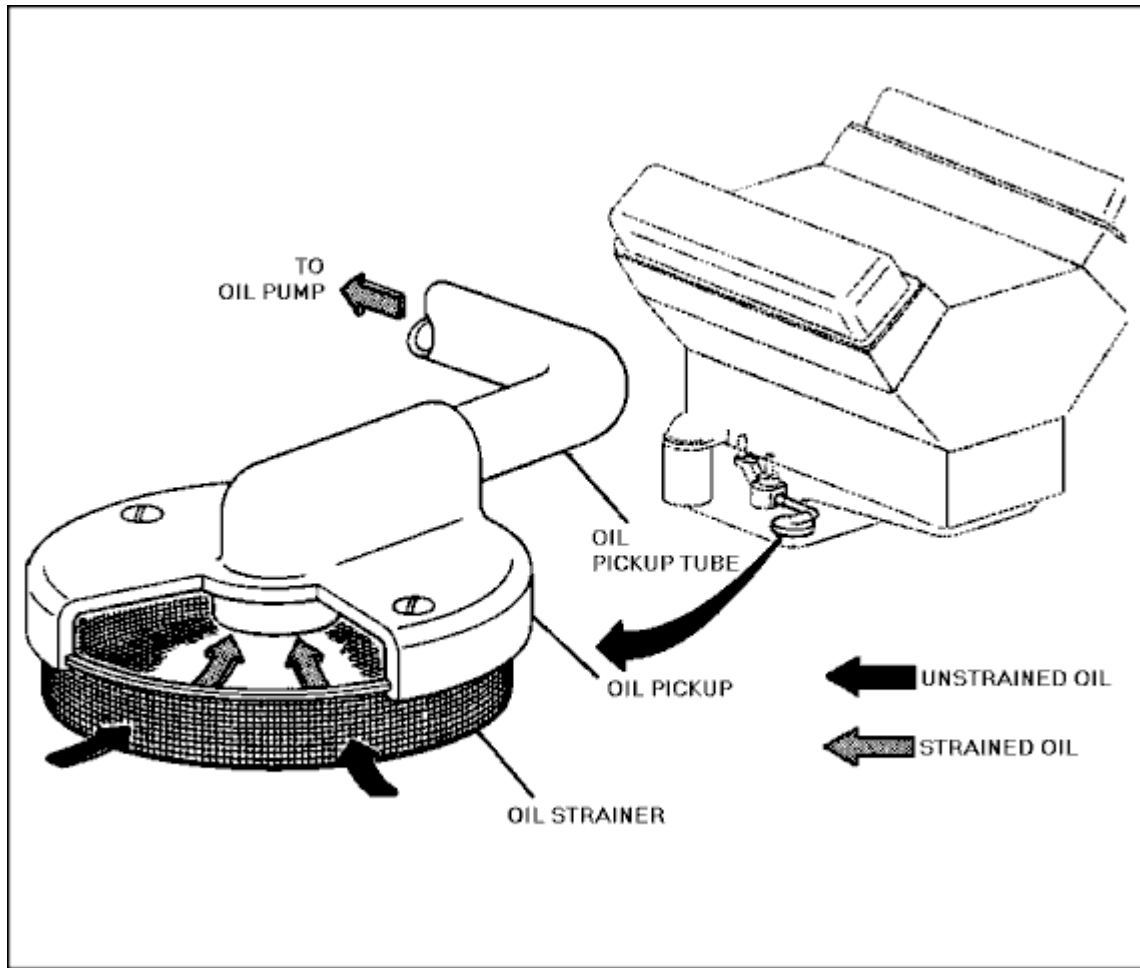


FIGURE 56. OIL PICKUP.

The oil pickup or inlet is usually mounted in the engine so that it extends down into the sump portion of the oil pan. It has a screen which is made of wire mesh to strain the oil before it is delivered to the pump.

Some oil pickup screens are designed to float on top of the oil and rise or fall with the oil level in the pan. Since dirt and water tend to settle in the bottom of the sump, the floating screen will pick up the cleanest part of the oil.

From the pickup screen, the oil is usually routed through a pipe or a tube to the inlet side of the oil pump. There are several types of oil pumps in use in modern automotive engines. All of them can be classified as positive displacement pumps, because they are pumping oil anytime the engine is running. Depending on the method used to pump the oil, the pumps are called gear, vane, rotor, or plunger types. The gear and rotor types are the most commonly used in automotive engines. In practically all cases, the pumps are driven by a gear on the camshaft. In the case of gasoline engines, this gear is usually the same one that drives the ignition distributor shaft.

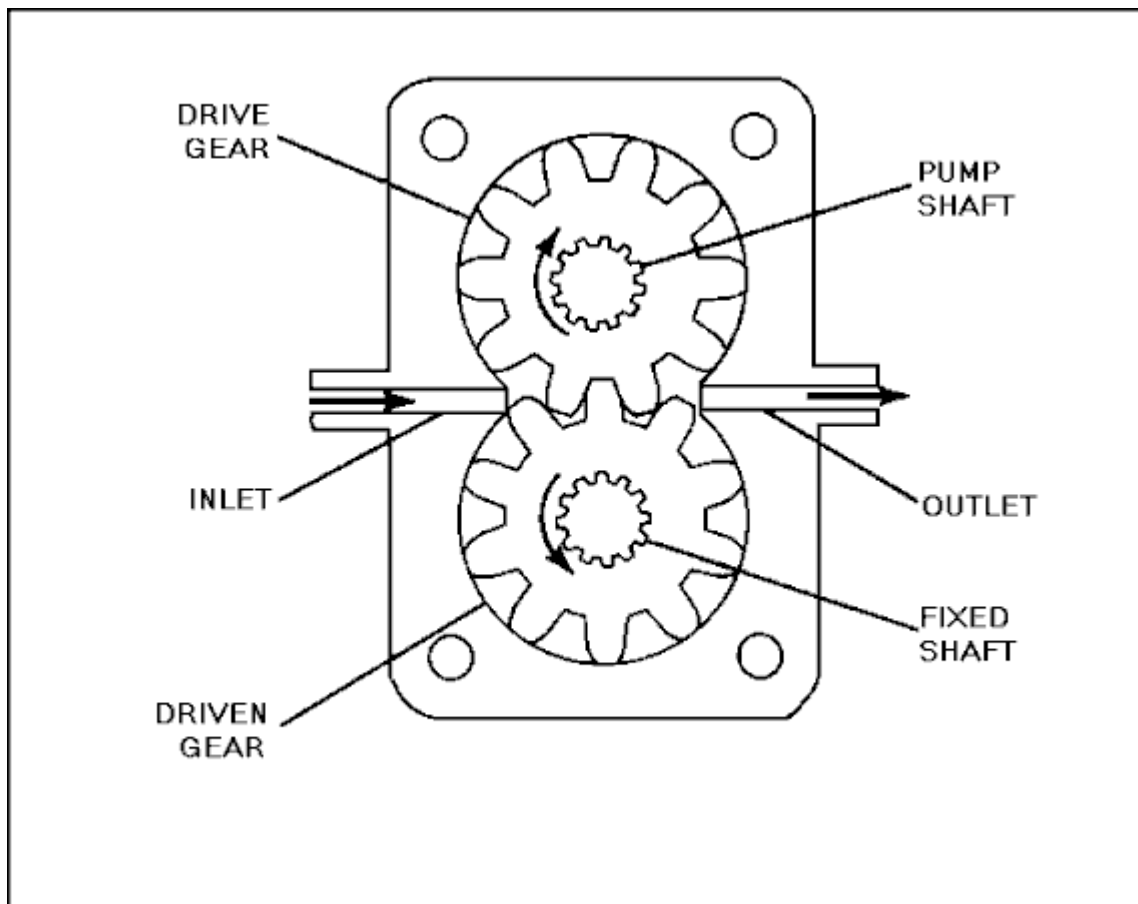


FIGURE 57. GEAR-TYPE PUMP.

This is a top view of a gear-type pump. The upper gear is the driving gear. The gears revolve in the directions indicated by the arrows.

On the inlet side of the pump, the teeth on the driving and driven gears are moving away from each other. Oil is picked up at the inlet and is carried between the gear teeth and the housing to the outlet side of the oil pump.

At the outlet side of the pump, the gear teeth come back into mesh (engagement). With the teeth of both gears in mesh, there is no longer room for oil between them. The oil is forced out from between the gear teeth into the outlet (discharge) side of the pump.

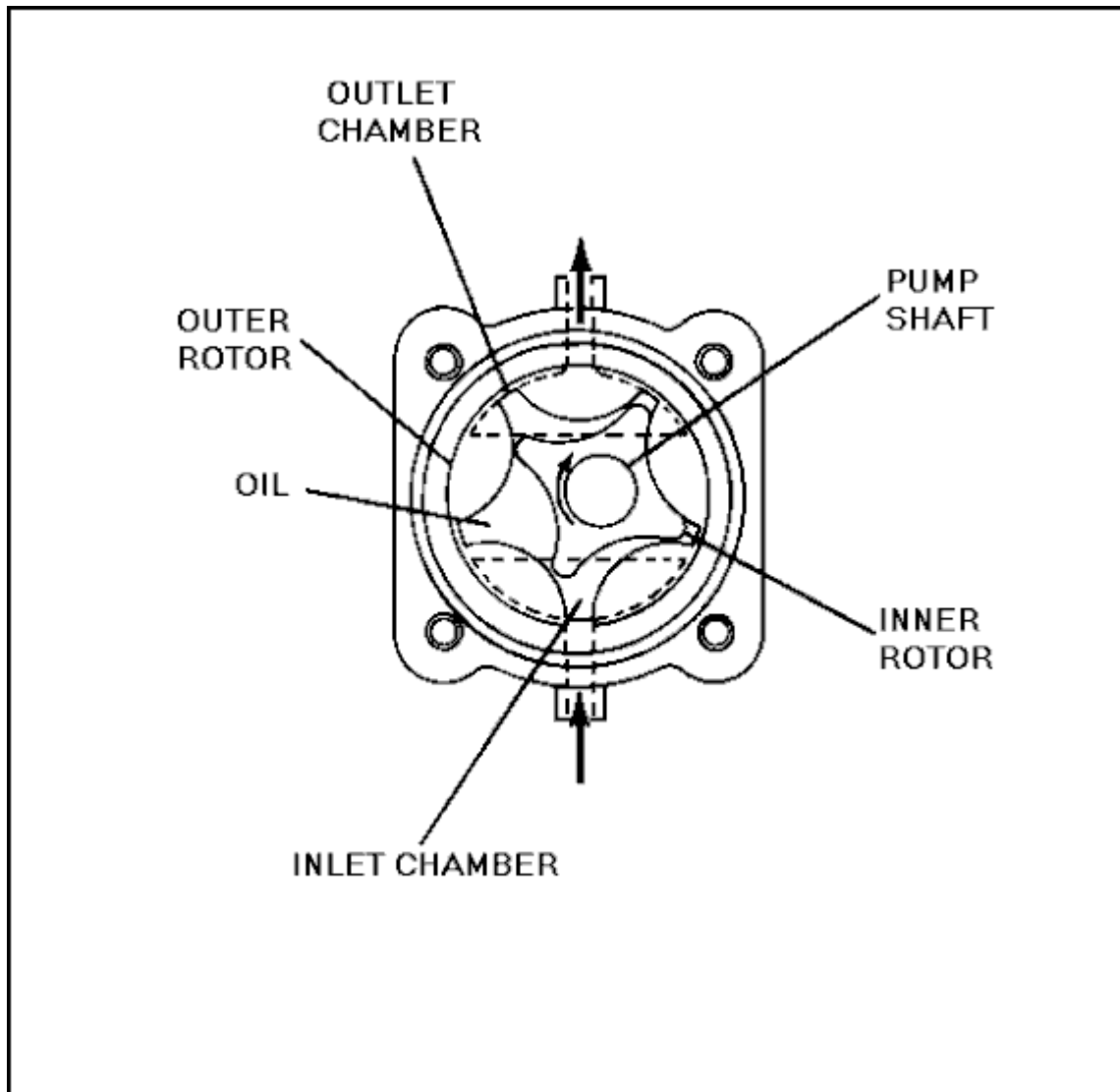


FIGURE 58. ROTOR-TYPE PUMP.

The rotor-type pump uses an inner rotor with lobes that move in and out of mesh with an outer rotor.

The inner rotor is keyed to, and driven by, a shaft like the gear in the pump in the illustration. As the inner rotor rotates, it carries the outer rotor with it in the same direction.

Notice that the inner rotor is not centered in the outer rotor. The teeth-like lobes of the two rotors are in mesh only at the bottom. As the two rotors turn to the left (counterclockwise), their lobes separate. The space between the rotors fills with oil. As the rotors continue to turn, the lobes start coming back together. As the lobes come together, oil is squeezed out the discharge sides of the pump.

All of the oil pumps discussed are capable of pumping oil under high pressure. In fact, the pressure such pumps can produce is too high for the lubrication systems used in automotive engines. An oil pressure relief valve is used to control the oil pressure at the desired amount (usually 60 PSI or less).

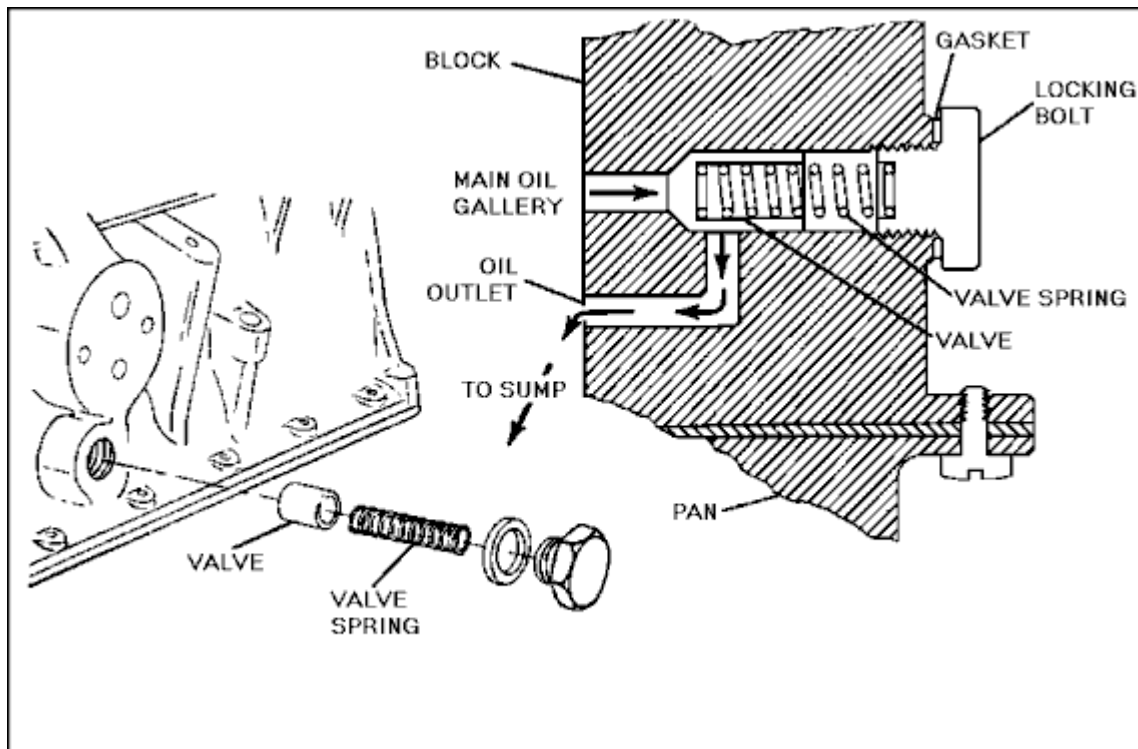


FIGURE 59. OIL PRESSURE RELIEF VALVE.

The relief valve, which is also known as a pressure regulator valve, is usually placed in the main oil line (also known as the oil gallery) leading from the pump or built into the discharge side of the pump itself.

The relief valve is usually a spring-loaded ball or plunger type. Oil under pressure is delivered through the main oil line to the parts that are pressure lubricated. The oil exerts pressure on the plunger in the pressure relief valve. When the oil pressure exceeds the plunger spring pressure, the plunger is forced off its seat and oil can flow by the plunger into the oil outlet and from there to the sump. The plunger is held off its seat by the oil pressure in the main oil line until the pressure drops to the point at which the spring can seat the plunger. The spring must have just the right amount of strength. The oil pressure from the pump is controlled by the strength of the plunger spring. The oil pressure in the system can be increased by increasing the spring tension or it can be reduced by decreasing the spring tension.

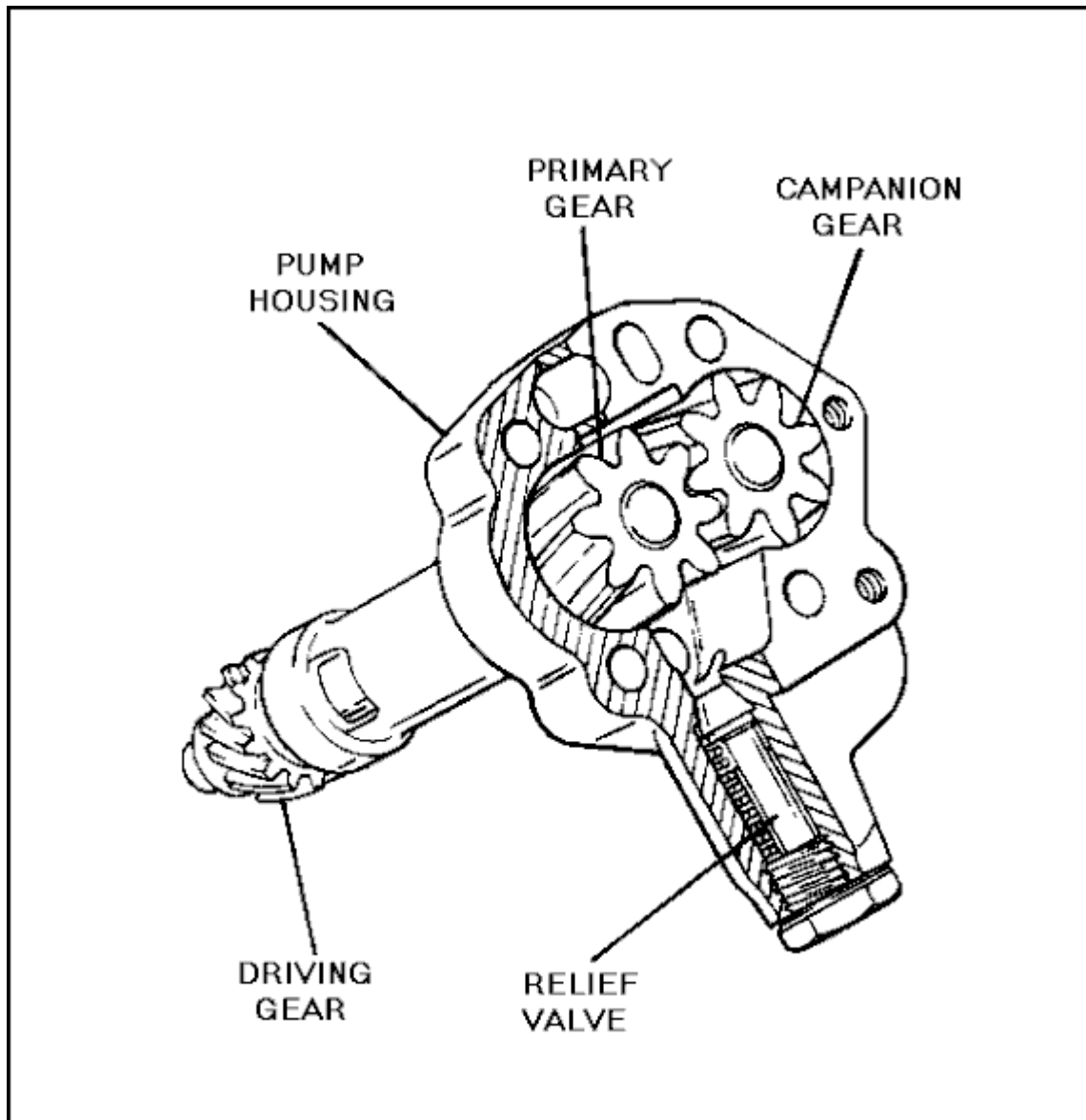


FIGURE 60. OIL PUMP WITH RELIEF VALVE.

This is a cutaway view of a gear-type oil pump with the relief valve in the discharge side of the pump. It is common practice by many engine manufacturers to place the relief valve in the pump.

Although the screen in the oil pump pickup in the sump will strain out much of the dirt and carbon, it cannot remove fine particles of dust and other abrasive materials that gather in the oil. An oil filter is used in the lubrication system to remove all the abrasive materials possible. The oil filter is connected in the lubrication system in one of two different ways, full flow or bypass.

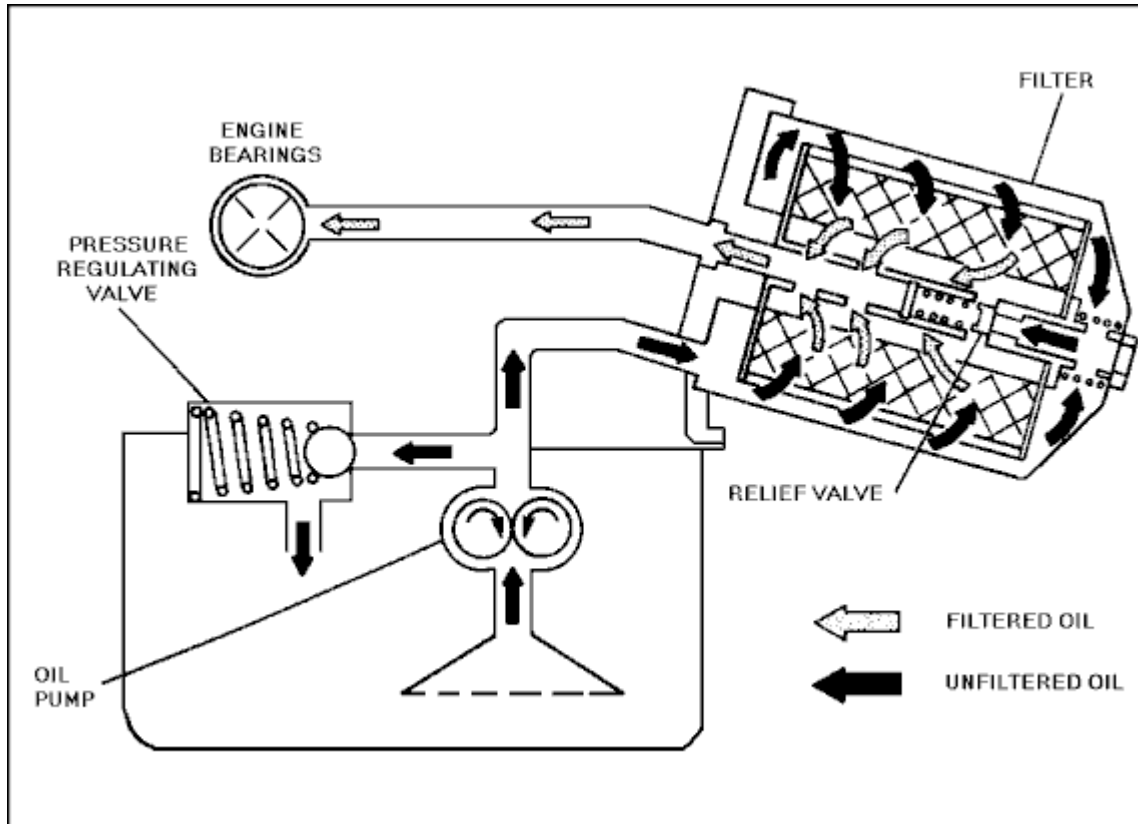


FIGURE 61. FULL-FLOW FILTER SYSTEM.

In the full-flow system all the oil from the pump is sent through the filter before being routed through the main oil line to the parts to be lubricated.

Let's trace the flow of the oil in the system. The oil is drawn from the sump through the pickup screen to the pump. There the oil is pressurized and sent through the discharge side of the pump to the oil filter. Notice the location of the pressure relief valve in the drawing. Notice, too, that oil getting through the relief valve is returned to the sump.

After the oil has been filtered, it is sent through the main oil line to the parts requiring lubrication.

The abrasives removed from the oil by the filter will eventually clog the filter to the extent that no oil can get through if the filter is not serviced. When this happens, a bypass valve, which is usually located in the filter, opens and allows the unfiltered oil to move into the main oil line.

Although most modern automotive engines are equipped with the full-flow type of oil filter, there are many engines that have the bypass type of filter.

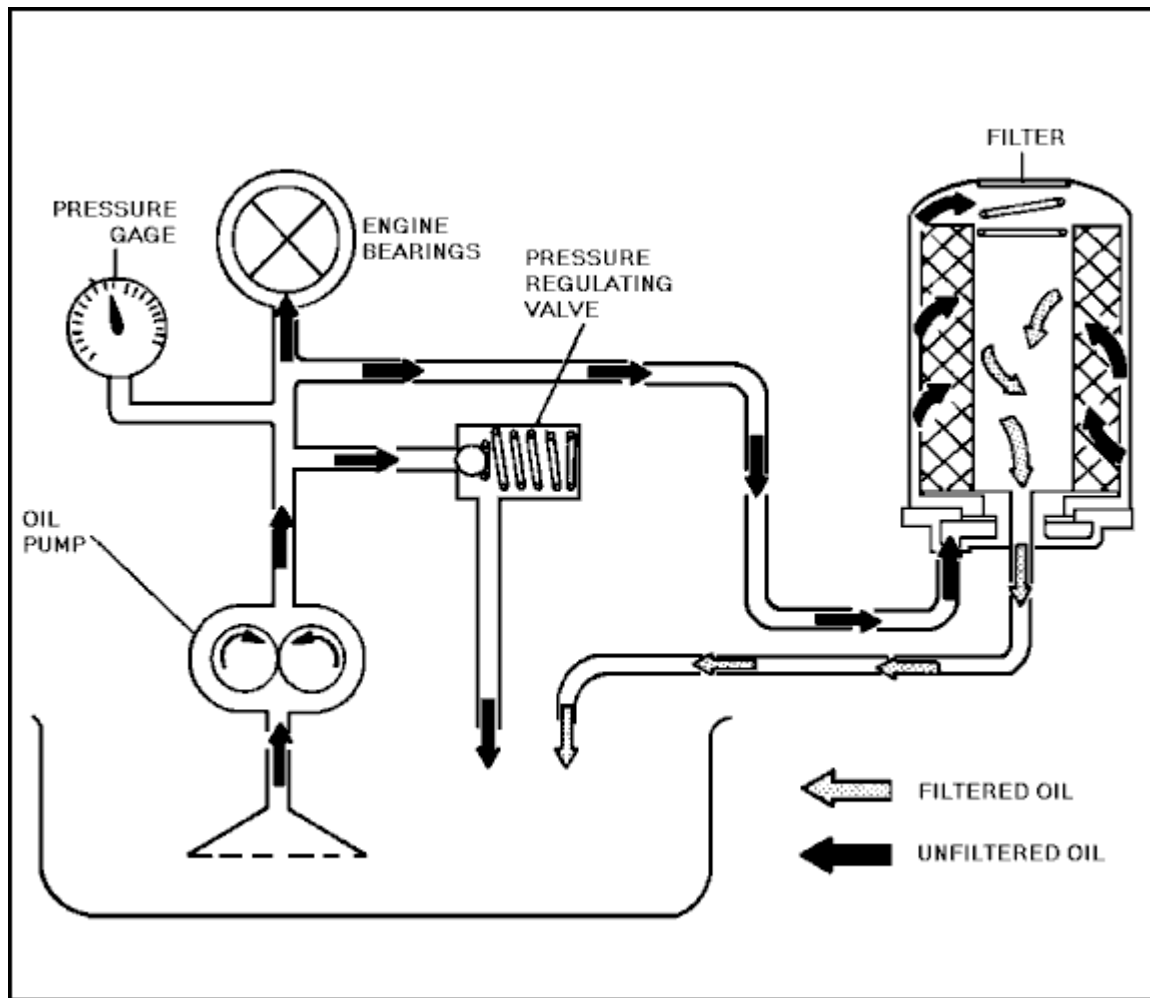


FIGURE 62. BYPASS FILTER SYSTEM.

Notice that the main oil line divides on the output side of the pump. Part of the oil is directed to the bearings and other moving parts, while part of the oil is directed through another oil line to the filter. Notice that the oil leaving the filter returns directly to the sump in the oil pan.

No bypass valve is needed with this type of filter because oil will still be delivered to the moving parts even if the filter becomes clogged.

At this point, let's study the entire lubrication system on a typical engine.

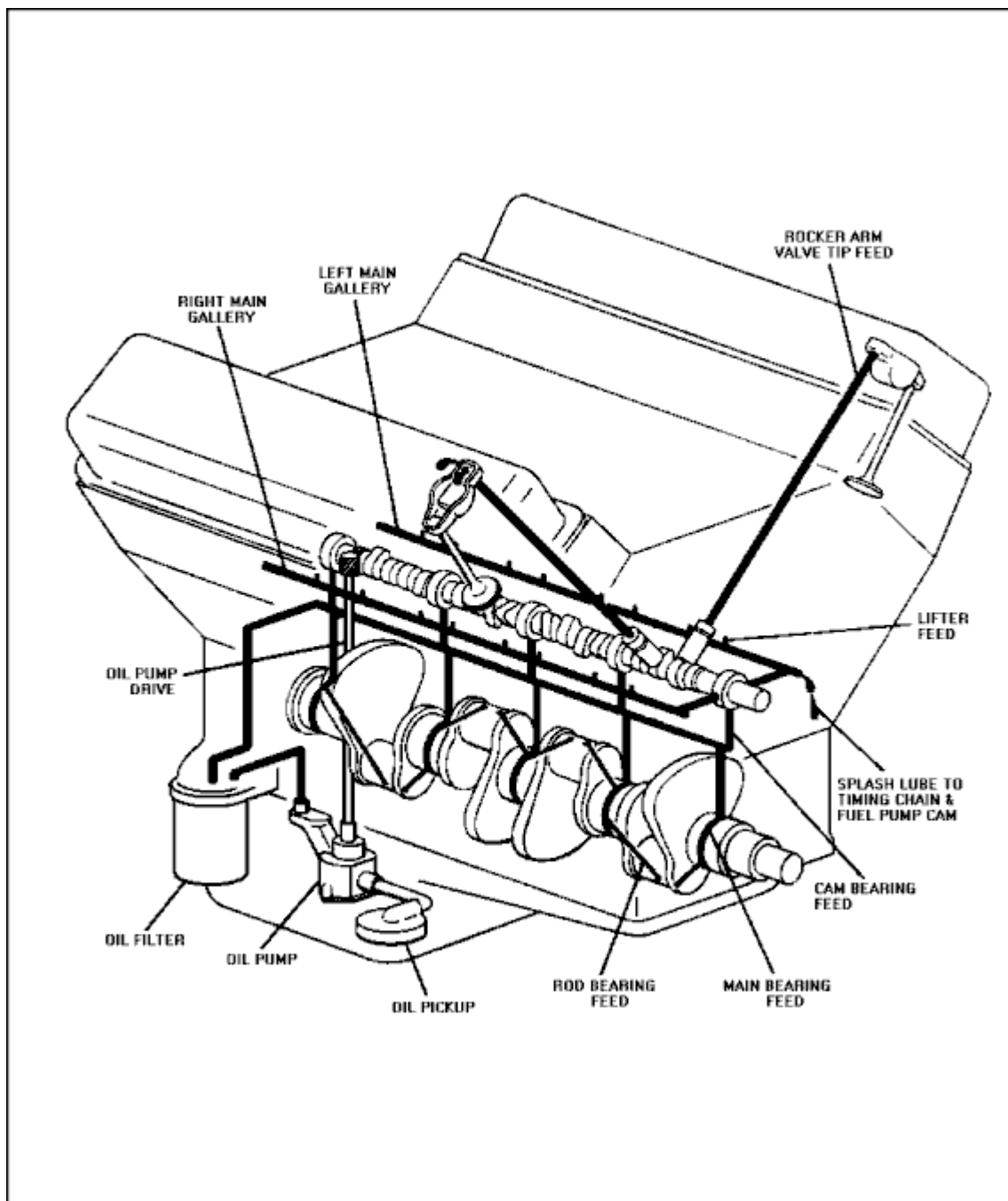


FIGURE 63. TYPICAL ENGINE LUBRICATION SYSTEM.

The oil passages and the main components for a typical full force-feed system are shown. Notice the location of the oil inlet in the sump of the oil pan. Now trace the flow of oil from the oil pickup to the main oil line. Then trace the small oil lines leading to each camshaft bearing and to each main bearing.

Notice that from two of the camshaft bearings, two oil lines lead to the hollow-valve rocker arm shafts at the top of the engine. These lines are usually very small or have restrictor valves in them to reduce the amount of oil going to the rocker arm shafts to lubricate the valve train.

In most engines the main oil line and oil feeder lines are drilled passages in the engine block and cylinder head. In all cases, the oil passages between the main bearings and connecting rod bearings are drilled holes in the crankshaft

.

Learning Event 2:

DESCRIBE PURPOSE OF CRANKCASE VENTILATION SYSTEM OPERATION

The crankcase ventilation system has two important jobs to do. It must get rid of the fuel and water vapors that collect in the crankcase. It must also remove the "blowby" gases that would otherwise build up considerable pressure in the crankcase and cause oil seals and gaskets to leak.

We have already discussed how the fuel and water vapors condense in the crankcase and form sludge when mixed with the oil. Now let's discuss what "blowby" is and what problem it creates.

As you know, the piston rings and the lubricating oil have the job of sealing the high-pressure gases in the combustion chamber that are present during the compression and power strokes of the piston. The rings cannot form a perfect seal because they must have a gap so they can be installed on the piston and to allow for expansion when they become hot. They must also be free to move in the piston ring grooves. Otherwise, they could not expand out against the cylinder walls. The film of oil on the pistons, cylinder walls, and rings can help to seal the gases in the combustion chamber, but the film is not 100 percent effective as a seal. So part of the high-pressure gases in the combustion chamber escape by the rings and oil film into the crankcase. The gases escaping by the rings and into the crankcase are known as blow by gases.

The gases entering the crankcase as a result of blow by can build up enough pressure to cause oil seals and gaskets to leak if they are not allowed to escape. In addition, these gases contain unburned fuel, carbon, and other byproducts of combustion that will mix with and ruin the oil in the crankcase.

Now let's see how one type of crankcase ventilation system works to get rid of the blow by gases and the water and fuel that get into the crankcase.

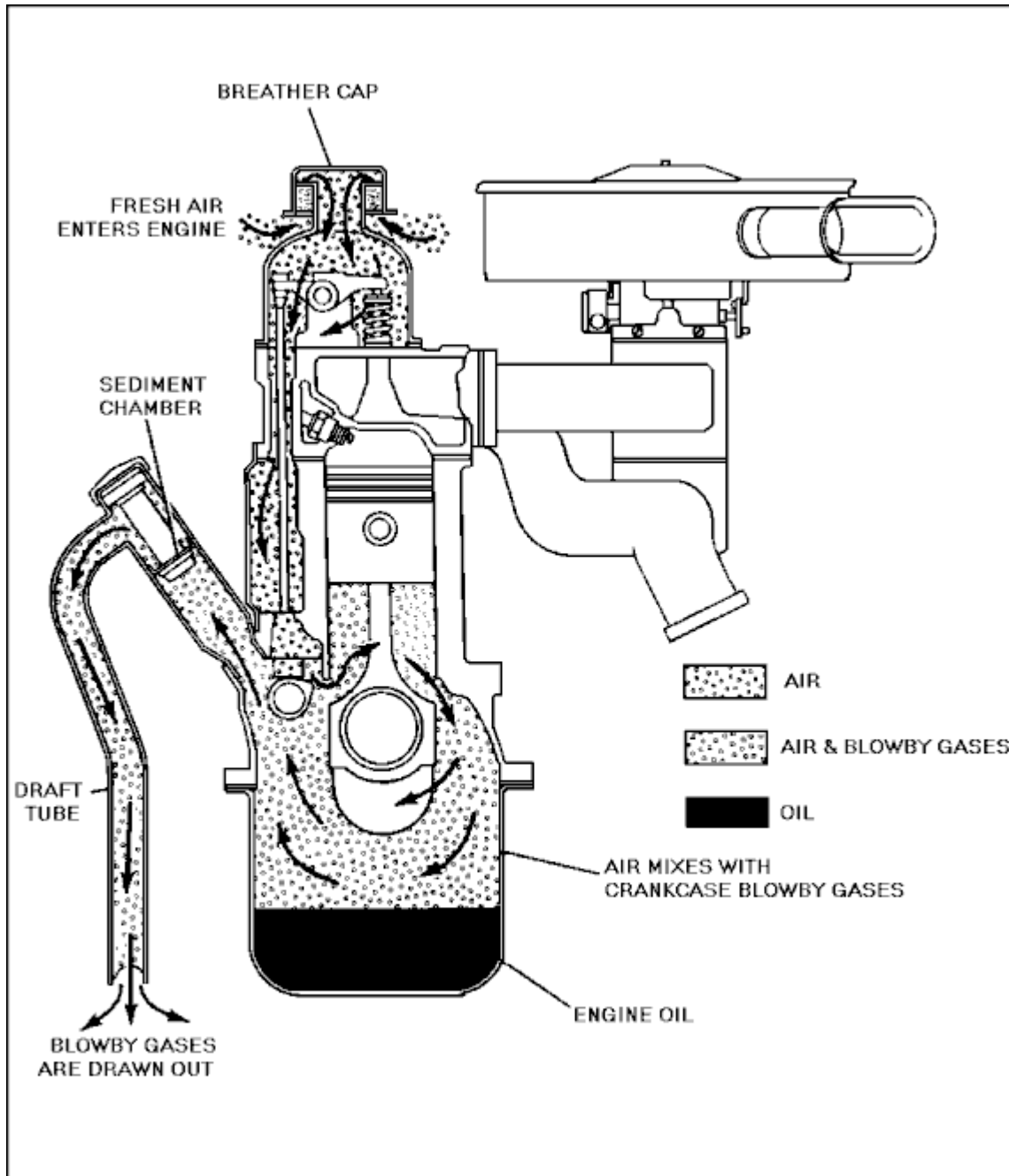


FIGURE 64. DRAFT TUBE SYSTEM.

One of the ventilation systems used on automotive engines is shown. Air is drawn into the crankcase through openings in the valve cover. The air circulates around the crankcase and above the oil in the oil pan. The blow by gases and the fuel and water vapors are mixed with the air. This mixture is drawn out of the crankcase through the road draft tube and discharged into the surrounding air as the car travels down the road.

For this system to work, the air must be moved rapidly through the crankcase and out of the road draft tube. The lower end of the road draft tube is designed to act like a suction pump to get this rapid circulation of air. Notice that the lower end of the road draft tube is cut at an angle.

Have you ever stuck your hand out of the window of a fast moving car? The wind blowing past your hand was a pretty powerful force, wasn't it?

If a vehicle with a road draft tube was moving down the road, the wind would be rushing by the end of the road draft tube at a pretty good clip. With the road draft tube cut at the angle shown, the wind moving by it would create a suction (known as a partial vacuum) at the end of the road draft tube. This will draw the air and vapors out of the crankcase.

This system is known as a nonpositive crankcase ventilation system because it will not work unless the vehicle is moving forward.

A positive crankcase ventilation system operates anytime the engine is running and does not depend on vehicle movement. Notice that the air enters the crankcase through a breather and goes out through a tube leading to the intake manifold. Anytime the engine is running there is a low-pressure area in the intake manifold. The air from the crankcase containing the blowby gases and fuel and water vapors is drawn through the intake manifold to the combustion chamber. There, the combustible gases are burned and discharged through the exhaust system.

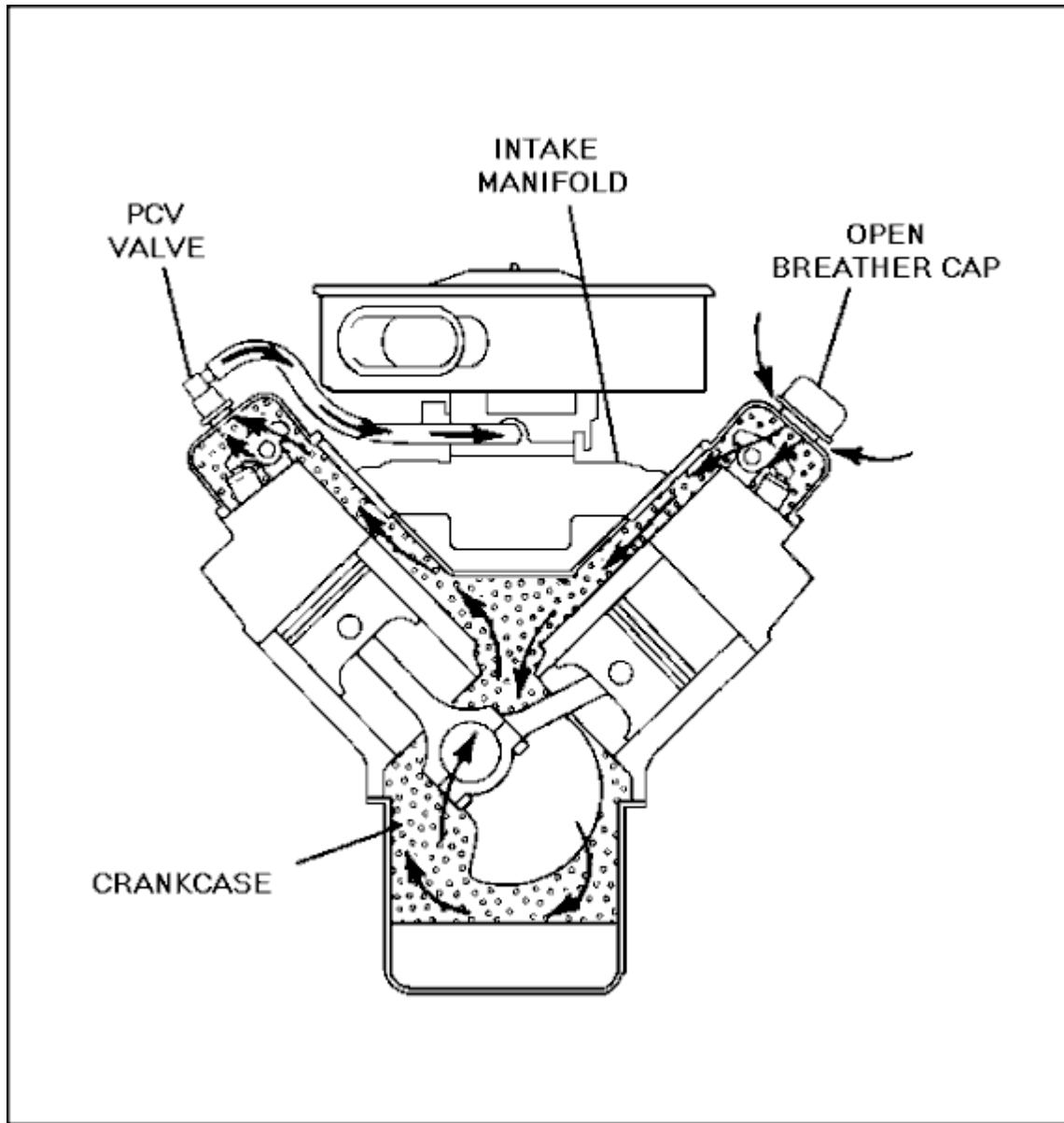


FIGURE 65. PCV SYSTEM.

When the intake manifold vacuum is high, too much of the vapors will be drawn into the manifold and will dilute (thin out) the fuel-air mixture coming from the carburetor if some steps are not taken to prevent it. This would cause a loss of power. To prevent this, a ventilator valve is located in the tube close to the intake manifold.

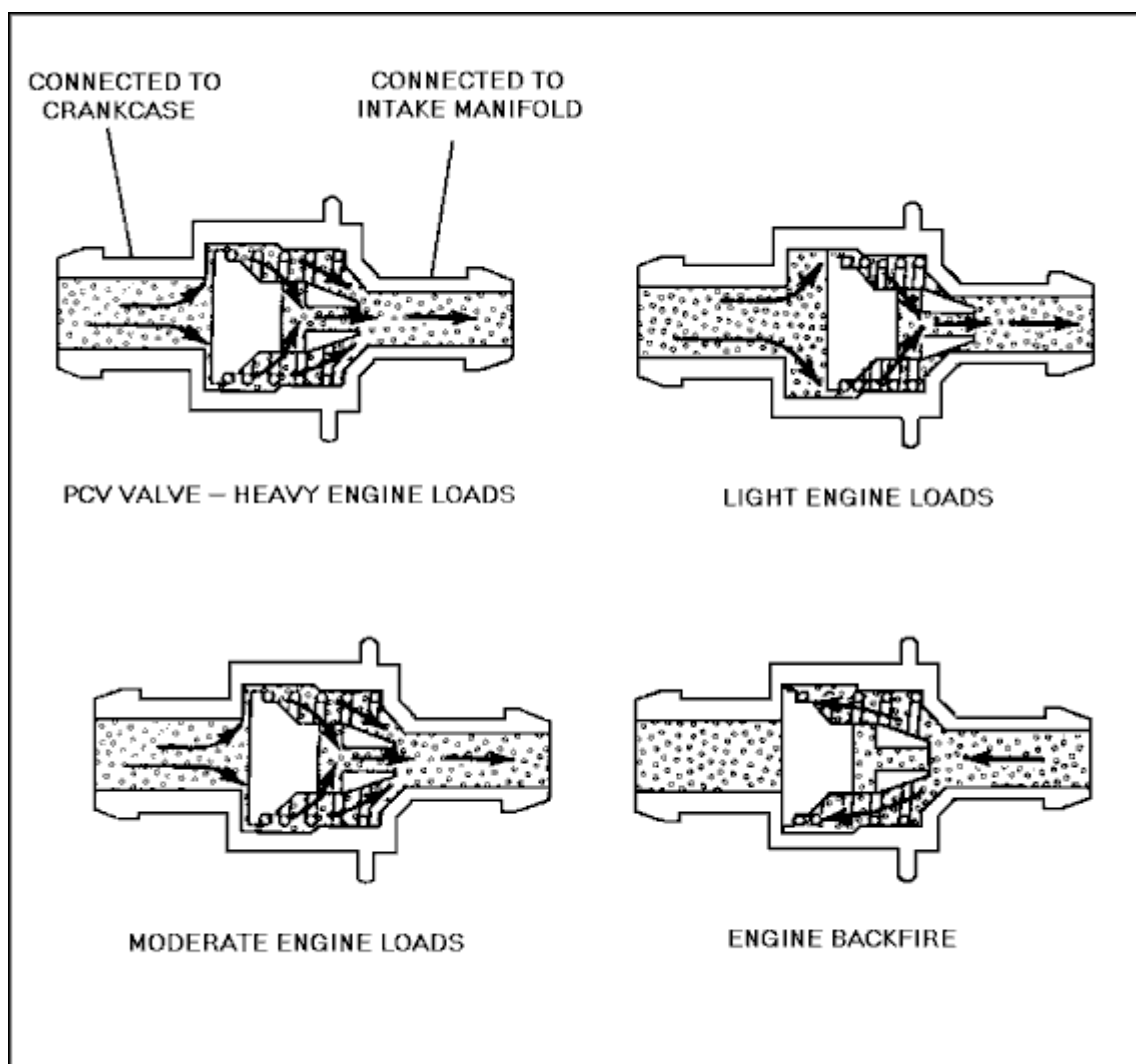


FIGURE 66. PCV VALVE.

This valve is normally held open by a spring, but high manifold vacuum will cause the valve to close. When the valve is closed, the amount of air entering the manifold from the crankcase ventilator system is reduced to prevent diluting or cleaning out the fuel-air mixture from the carburetor.

It is very important to remember that neither type of crankcase ventilation system can remove liquids. Gasoline and water in the crankcase cannot be removed unless they are changed from a liquid to a gas. For this reason, the engine must get hot enough to change these liquids into a gas. Engines that are operated without proper warm-up, or are used for short runs only, will soon have a crankcase full of sludge. If the thermostat in the cooling system opens too soon or if it is stuck open, the engine will not get hot enough to vaporize the water and gasoline. To keep the lubricating oil clean, the engine must get hot!

All military vehicles use the positive crankcase ventilation system. Since 1965, federal law requires that all new automotive vehicles manufactured or sold in this country use this system. The positive crankcase ventilation system is part of the emission control system for vehicles which reduces the pollution in the air we breathe.

Learning Event 3:

DESCRIBE MAINTENANCE PROCEDURES FOR ENGINE LUBRICATION SYSTEMS

As an automotive repairer, the major problem you will probably have with the engine lubrication system is oil leaks. Such leaks are usually visible, so be thorough when looking for oil leaks. When oil leaks are found, look for the causes. An oil leak is almost certain to develop if things, such as the oil pan bolts or valve cover bolts, are loose. Oil levels too high and clogged crankcase ventilation systems are other major causes for oil leaks. Let's go through a step-by-step procedure for checking the lubrication system on an Army truck. The procedures described here are for the M151 1/4-ton truck, but most of the procedures will apply to any automotive vehicle.

First, check the level and condition of the oil. If you find the oil level too high, check the level of the coolant in the radiator. Unless the vehicle driver put too much oil in the crankcase, the most likely cause of a high oil level is water leaking from the cooling system into the oil.

If the coolant level in the radiator is low, allow the vehicle to sit without the engine running for awhile, and then remove the oil drain plug slowly. If there is water in the crankcase, it will run out first, because water is heavier than oil and will settle to the bottom of the oil pan sump. Water from the cooling system usually gets into the oil pan by a leaking cylinder head gasket.

Of course, if the engine has been running, the oil and water will be mixed. The water may give the oil a milky color or if the oil is cold it will be sludgy. Oil mixed with water also has a different feel when rubbed with the fingers than plain oil.

In checking for oil leaks, look for drops of oil on the floor under the engine. Then examine all possible places the oil may leak out. In addition to such places as the oil pan, timing gear cover, valve pushrod cover, and valve rocker arm cover gaskets, oil can leak out around the oil filter, vacuum booster pump, oil gage, and any external oil lines. The crankshaft oil seals can also leak. Oil leakage around the front crankshaft oil seal will probably be thrown all over the front of the engine by the crankshaft pulley. The fan belts will probably be oil soaked, too.

Oil leaking around the rear main bearing oil seals usually soaks the clutch disk facing and drips out through the drain hole in the bottom of the engine flywheel housing.

If oil has to be added to an engine too often but no leaks are found, the oil is being burned. The most likely causes of oil burning are worn or broken rings, worn or scored pistons or cylinder walls, loose bearings, worn intake valve guides or leaking valve seals (intake valves only), and leaking vacuum booster pump diaphragm.

If an engine is burning oil, it usually shows up in the exhaust as smoke. When oil is being burned in the combustion chamber, the exhaust smoke will have a bluish color. Locating the causes of an engine using too much oil is described in the lesson on engine inspection and testing.

All of the engines used in the Army's wheeled vehicles are equipped with oil filters. Some use the full-flow type, while others are equipped with the bypass type. The full-flow filter most commonly used is the throwaway type.

The oil pressure gages used on the military wheeled vehicles are operated electrically. Procedures for testing these gages are described in the lesson on wheeled vehicle electrical systems.

All Army wheeled and tracked vehicles use the positive crankcase ventilation system. The air that circulates through the crankcase enters the engine through a filter on the breather tube or through the air cleaner. In either case, be sure the filters are clean or that the oil is at the proper level in oil bath filters.

Some engines have a shutoff valve on the air filter in the breather line. Be sure this valve is open at all times except during fording operations.

Anytime oil is leaking out of the engine by the front or rear crankshaft oil seals, always suspect the crankcase ventilation system. If the ventilation system is clogged, enough pressure can be built up in the crankcase to blow the crankshaft oil seals.

If a large amount of sludge is found in the breather pipe, vent lines, or in the ventilator valve, check the cooling system--especially the thermostat. Remember the engine must get hot enough to vaporize the water and fuel that gets onto the crankcase. If the engine thermostat opens too soon (at a low engine temperature), sludge is sure to form in the crankcase and breather lines.

Proper care of the lubrication and ventilation systems can lengthen the life of the engine. If care is not given to these systems, you can expect to replace a lot of engines. A practice task list is included with this lesson. Practice as many of the tasks as you can.

PRACTICE EXERCISE

1. A passage is drilled in the connecting rod between the rod bearing and piston pin with which type of lubrication system?
 - a. Full-force feed
 - b. Force feed
 - c. Splash

2. Under what conditions does the oil bypass valve open?
 - a. When the oil filter is clogged
 - b. When the oil pump becomes worn
 - c. When the relief valve closes

3. During which two strokes of the piston is blowby most likely to occur?
 - a. Intake and exhaust
 - b. Power and exhaust
 - c. Compression and power

4. If an engine is burning oil, the exhaust smoke will usually have a
 - a. black color.
 - b. bluish color.
 - c. whitish color.

5. Which is the most likely cause of water in the engine oil?
 - a. Leaking head gasket
 - b. Cracked piston
 - c. Worn piston rings

ANSWERS TO PRACTICE EXERCISE 4

1. a (page 99)
2. a (page 108)
3. c (page 112)
4. b (page 119)
5. a (page 118)

LESSON 5 ENGINE COOLING SYSTEMS

TASK

Describe the principles of engine liquid-cooling systems.

CONDITIONS

Given information about the fundamentals of liquid-cooling system components, and inspecting, testing, and repairing representative engine liquid-cooling systems.

STANDARDS

Solve 70 percent of the multiple-choice test items covering engine liquid-cooling systems.

REFERENCES

TM 9-8000

Learning Event 1:

DESCRIBE THE PRINCIPLES OF OPERATION AND COMPONENTS OF LIQUID-COOLING SYSTEMS

All internal combustion engines have some type of cooling system because of the high temperatures created during their operation. The heat is produced both by friction and burning of fuel, with the largest amount being caused by the burning of fuel. There is no sure way of telling just exactly how hot it gets inside the combustion chamber of an engine, but it is thought to be about twice the temperature at which iron melts. Therefore, if an engine is not cooled, the valves will burn and warp, lubricating oil will break down, pistons and bearings will overheat, and pistons will seize in the cylinders.

The engine cooling system is called upon to carry away about one-third of the heat inside the combustion chambers.

Usually, a cooling system works by moving a liquid over the hot cylinder and combustion chamber walls. The liquid absorbs heat and carries it away. This is a liquid-cooling system.

Sometimes a cooling system uses no liquid. Instead, air is moved over the hot walls of the cylinders and combustion chambers to carry away heat. This is an air-cooling system.

SOME HEAT IS NEEDED

At the same time, the engine must not be allowed to run too cold either. An engine running too cold does not burn all the fuel taken into the combustion chambers and will cause a lot of sludge to form in the crankcase. This causes poor gasoline mileage, forms carbon deposits, increases wear, and cuts down on engine power.

JOBBS OF THE COOLING SYSTEM

The cooling system does three jobs to provide a satisfactory temperature operating range for the engine. First, it removes the unwanted heat. Second, it regulates the engine temperature to keep it just right during all operating conditions. Last, when the engine is first started, it makes the engine warm up to its normal operating temperature as soon as possible.

METHODS OF COOLING

Fuel, Oil, and Exhaust

Although they are not ordinarily thought of as being a part of the cooling system, the fuel, lubrication, and exhaust systems help a lot toward cooling the engine. The repairer must not overlook these systems as trouble here may appear to be problems in the cooling system.

Fuel. When fuel enters the engine, it is cool; therefore, it absorbs or soaks up a lot of the heat. You can get an idea of just how cool the fuel is when it enters the engine by feeling the carburetor throttle body on an engine that is running. The throttle body will feel cool, even though the engine is hot.

Oil. Lubricating oil helps to keep the engine running cool in two ways. First, it prevents a lot of heat from being produced by friction. Second, it absorbs and carries heat away from parts, such as the pistons and cylinder walls, as it comes in contact with them.

Exhaust. The exhaust system aids cooling by carrying hot exhaust gases away from the engine. You have probably already noticed how hot the exhaust is that comes out of the exhaust system on a vehicle. All three of these methods put together do not even come close to cooling the engine as much as needed. The rest of the unwanted heat is carried away by the cooling system.

LIQUID-COOLING SYSTEM

At sometime, everyone has cooled something that was too hot by either blowing on it or pouring water over it. Both of these two methods are used in liquid-cooling systems. For a more detailed understanding of how this is done, let's discuss the different parts of the cooling system.

Coolant Jacket

You could think of a basic engine as each cylinder and combustion chamber being a separate part, and then all of them enclosed by one container. Thus, if the container is filled with water, the cylinders and combustion chambers would be completely surrounded by a jacket of coolant.

In actual practice, the engine block contains the cylinders which are surrounded by coolant passages. The combustion chambers in the cylinder head also have coolant passages all around them. Coolant transfer ports in the block, head, and head gasket align when the head is bolted to the block so the coolant can flow between the block and head. When coolant is placed in these passages, the cylinders and combustion chambers are then surrounded by a jacket of coolant, generally known as a water jacket.

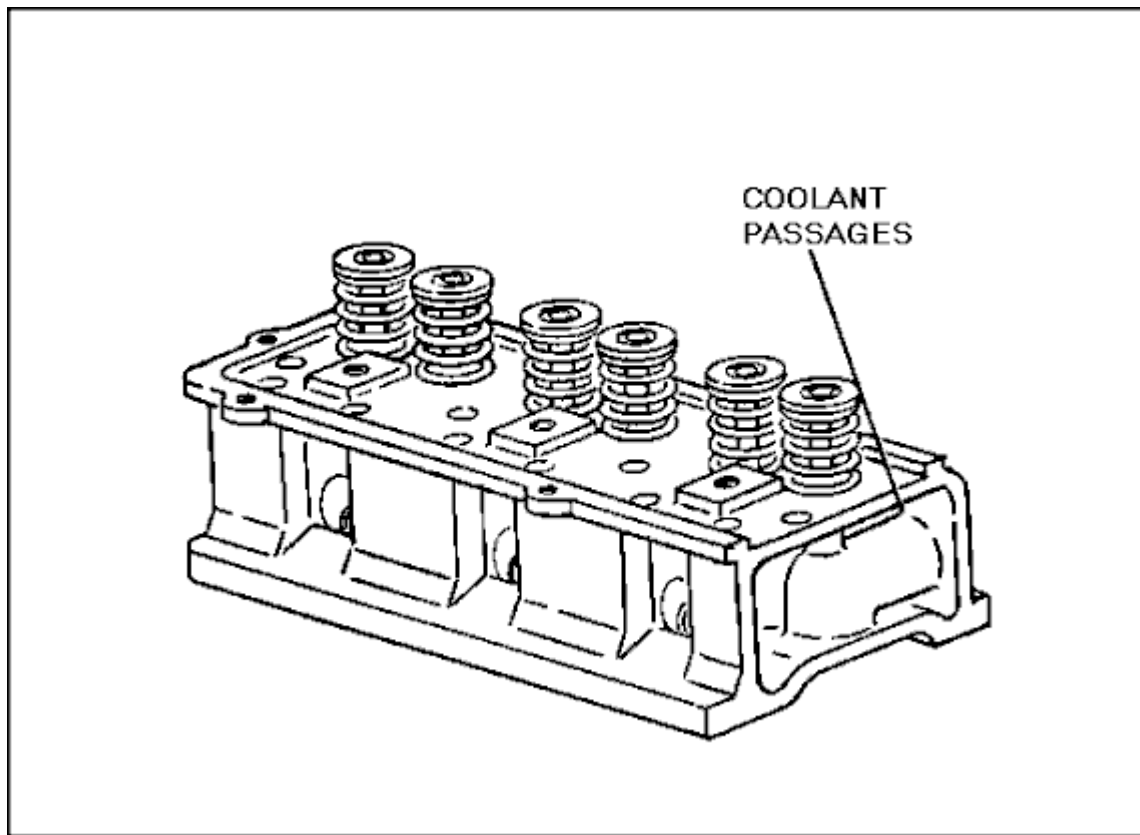


FIGURE 67. CYLINDER HEAD COOLANT JACKET.

The pistons, valves, and walls of the combustion chambers and cylinders absorb the heat of the burning fuel. Heat in the combustion chamber and cylinder walls is then passed into the jacket of coolant. The hot pistons are cooled by passing heat into the coolant-filled cylinder walls. Heat from the valves is passed into the valve guides and valve seats and then into the coolant jacket.

If the jacket of coolant remains still, it will absorb just so much heat and then begin to boil away. Therefore, the heated coolant must be moved away and replaced.

Coolant Pump

A pump is used to move the coolant in the engine. The pump, generally known as a water pump, is usually located on the front of the engine block. The system is designed so the pump forces coolant into the coolant jacket in through the block and out through the head. The output of the coolant pump and coolant jacket passages must be designed so that all of the heated coolant is moved. If coolant is allowed to stand still in some places, uneven cooling or hot spots will develop.

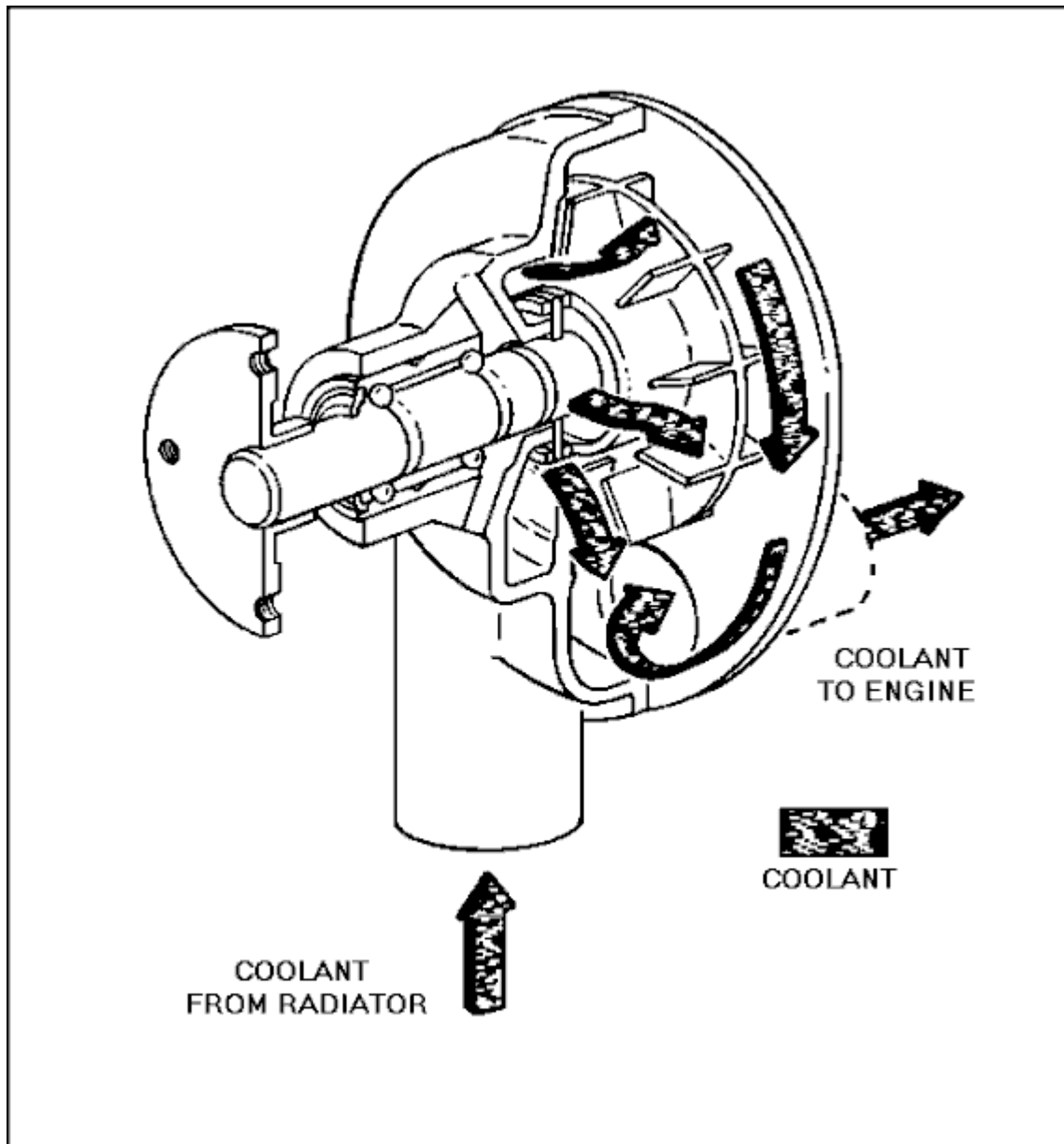


FIGURE 68. COOLANT PUMP CONSTRUCTION.

Automotive engines usually use a centrifugal (impeller) type pump that consists of a round plate which has blades or vanes on one side of it. The plate, or impeller as it is usually known, is fastened to a turning shaft. As the impeller turns, its blades will throw coolant outward.

The pump is completed by placing the impeller in a closed housing that has a coolant inlet at the center of the impeller and an outlet at its outer edges. On some pumps, the impeller may be placed directly into the coolant jacket of the engine instead of being enclosed in the pump housing. Then the cylinder block will serve as a part of the pump housing.

The impeller shaft turns on bearings in the housing and has a pulley attached to its outer end. A seal assembly prevents coolant from leaking out by the impeller shaft.

The pump is driven by a V-type belt that generally fits in the pulleys on the crankshaft, generator, and coolant pump.

Radiator

It is not enough just to pump coolant out of an engine and back into it again. When the coolant leaves the engine, it is quite hot. If this hot coolant was pumped right back into the engine, all the coolant would start to boil soon. Therefore, before the coolant can be used again, it must be cooled. This is the job of the radiator.

A radiator has two tanks or containers connected by a center section called the core. The top tank contains an inlet, a filler opening, and an overflow tube. The bottom tank has an outlet and drain openings. A frame for mounting the radiator in the vehicle is soldered to the upper and lower tanks.

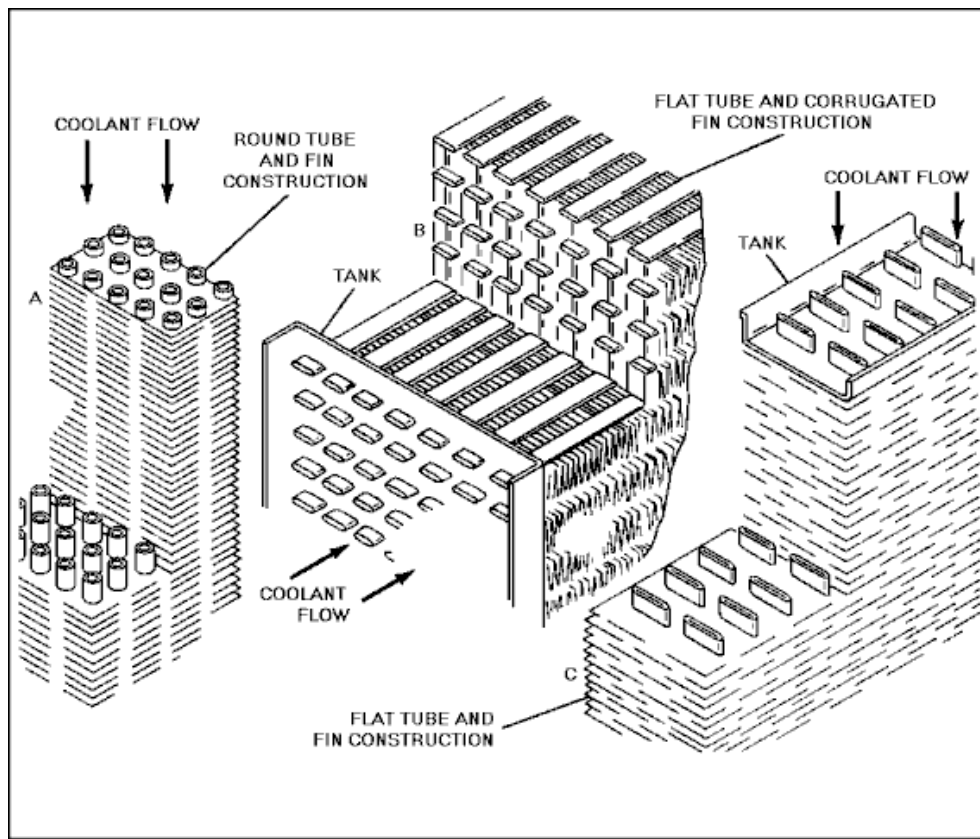


FIGURE 69. ENGINE RADIATOR CONSTRUCTION.

Almost all radiators in use at this time have cores that are made up of a lot of tiny tubes. These tubes are coolant passages between the upper and lower tanks. The tubes have thin copper air fins soldered over their entire length. This type of construction makes it possible for air to pass between the tubes and fins.

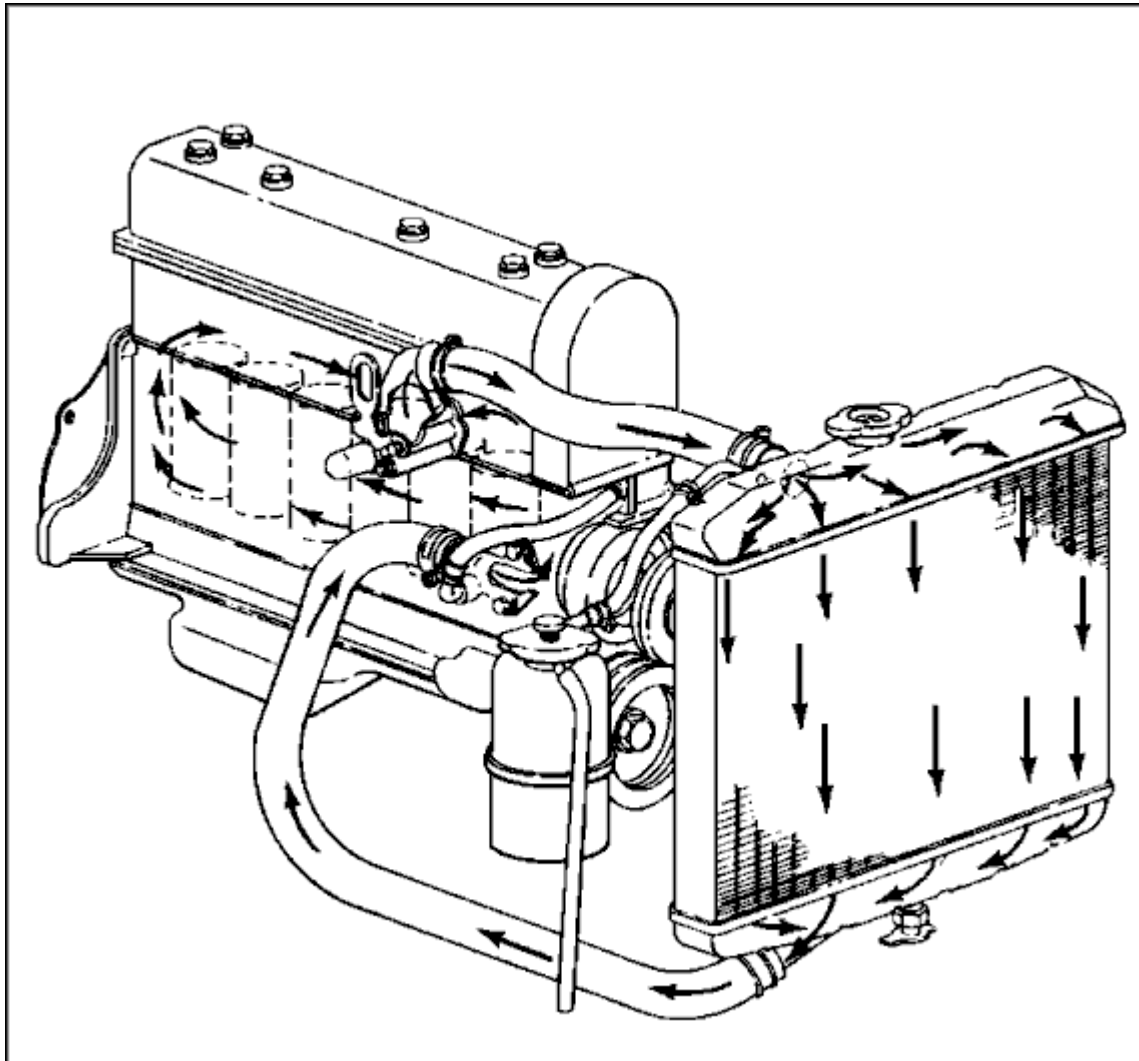


FIGURE 70. COOLANT FLOW THROUGH RADIATOR.

The radiator is usually mounted in the front of the engine compartment so cool air can pass freely through the core. The outlet on the bottom radiator tank is connected to the coolant pump inlet. The top tank inlet of the radiator is then connected to the outlet at the top of the engine. Rubber hoses and hose clamps are used to make these connections to prevent engine vibrations from being transferred to the radiator.

Hot coolant is pumped out the top of the engine into the top radiator tank. It flows from the top tank through the tubes in the core to the bottom tank. As the coolant makes its way down the tubes, it gives off heat to the tubes. The heat is then transferred to the air fins and finally to cooling air as it passes between the fins. By the time the coolant reaches the bottom radiator tank, it is cool enough to reuse in the engine. The coolant pump draws the coolant from the bottom tank and forces it back into the engine.

Fan

A fan is used to draw air through the radiator core to speed up the cooling action of the radiator. The fan also blows air on the engine to provide some direct air cooling of the engine. The fan is generally bolted to, and turns with, the coolant pump shaft. In this way, the coolant pump and fan are driven by the same belt.

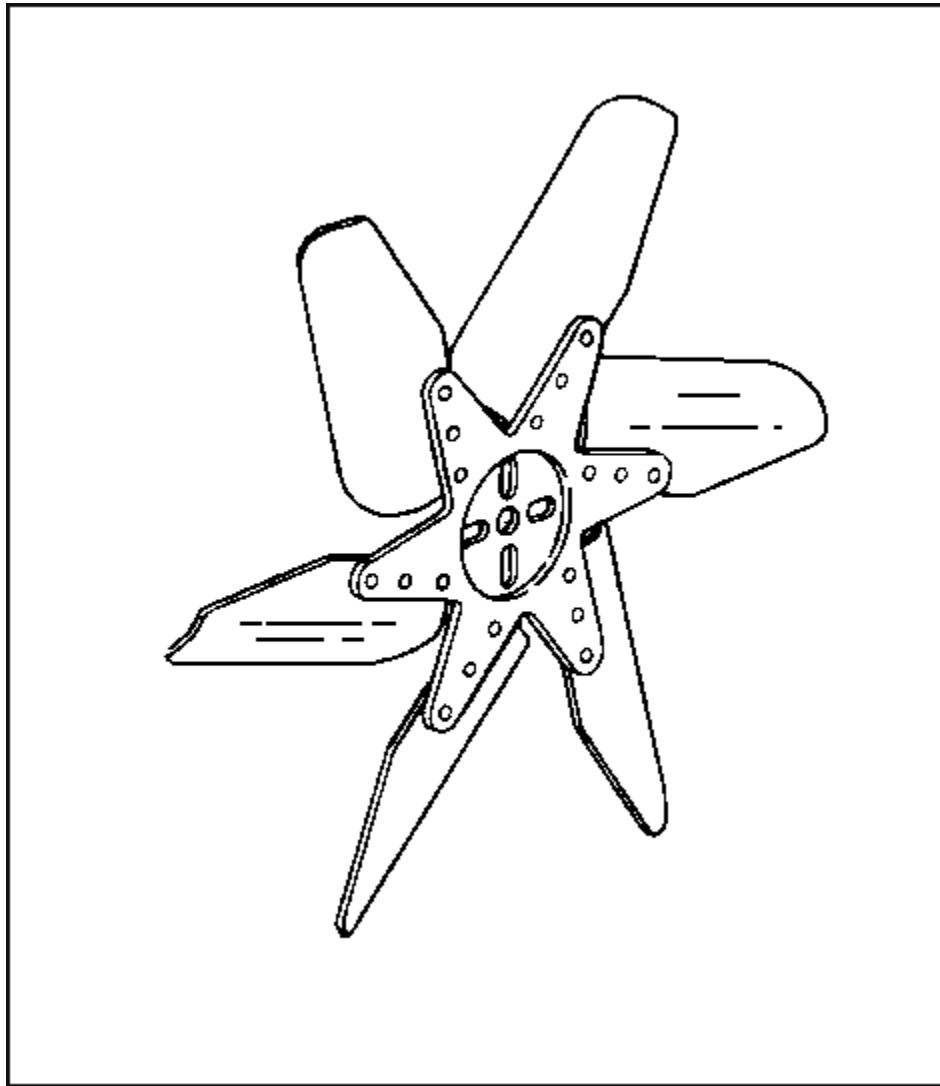


FIGURE 71. COOLING FAN.

Usually the fan blades are not all equally spaced around its hub. This is so the noise made by each blade will not be the same. If all the blades made identical noises, they would add together to make one loud noise. But by making noises slightly different (different pitch), they do not add together; therefore, the fan sounds quieter.

If the fan is set very far from the radiator, some air is drawn into the fan from its sides without going through the radiator core. This reduces the amount of air flowing through the core and the amount of engine cooling. Some vehicles have a funnel-shaped part known as a shroud to prevent the air from bypassing the radiator. The larger end of the shroud is generally bolted to the radiator frame with the smaller end extending out to enclose the fan.

Thermostat

The coolant jacket, radiator, coolant pump, and fan work together to remove unwanted heat from the engine. But the system, as studied so far, would cool the same amount all the time. The cooling system must be able to vary the amount of cooling it does to reduce the amount of warm-up time and to regulate engine

temperature. A thermostat valve is installed in the cooling system to provide this feature.

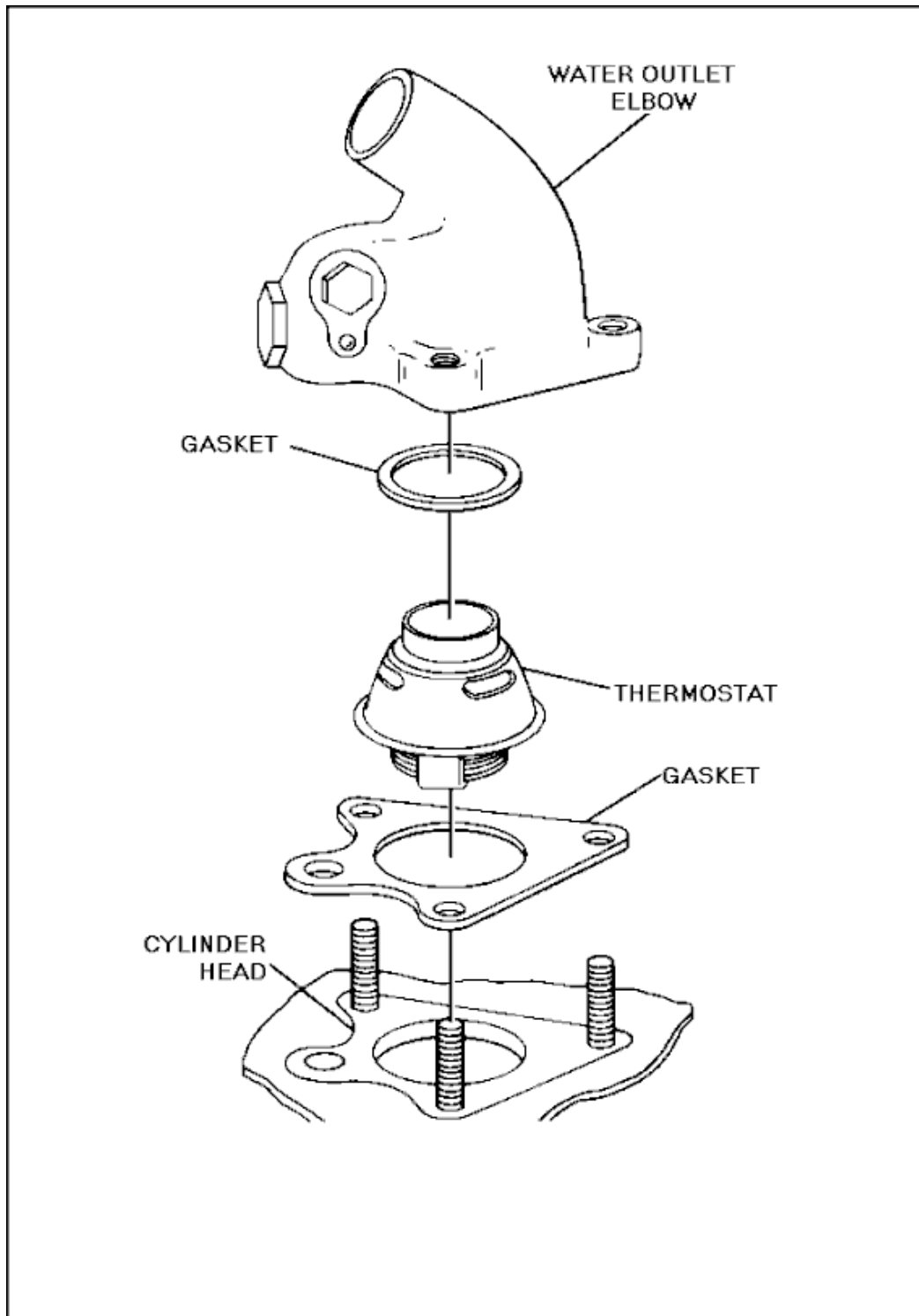


FIGURE 72. THERMOSTAT AND HOUSING.

The thermostat is generally placed under the coolant pump outlet on the engine. Coolant outlets are bowl-shaped on the bottom to house the thermostat and are sometimes known as the thermostat housing.

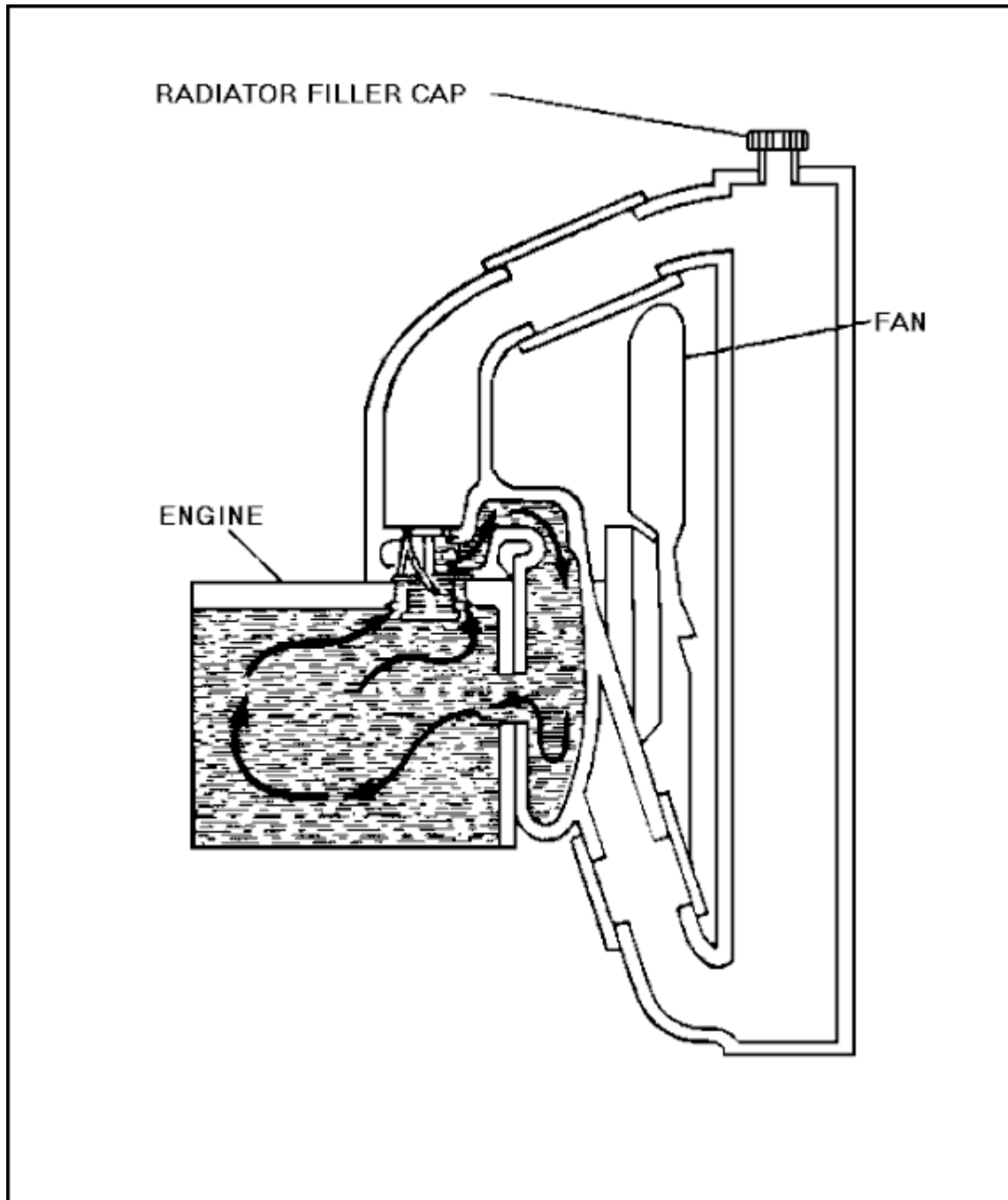


FIGURE 73. COOLANT FLOW - THERMOSTAT CLOSED.

When the engine is cold, the thermostat shuts off the flow of coolant from the engine to the radiator. This causes the engine to heat up quickly. However, if the coolant is allowed to stand still in the engine at this time, hot spots may occur and the engine will not warm up evenly. Engines have a bypass passage that allows coolant to be pumped through the engine without going through the radiator to prevent this.

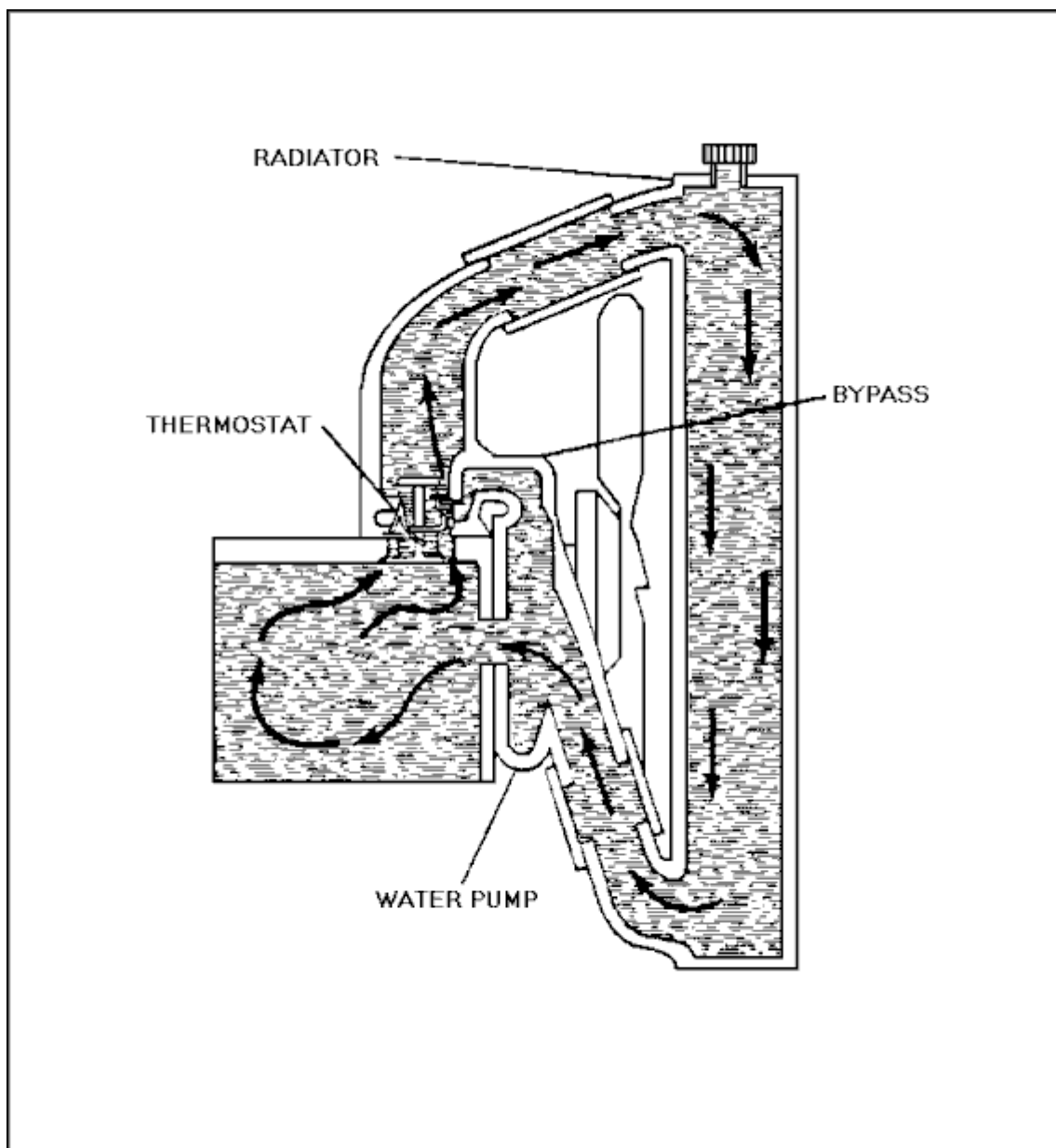


FIGURE 74. COOLANT FLOW - THERMOSTAT OPEN.

When the proper engine operating temperature is reached, the thermostat valve opens and allows coolant to flow through the radiator. If the weather is cold or if the engine is operating at less than full power, the thermostat does not open up all the way. It will allow just enough coolant to flow through the radiator to keep the engine at the proper temperature. When the engine load changes, the thermostat valve opening changes, providing just the amount of cooling that is needed.

Two kinds of thermostats in common use are the bellows and pellet type. Both types operate on the same principle; the difference is in the unit that opens and closes the valve. The bellows type consists of a flexible metal bellows attached to a valve. The sealed bellows is filled with a liquid such as ether. When the liquid is cold, the bellows is contracted so the valve is closed. When heated, the liquid turns to a vapor and expands the bellows, opening the valve. This thermostat is sensitive to outside pressure, so it does not work very well if the cooling system is pressurized.

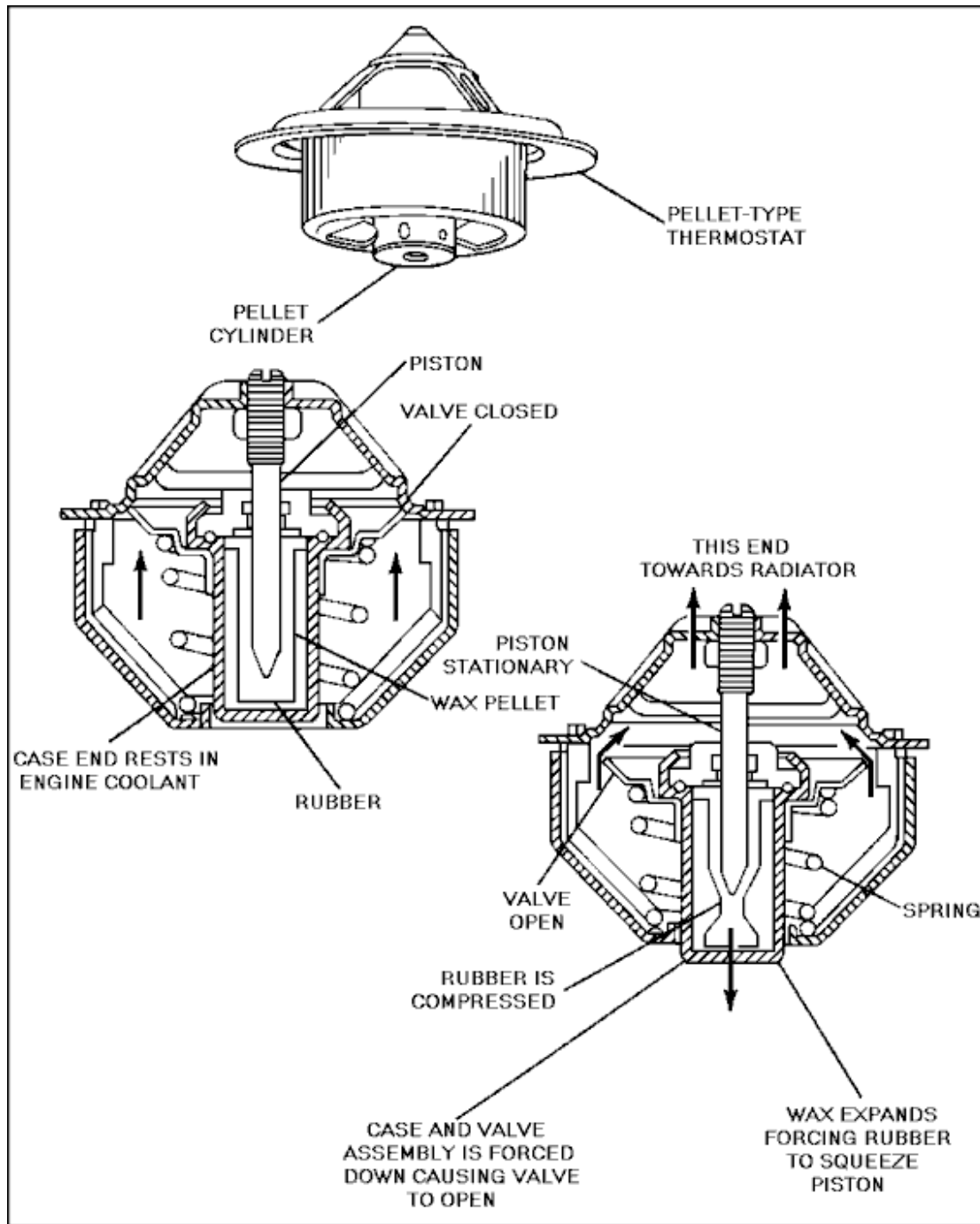


FIGURE 75. PELLET-TYPE THERMOSTAT.

The pellet-type thermostat is also commonly known as a cartridge- type thermostat. It has a small cylinder containing a special paste. When the paste is heated, it expands, pushing a piston

out of the cylinder to open the thermostat valve. Tension to hold the valve closed is supplied by a spring. The pellet-type thermostat is not sensitive to pressure, so it works well in a pressurized cooling system.

Thermostats that are used in military vehicles generally start to open at about 180°F of coolant temperature. This may vary a little from one engine model to another, depending on the engine design. However, the boiling point of the coolant must always be considered when determining just how hot the engine should run. If the coolant is allowed to boil, it will turn to steam and lose its cooling qualities. Therefore, the coolant temperature must always be kept safely below its boiling point (water boils at 212°F at sea level).

When military vehicles are used in extremely cold climates, they are generally equipped with a radiator cover to help the thermostat raise the engine temperature. The radiator cover may be a piece of canvas or it may be metal shutters. Either type of cover can be closed varying amounts to reduce the amount of cooling air that flows through the radiator core.

Pressure Radiator Cap

It has been found that increasing the amount of pressure on water will raise its boiling point. Therefore, most liquid-cooled engines are designed to operate with a pressure in the cooling system to provide a greater difference in the coolant boiling point and operating temperature. Each pound of pressure on the water in the cooling system will raise the coolant's boiling point about 3°. The pressure is regulated by a pressure-type cap on the radiator.

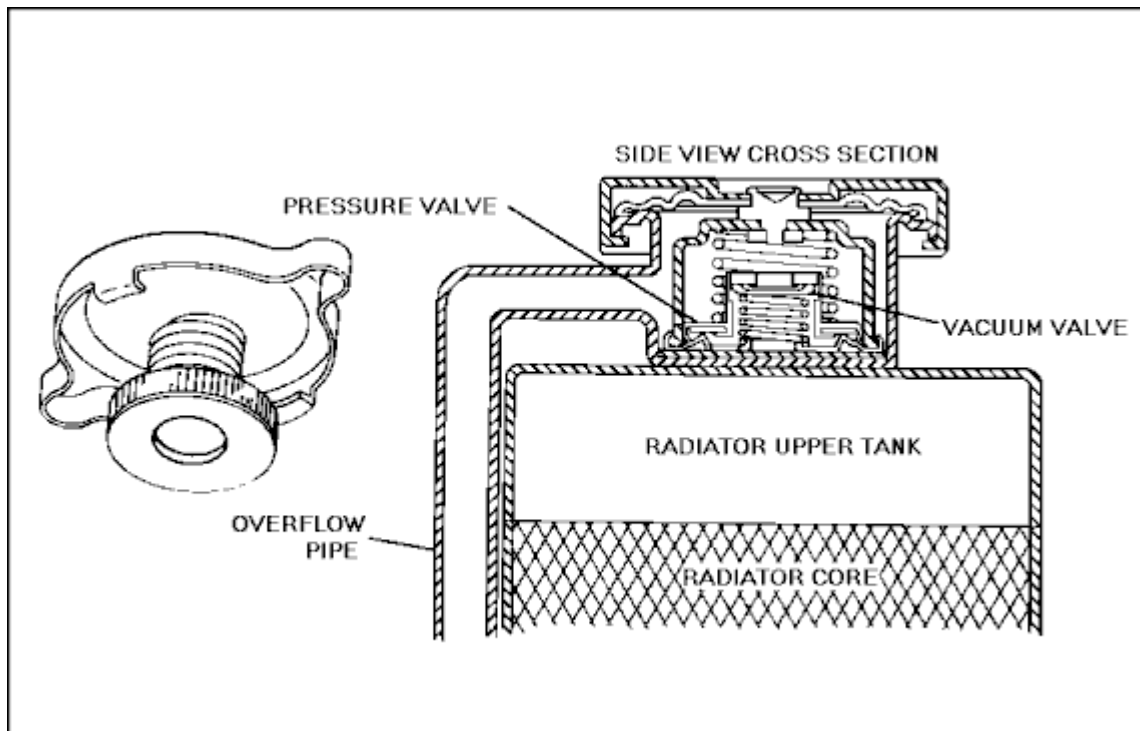


FIGURE 76. PRESSURE RADIATOR CAP.

The pressure radiator cap has two spring-loaded valves that are normally in the closed position. The largest of the two valves is the pressure valve, and the smaller is a vacuum valve. When the cap is installed in the radiator filler neck, it seals at the bottom as well as at the top of the filler neck.

When the engine is cold, there is no pressure in the cooling system. As the water in the cooling system warms up, it expands. Since the cooling system is sealed by the cap, the water expansion causes pressure to build up. When the pressure builds up enough to overcome the spring tension holding the pressure valve closed, it lifts the valve. The excess pressure escapes by the pressure valve and out through the radiator overflow pipe. The amount of pressure the cooling system is able to build up depends on the strength of the pressure valve spring. In some vehicles as much as 15 PSI is developed in the cooling system.

The vacuum valve in the cap operates after the engine has been stopped and begins to cool off. As the water cools, it contracts, forming a vacuum or low pressure in the cooling system. When the vacuum gets great enough, normal air pressure entering the overflow pipe forces the vacuum valve off its seat and flows into the cooling system. If a vacuum valve was not used, the hoses and perhaps the radiator tanks would be drawn together by the vacuum.

Expansion Plug

You will not work on many cooling systems before coming in contact with the expansion plugs. These plugs are commonly known by such names as core hole plugs or freeze plugs. Actually, they are metal plugs that are driven into, and seal round core openings in, the outside wall of the engine coolant jacket.

The core openings in the coolant jacket of the cylinder block and head are necessary for the casting process when the block and head are being manufactured. But once they have been built, the openings have no further use, so they are plugged with the expansion plugs.

Expansion plugs may be forced out of the openings if the water freezes in the coolant jacket. However, they cannot be depended upon to keep the engine from cracking in case of a freeze-up.

Temperature Sending Unit

A temperature gage sending unit is installed in the cylinder head or some other part at the top of the engine that contains water passages. On combat vehicles an electrical-type unit is used. Electrical units always have a wire attached and are screwed into a hole tapped into a coolant passage. The sending unit has a heat-sensitive element that extends into the coolant. The element senses the temperature and sends corresponding electrical signals to the temperature gage.

Coolant Solutions

It is not a good practice to operate a vehicle with water alone in the cooling system. If just plain water is used, parts in the cooling system will rust and corrode, causing leaks and plugging small passages. Also, in cold weather water will freeze, which may crack the engine block and radiator.

In the summertime when there is no danger of freezing, plain water with a rust inhibitor added is used. The inhibitor will reduce or prevent rusting and corrosion, but it will not remove rust or corrosion that has already formed.

In the wintertime when the temperature falls below 32°F, an antifreeze solution must be used in the cooling system to prevent freeze-up. A rust inhibitor is included in the antifreeze mixture, so it is not necessary to add the inhibitor too. Ethylene glycol and an arctic-type solution are two types of antifreeze issued for use by the military.

The ethylene glycol antifreeze must be mixed with water at the time of installation to lower the freezing point of water. The best protection from freezing can be obtained from a mixture of 40 percent water and 60 percent ethylene glycol antifreeze. This lowers the freezing point to -65°F. Although it may sound odd to you, adding either more or less ethylene glycol to this mixture will raise the freezing point. Ethylene glycol antifreeze solutions are used where the temperature is not expected to go lower than -55°F.

In arctic climates where temperatures often go lower than -55°F, the arctic-type antifreeze is used. It provides freeze-up protection to -90°F. Arctic-type antifreeze is premixed at the factory and is used full strength. It should never have water or any other type of antifreeze added to it.

Other types of antifreeze containing alcohol or glycerin are made, but they should never be used in a military vehicle unless it is an emergency. If they are used, they must be drained at the first opportunity and replaced by an ethylene glycol or arctic-type antifreeze. Alcohol and glycerin antifreeze will boil and evaporate at a low temperature very close to that of the engine's normal operating range. To use them, you must mix them with water at the time of installation.

Learning Event 2:**DESCRIBE MAINTENANCE AND TROUBLESHOOTING PROCEDURES OF LIQUID-COOLING SYSTEMS**

The inspection procedures for the cooling system are about the same for all vehicles. But repair procedures vary a great deal. You should always refer to the technical manual for the vehicle you are working on for specific procedures and specifications. When you are working on the cooling system of a vehicle, you will probably inspect the complete system before making any repairs. But in this lesson, let's discuss the inspection, repair, and replacement of parts, one part at a time, to prevent confusion and repetition.

Radiator

Examine the radiator for proper coolant level, leaks, blocked air passages, secure mounting, and plugged overflow. White, rusty, or colored stained spots indicate a leak. If plain water is used as the coolant, these spots may not be damp as water evaporates quickly when it is hot. If an ethylene glycol antifreeze is used, small leaks are more likely to be damp as this type of antifreeze does not evaporate. The radiator should be replaced if any leaks are found.

When coolant is lost from the cooling system, refill it to check for leaks. But if the engine is overheated, do not just pour in cold water right away. Allow the engine to cool, or refill the radiator slowly while the engine is running. If cold water is poured into the radiator when the engine is overheated, there is danger of cracking the cylinder block or head.

Remove any leaves, bugs, or other foreign matter in the radiator core or brush guard where it can reduce the amount of cooling air flowing through the core. Foreign matter that is stuck between the radiator cooling fins can be cleaned out with water and compressed air. However, you should not use any water for this until you have checked the complete cooling system for leaks.

Check the radiator mounting for loose or missing bolts. Also check the radiator for being loose where the tanks are soldered to the mounting frame. Tighten or replace any loose or missing bolts. If the radiator-to-mounting-frame soldered joints are loose, the radiator should be replaced or it may be repaired at a higher maintenance level.

If the radiator overflow tube is plugged, too much pressure may build up in the cooling system and cause damage to the radiator or hoses. Check the tube for being plugged by blowing through it with the radiator cap removed. If the tube is stopped up, clear it out by running a flexible wire or an old speedometer cable through it.

Radiator Cap

The radiator pressure cap should seal and regulate the pressure in the cooling system. If the cap fails to seal, pressure will not build up in the system. Without the proper pressure, coolant will be lost through excessive evaporation and boiling. If the cap seals but maintains a pressure that is too high, the radiator and hoses may be damaged.

Always use extreme care when removing the radiator cap from a warm or running engine. In overheated systems the sudden release of pressure when the cap is loosened will cause steam and hot water to boil out. This can burn you very badly. To remove the radiator cap when the engine is hot, place a cloth over the cap for protection. Then turn the cap counterclockwise until a click or notch is felt (about one-quarter turn) to release the trapped pressure. When all the pressure has escaped, press down on the cap and turn it counterclockwise until it can be removed.

The best way to find out if the radiator cap is operating properly is to test it with a pressure tester. The pressure tester consists of a hand pump, pressure gage, and adapters. To use the tester, select an adapter that fits the radiator cap to be tested. Install the adapter and cap on the tester and operate the hand pump. Watch the pressure gage and stop pumping when a higher pressure reading cannot be obtained on the gage.

Watch the gage for a while to see if the pressure bleeds off. If the pressure does bleed off, the radiator cap is leaking and should be replaced. The highest reading obtained on the pressure tester gage is the amount of pressure that the cap will maintain in the cooling system. If this reading does not agree with the radiator cap specifications, replace the cap. The proper amount of pressure varies among the vehicle models, so you must always check the vehicle technical manual for specifications.

If you do not have a pressure tester, make a visual inspection of the radiator cap. Check the rubber sealing surfaces of the pressure and vacuum valves of the cap. Check the valves for freedom of operation. If the cap is damaged or worn in any way that will prevent it from sealing or operating, replace it.

To further ensure that the radiator cap will seal, clean the radiator filler neck and examine it for damage. Install the cap by placing it on the radiator filler neck and turning it clockwise as far as it will go. If the cap fits properly, two distinct clicks or notches can be felt as it is being turned.

Hoses

Radiator hoses should be examined for leaks, condition, and proper installation. If the hose connections are leaking, tighten the hose clamps and recheck for leaks. Hoses that are collapsed, cracked, or have a soft spot should be replaced. Ensure that the hoses are positioned so they do not rub against other parts. All clamps and hoses should be installed over the connections far enough to provide secure fastening. The normal pressure in the cooling system can blow off improperly installed hoses.

Shroud

If the vehicle is equipped with a shroud, examine it for secure mounting bolts, position, and condition. Replace or tighten any missing or loose mounting bolts. Ensure that the shroud is positioned so the fan will not hit it. If the shroud has any large cracks or is excessively bent, it should be replaced.

Fan Belts

Fan belts must be checked often to ensure that they are in good condition and properly adjusted. Belts that are badly frayed, worn, or cracked should be replaced before they break in operation. When more than one belt is used, they must be replaced in matched sets.

If a belt is adjusted too tight, it will put undue strain on the water pump and generator bearings. If the belt is too loose, it will prevent the water pump and generator from operating properly. This can cause an overheated engine or undercharged batteries.

Coolant Pump

A coolant pump may be defective due to faulty bearings, leaks, or failure to pump. The coolant pump is checked with the engine stopped and then again when it is running.

With the engine stopped, check the pump bearings for looseness by attempting to move one of the fan blades back and forth lengthwise with the pump shaft. Do not exert enough force to bend the fan. Since the fan is bolted to a hub on the coolant pump, any slack felt in the fan is caused by loose bearings on the pump shaft.

Unless the coolant pump leaks bad enough to drip, the leak can be hard to locate. The coolant usually leaks past the pump shaft seal and then escapes through a drain hole in the pump housing. The drain hole is located on the bottom of the housing, and on most vehicles it is covered by the belt pulley. However, it can usually be viewed by using a small mirror or flashlight. Any dampness or water stains left by evaporation around the drain hole indicate a coolant leak.

On some vehicles you can look in the radiator filler neck to see if the pump is operating. Run the engine until the thermostat opens; then look through the filler neck into the radiator. If you see the coolant circulating, the pump is operating. If the radiator inlet or baffles in the radiator tank prevent you from being able to see the circulation of coolant, squeeze the upper radiator hose almost together. Accelerate the engine. If the pump is operating, you can feel the coolant force its way through the hose.

The coolant pump should be replaced if it has loose bearings, is leaking, is noisy, or does not operate.

Thermostat

If the thermostat fails to close, the engine will warm up slowly. If it fails to open, the engine will overheat. When thermostat trouble is suspected, the thermostat should be removed and tested. The thermostat is located at the coolant outlet of the engine.

If the thermostat appears to be in good condition, test it in the following manner. Force the thermostat valve open and place a 0.003-inch thickness gage between the valve and frame. Release the valve. If the valve does not close on the gage tight enough so the thermostat can be suspended by the gage, discard the thermostat.

If the thermostat valve holds onto the gage, place it in water that has been heated to 175°F. If the gage is released, discard the thermostat. If the gage is not released, continue to heat the water. A good thermostat will release the gage when the water temperature is between 177° and 182°F. If the thermostat holds onto the gage above 182°F, discard it.

Cylinder Block and Head

Coolant may be lost through external (outside) or internal (inside) leaks in the engine. External leaks occur at the core hole expansion holes, at gaskets where joints are sealed, and through cracked parts. If coolant leaks internally, it will be into the crankcase or a combustion chamber. Internal leaks usually occur at the head gasket or through a cracked cylinder head or block.

Inspect the engine for external leaks by examining the expansion plugs, the outside surfaces, and the point where the cylinder block and head join. When needed, use a mirror and flashlight to aid in the inspection. Some engines contain expansion plugs that you cannot see because they are in the rear of the cylinder block and are covered by the flywheel housing. If one of these plugs is leaking, the coolant will run out of the drain hole in the flywheel housing cover.

Coolant leaks in the cylinder block and head will be affected by the amount of pressure in the coolant jacket. Pressure is created by the coolant pump as well as by expansion of the coolant when the radiator cap is in place. Also, expansion and contraction of the cylinder block and head, resulting from temperature changes, will affect leaks. For these reasons, check the engine for leaks when it is stopped and cold and then again when it is running and warm.

All leaks must be corrected even though they may appear as no more than a stain spot where leakage has evaporated. A leaking drain cock or pipe plug that cannot be tightened should be replaced. Leaking expansion plugs must be replaced. If tightening gasketed joints will not correct leaks, replace the gaskets.

Since you cannot see internal coolant leaks in an engine, you must detect these leaks by looking for their results instead of the actual leak. Coolant leaking into the crankcase can often be detected by checking the level and condition of the engine oil. Any large leaks will raise the oil level a noticeable amount. Also, if the engine has been operated recently, any coolant in the crankcase will be mixed with the engine oil. Coolant mixed with oil will cause the oil to have a milky color.

On the other hand, if the engine has not been operated for some time, the coolant and oil in the crankcase will separate. The coolant, being heavier than oil, will settle to the bottom of the oil pan. Therefore, to check for coolant in the crankcase when the engine is cold, slowly remove the oil drain plug and watch for any coolant. The results of coolant leaks into a combustion chamber will depend on the size of the leak. A liquid, such as engine coolant, cannot be compressed at ordinary pressure. Therefore, if the leak is large, enough coolant will leak into the combustion chamber to lock the engine as the piston comes up on the compression stroke. When an engine is locked up by any kind of liquid in the combustion chamber, it is referred to as a "hydrostatic lock."

If an engine will not crank and a hydrostatic lock is suspected, remove the spark plugs and then attempt to crank the engine. Any liquid that is trapped in a combustion chamber will be forced out of the spark plug hole, relieving the hydrostatic lock. The cause of the engine lockup should be corrected before the engine is operated.

Small coolant leaks in the combustion chamber may be indicated by white smoke (steam) from the exhaust, loss of coolant, engine overheating, and engine misfiring. To check for a small leak, either remove the thermostat or operate the engine until the thermostat has opened. Remove the fan belts so the coolant pump will not operate, and then fill the radiator all the way to the top.

Operate the engine and look for bubbles in the coolant at the radiator filler neck. If there are any bubbles, there is a leak between a coolant passage and a combustion chamber. The bubbles are caused by pressure leaking from the combustion chamber into the coolant during the compression and power strokes. Do not operate the engine any longer than necessary to make this test as it will overheat very quickly with the fan belts removed.

If the engine has an internal coolant leak, the problem is most likely a faulty head gasket or a cracked cylinder block or head. The cylinder head will have to be removed to determine if these faults exist.

To test the sending unit, first run the engine until it has had time to warm up. If no reading is indicated on the gage, remove the wire from the sending unit and momentarily ground the wire to the engine block. If the gage now indicates, the temperature sending unit is faulty and must be replaced. If the gage still does not indicate, the gage or wiring is probably defective.

If the gage or circuit is defective but still indicates, it will most likely read full scale. When the gage reads full scale, disconnect the wire from the sending unit. If the gage pointer moves all the way to the cold position, the sending unit is defective. If the pointer remains at full scale, the gage or wiring is defective.

PREVENTIVE CLEANING

Sometimes it is recommended that the cooling system be flushed out twice a year—once in the fall when antifreeze is added and again in the spring when antifreeze is drained. Other times flushing may only be done when the coolant is contaminated. At any rate, regular flushing by organizational repairers will reduce clogging and overheating so that corrective cleaning by higher maintenance will not be needed very often. However, anytime the cooling system is clogged enough so that it causes the engine to overheat, turn the vehicle in to higher maintenance for repairs.

Cleaning Compound

To do a good job, you should use a cleaning compound before flushing the cooling system. The cleaner is a very strong acid that will loosen rust, scale, and sludge. The acid will damage cooling system parts if it is allowed to stay in the system, so its use must always be followed by a neutralizer to stop the action of the cleaner. The cleaner and the neutralizer normally come packed in separate compartments of the same container. Always read and use the instructions printed on the cleaner container and in the -20 technical manual for the vehicle you are working on.

Normal Flushing

With the drain cocks closed and the engine temperature below 200°F, fill the cooling system with clean, fresh water. Install the radiator cap and run the engine for about five minutes after it has reached normal operating temperature. Stop the engine and drain the cooling system. If the water is discolored to any extent, repeat this flushing process until it drains clear.

Pressure Flushing

Always flush the cooling system by the pressure flushing method if a flushing gun is on hand. The pressure method is more effective than normal flushing for removing loosened rust and scale. Pressure flushing is done through the system in a direction opposite to the normal coolant flow. This allows the flushing pressure to get behind the deposits, forcing them out.

Coolant Service

The cooling system should never be allowed to stay for an extended time without the protection of a rust inhibitor. This is particularly true just after cleaning as considerable corrosion may take place in a few hours. Use an antifreeze hydrometer to check the amount of protection given by the antifreeze.

After cleaning and flushing a cooling system and the temperature is expected to stay above 32°F, add the amount of inhibitor that is recommended on the inhibitor container or in the technical manual. Start the engine and operate it until operating temperature is reached. This is to open the thermostat valve so the inhibitor will circulate through the entire system. If antifreeze is to be added to the system, do not add the inhibitor.

When the temperature is expected to go below 32°F or if the vehicle is to be maintained combat ready, antifreeze is used. If temperatures are expected to go lower than -55°F, completely drain the cooling system and refill it with arctic-type antifreeze.

If the freezing temperatures are expected to remain above -55°F, fill the cooling system with a mixture of water and ethylene glycol antifreeze. Prepare the mixture according to the protection tables given on the antifreeze containers. Always tie a tag on the radiator, telling how long it is protected.

TROUBLESHOOTING

When you are asked to locate trouble in a cooling system, it will probably be because one or more of the following complaints: the engine overheats, coolant is being lost, or the engine fails to reach operating temperature. Because of the differences in the design of different vehicles, the causes for these complaints may vary. For this reason, you should always refer to the troubleshooting section of the technical manual for the vehicle you are working on.

Engine Overheats

Let's assume that you are trying to locate the cause for an engine overheating in an M151 1/4-ton truck. As you check the truck out, do not be too hasty in deciding that the cooling system is at fault. There are many things other than the cooling system that may cause the engine to overheat.

Outside the cooling system, incorrect ignition timing is a common cause of engine overheating. Therefore, this possibility should be checked out and the timing corrected if needed.

Another cause for overheating, other than the cooling system, is a clogged muffler or exhaust outlet pipes. Recall that the exhaust carries heat away from the engine. If the muffler or pipes are restricted so they fail to carry exhaust and heat away from the engine as they should, replace the clogged parts.

Still another cause for overheating, outside the cooling system, is excessive friction in the power train. This could be anything, such as binding gearboxes or brakes, which will put an excessive load on the engine. In this case, the binding must be located and corrected.

If the overheating is actually caused by the cooling system, one common cause is low coolant level. When the coolant is low, refill the radiator and inspect the system thoroughly for leaks. All leaks must be corrected. Another common trouble that causes overheating is loose or worn fan belts. Always adjust or replace loose or worn fan belts.

A thermostat that fails to open will cause the engine to overheat very quickly. If the thermostat is suspected of being faulty, remove and test it.

Anything that blocks or reduces airflow through the radiator core will cause overheating. Therefore, you should always check for and remove any obstructions that may restrict the flow of cooling air.

If the coolant pump does not pump, the coolant will not flow through the system well enough to keep the engine cool. The coolant pump will fail to operate if the impeller comes loose from the pump shaft or the shaft breaks. This may happen if the engine is started and the coolant is frozen. In any event, if the pump does not operate it must be replaced.

Loss of Coolant

If the complaint is that the cooling system is losing coolant, the trouble is most likely caused by a leak. The most likely spots where leaks occur are at the hoses, drain cock, cylinder head gasket, radiator cap, coolant pump, radiator, and cracks in the cylinder head or block. When a leak cannot be stopped by tightening, the leaky part must be replaced.

Engine Fails to Reach Operating Temperature

The temperature gage may not reach the normal operating range in a reasonable time when the engine is started. This could be caused by a faulty thermostat or gage circuit. The thermostat may be faulty or be of the wrong heat range. You would have to remove, inspect, and test the thermostat to check this. If the temperature gage does not indicate any temperature, but the engine gets warm, the trouble will be a defective gage, wiring, or gage sending unit.

In this lesson, the major topics for discussion have been why an engine cooling system is needed; why the engine needs some heat; the three jobs of the cooling system; how fuel, oil, and exhaust aid the cooling system; how the liquid-cooling system parts are constructed and operate; how to inspect and repair cooling system parts; how to do preventive cleaning of the cooling system; and how to troubleshoot the cooling system. If there is any part of the lesson that you do not understand, go back and review that part of the lesson. Then turn to the practice tasks at the end of this lesson and do all of the suggested tasks that you can.

PRACTICE EXERCISE

1. The radiator core consists of
 - a. tubes and fins.
 - b. a tank and baffles.
 - c. an impeller and a housing.

2. What are the two spring-loaded valves in a radiator cap called?
 - a. Pressure and steam
 - b. Hot flow and cold flow
 - c. Pressure and vacuum

3. Small coolant leaks are likely to be moist if the cooling system contains
 - a. arctic antifreeze.
 - b. ethylene glycol.
 - c. plain water.

4. What is indicated if the oil on the dipstick is a milky color?
 - a. Improper grade of oil
 - b. Oil level too low
 - c. Coolant in the oil

5. If an engine does not reach its normal operating temperature, the cause is most likely to be a defective
 - a. coolant pump.
 - b. thermostat.
 - c. head gasket.

ANSWERS TO PRACTICE EXERCISE 5

1. a. (page 129)
2. c. (page 139)
3. b. (page 142)
4. c. (page 147)
5. b. (page 152)