Chapter 3

Construction of an Internal Combustion Engine

Topics

To hear audio, click on the box.

Overview

As a Construction Mechanic, you will benefit from knowledge about the construction of an internal combustion engine and its many moving and stationary parts, including the materials they are made of and their relationship to one another for the engine's smooth and efficient operation.

The information provided in this chapter will also help you both to diagnose malfunctions and to correct the problems. Since the gasoline and diesel engines used in today's construction equipment are basically the same internally, the majority of information provided here applies to both.

Objectives

When you have completed this chapter, you will be able to do the following:

1. Identify the stationary and moving parts of an internal combustion engine.
2. Identify the basic testing procedures used in constructing an internal combustion engine.
3. Recognize operating principles and functions of stationary and moving parts within an internal combustion engine.
4. Understand the techniques used in valve reconditioning.
5. Understand the techniques used in timing gear installation.
6. Understand the techniques used in adjusting engine valves.
7. Recognize basic engine testing procedures and required tools.

Prerequisites

None.

This course map shows all of the chapters in Construction Mechanic Basic. The suggested training order begins at the bottom and proceeds up. Skill levels increase as you advance on the course map.

Automotive Chassis and Body	↑	C
Brakes		M
Construction Equipment Power Trains		
Drive Lines, Differentials, Drive Axles, and Power Train Accessories		
Automotive Clutches, Transmissions, and Transaxles		
Hydraulic and Pneumatic Systems		
Automotive Electrical Circuits and Wiring		B A
Basic Automotive Electricity		S
Cooling and Lubrication Systems		I
Diesel Fuel Systems		C
Gasoline Fuel Systems		
Construction of an Internal Combustion Engine		
Principles of an Internal Combustion Engine		
Technical Administration		

Features of this Manual

This manual has several features which make it easy to use online.

- Figure and table numbers in the text are italicized. The figure or table is either next to or below the text that refers to it.
- The first time a glossary term appears in the text, it is bold and italicized. When your cursor crosses over that word or phrase, a popup box displays with the appropriate definition.
- Audio and video clips are included in the text, with italicized instructions telling you where to click to activate it.
- Review questions that apply to a section are listed under the Test Your Knowledge banner at the end of the section. Select the answer you choose. If the answer is correct, you will be taken to the next section heading. If the answer is incorrect, you will be taken to the area in the chapter where the information is for

review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.

- Review questions are included at the end of this chapter. Select the answer you choose. If the answer is correct, you will be taken to the next question. If the answer is incorrect, you will be taken to the area in the chapter where the information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.

1.0.0 ENGINE CONSTRUCTION

The construction of an engine varies little, regardless of size and design. The intended use of the engine determines its size and design, and the temperature at which the engine will operate determines the type of metal it will be built from.

To simplify the service parts and servicing procedures in the field, the current trend in engine construction and design is toward *engine families*. Typically, there are several types of engines because of the many jobs to be done; however, the service and service parts problem are simplified by designing engines so they are closely related in ***cylinder*** size, valve arrangement, and so forth. For example, the GM series 71 engines can be obtained in two-, three-, four-, and six-cylinder in-line models. GM V-type engines come in 6-, 8-, 12-, and 16-cylinder models. These engines are designed in such a way that many of the internal parts can be used on any of the models.

1.1.0 Stationary Parts of and Engine

The stationary parts of an engine include the cylinder block and cylinders, the cylinder head or heads, and the exhaust and intake manifolds. These parts furnish the framework of the engine. All movable parts are attached to or fitted into this framework.

1.1.1 Engine Cylinder Block

The cylinder block is the basic frame of a liquid-cooled engine whether it is in-line, horizontally opposed, or V-type. The cylinder block is a solid casting made of cast iron or aluminum that contains the crankcase, the cylinders, the coolant passages, the lubricating passages, and, in the case of flathead engines, the valves seats, the ports, and the guides.

The cylinder block is a one-piece casting usually made of an iron alloy that contains nickel and molybdenum. This is the best overall material for cylinder blocks. It provides excellent wearing qualities and low material and production cost, and it changes dimensions only minimally when heated. Another material used for cylinder blocks, although not extensively, is aluminum. Aluminum is used whenever weight is a consideration. However, it is **NOT** practical to use for the following reasons:

- Aluminum is more expensive than cast iron.
- Aluminum is not as strong as cast iron.
- Because of its softness, it cannot be used on any surface of the block that is subject to wear. This necessitates the pressing, or casting, of steel sleeves into the cylinder bores. Threaded holes must also be deeper. This introduces extra design considerations and increases production costs.
- Aluminum has a much higher expansion rate than iron when heated. This creates problems with maintaining tolerances.

1.1.2 Cylinder

The cylinders are bored right into the block. A good cylinder must be round, not varying in diameter by more than approximately 0.0005 inch (0.012 mm). The diameter of the cylinder must be uniform throughout its entire length. During normal engine operation, cylinder walls wear out-of-round, or they may become cracked and scored if not lubricated or cooled properly. The cylinders on an ***air-cooled*** engine are separate from the crankcase. They are made of forged steel. This material is most suitable for cylinders because of its excellent wearing qualities and its ability to withstand the high temperatures that air-cooled cylinders obtain. The cylinders have rows of deep fins cast into them to dissipate engine heat. The cylinders are commonly mounted by securing the cylinder head to the crankcase with long studs and sandwiching the cylinders between the two. Another way of mounting the cylinders is to bolt them to the crankcase, and then secure the heads to the cylinders.

1.1.3 Cylinder Sleeve

Cylinder sleeves, or liners, are metal pipe-shaped inserts that fit into the cylinder block. They act as cylinder walls for the piston to slide up and down on.

Cast iron sleeves are commonly used in aluminum cylinder blocks. Sleeves can also be installed to repair badly damaged cylinder walls in cast iron blocks. There are two basic types of cylinder sleeves, dry and wet.

A dry sleeve *(Figure 3-1)*, presses into a cylinder that has been bored or machined oversize. A dry sleeve is relatively thin and is not exposed to engine coolant. The outside of a dry sleeve touches the walls of the cylinder block. This provides support for the sleeve.

Figure 3-1 – Dry cylinder sleeve.

When a cylinder becomes badly worn or is damaged, a dry sleeve can be installed. The original cylinder must be bored almost as large as the outside of the sleeve. Then, the sleeve is pressed into the oversized hole. Next, the inside of the sleeve is machined to the original bore diameter. This allows the use of the original piston size.

A wet sleeve *(Figure 3-2)*, is exposed to the engine coolant. It must withstand combustion pressure and heat without the added support of the cylinder block. Therefore, it must be thicker than a dry sleeve.

A wet sleeve will generally have a flange at the top. When the head is installed, the clamping action pushes down on the sleeve and holds it in position. The cylinder head gasket keeps the top of the sleeve from leaking. A rubber or copper O-ring is used at the bottom of a wet sleeve to prevent coolant leakage into the crankcase. The O-ring seal is pinched between the block and the sleeve to form a leak-proof joint.

Figure 3-2 – Wet cylinder sleeve.

Many vehicles use aluminum cylinder blocks with cast iron wet sleeves. The light aluminum block reduces weight for increased fuel economy. The cast iron sleeves wear very well, increasing engine service life.

Most cylinder sleeve casualties are directly related to a lack of maintenance or improper operating procedures. *Figure 3-3* shows two common types of cylinder sleeve casualties: cracks and scoring. Both types of casualties require replacement of the sleeve.

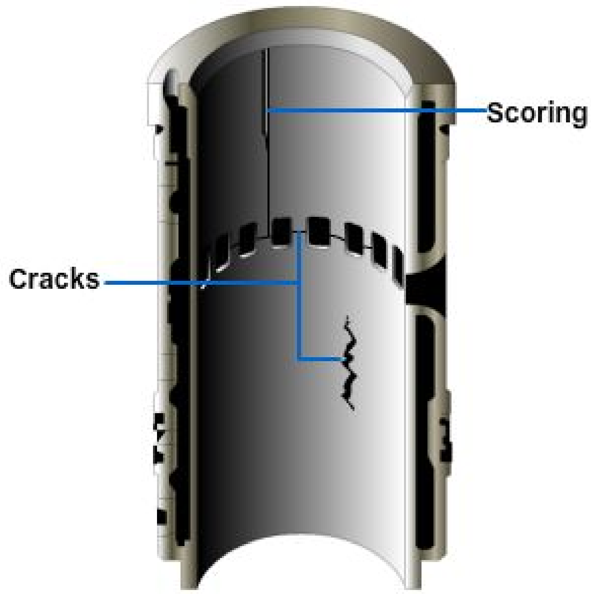

Figure 3-3 – Sleeve casualty.

1.1.4 Cylinder Liner

See cylinder sleeve.

1.1.5 Water Jacket

The cylinder block also provides the foundation for the cooling and lubricating systems. The cylinders of a liquid-cooled engine are surrounded by interconnecting passages cast in the block. Collectively, these passages form the water jacket that allows the circulation of coolant through the cylinder block and the cylinder head to carry off excessive heat created by combustion.

1.1.6 Core Hole Plug

The water jacket is accessible through holes machined in the head and block to allow removal of the material used for casting of the cylinder block. These holes are called core holes and are sealed by core hole plugs (freeze plugs). These plugs are of two types: cup and disk. *Figure 3-4* shows a typical location of these plugs.

1.1.7 Crankcase

The crankcase *(Figure 3-5)*, is that part of the cylinder block below the cylinders. It supports and encloses the crankshaft and provides a reservoir for lubricating oil.

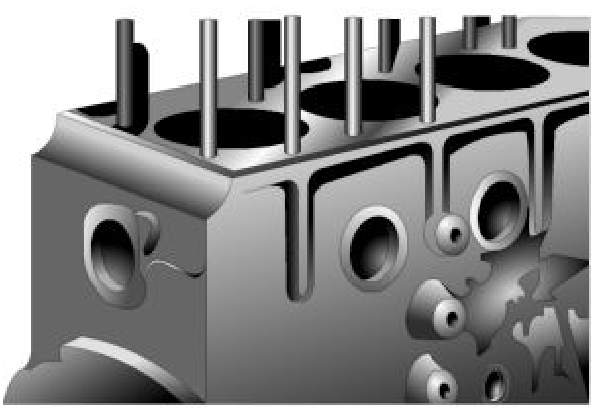

Figure 3-4 – Core hole plugs.

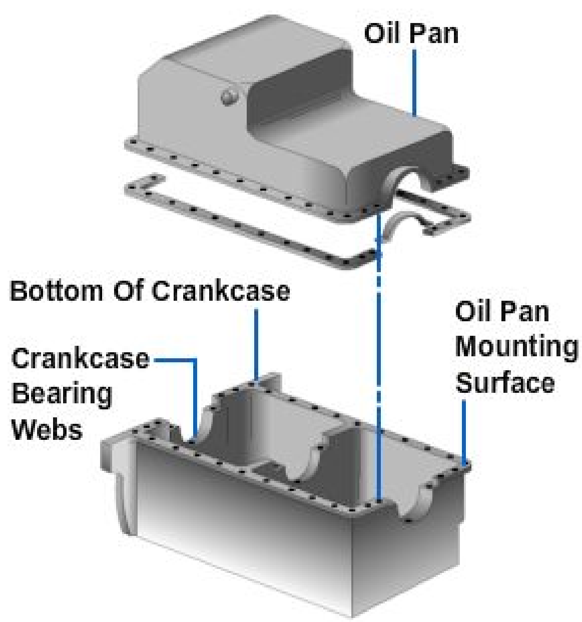

Figure 3-5 – Crankcase.

The crankcase also has mounting brackets to support the entire engine on the vehicle frame. These brackets are either an integral part of the crankcase or are bolted to it in such a way that they support the engine at three or four points. These points are cushioned by rubber mounts that insulate the frame and body of the vehicle from engine vibration. This prevents damage to engine supports and the transmission.

The crankcase shown in *Figure 3-6* is the basic foundation of all air-cooled engines. It is made as a one- or two-piece casting that supports the crankshaft, provides the mounting surface for the cylinders and the oil pump, and has the lubrication passages cast into it. It is made of aluminum since it needs the ability to dissipate large amounts of heat. On air-cooled engines, the oil pan usually is made of cast aluminum and is covered with cooling fins. The oil pan on an air-cooled engine plays a key role in the removal of waste heat from the engine through its lubricating oil.

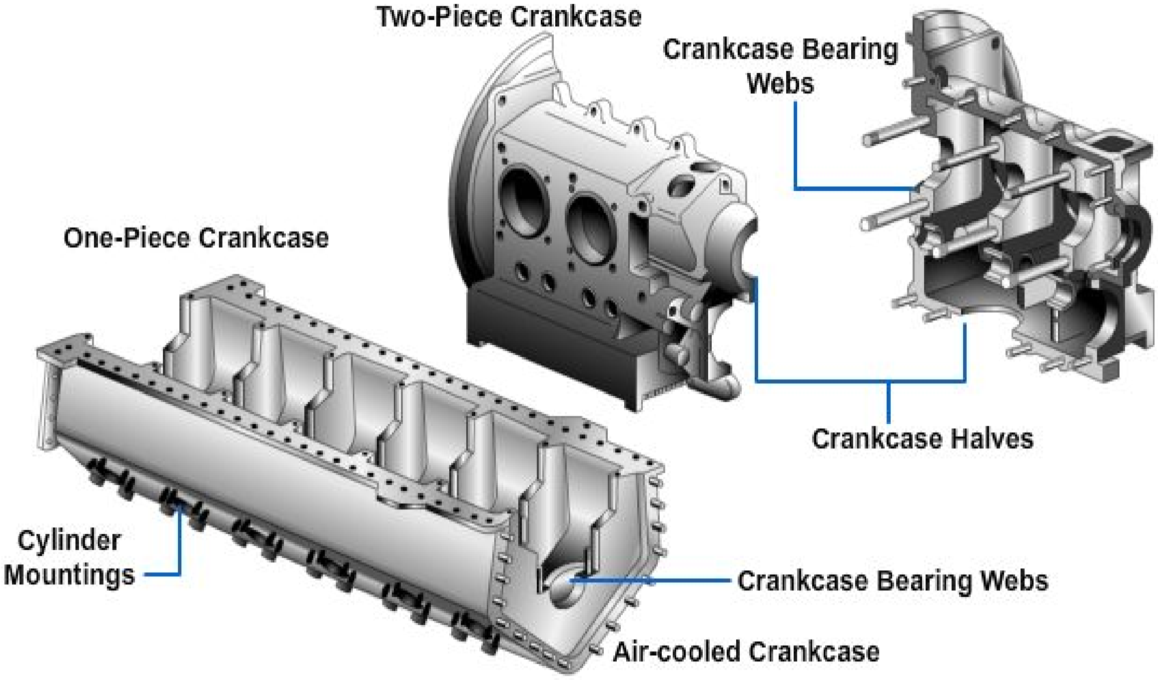

Figure 3-6 — Air-cooled crankcase.

1.1.8 Cylinder Head

The cylinder head *(Figure 3-7)*, bolts to the deck of the cylinder block. It covers and encloses the top of the cylinders. Combustion chambers, small pockets formed in the cylinder heads where combustion occurs, are located directly over the cylinders. Spark plugs (gasoline engine) or injectors (diesel engine) protrude through holes into the combustion chambers.

Intake and exhaust ports are cast into the cylinder head. The intake ports route air (diesel engine) or air and fuel (gasoline engine) into the combustion chambers. The exhaust port routes burned gases out of the combustion chamber.

Figure 3-7 – Cylinder head.

Valve guides are small holes machined through the cylinder head for the valves. The valves fit into and slide in these guides.

Valve seats are round, machined surfaces in the combustion chamber port openings. When a valve is closed, it seals against the valve seat.

The cylinder head is built to conform to the arrangement of the valves: L-head, I-head, or others. Cylinder heads on liquid-cooled engines have been made almost exclusively from cast iron until recent years. Because weight has become an important consideration, a large percentage of cylinder heads now are being made from aluminum.

The cylinder heads on air-cooled engines are made exclusively from aluminum because aluminum conducts heat approximately three times as fast as cast iron. This is a critical consideration with air cooling.

In liquid-cooled engines, the cylinder head is bolted to the top of the cylinder block to close the upper end of the cylinders and, in air-cooled engines, the cylinder heads are bolted to the top of the cylinders.

In a liquid-cooled engine, a cylinder head also contains passages, matching those of the cylinder block, that allow coolant to circulate in the head. These water jackets are for cooling spark plug openings, valve pockets, and part of the combustion chamber. In this type of cylinder head, the water jackets must be large enough to cool not only the top of the combustion chamber but also the valve seats, valves, and valve-operating mechanisms.

The cylinder heads are sealed to the cylinder block to prevent gases from escaping. This is accomplished on liquid-cooled engines by the use of a head gasket. In an air-cooled engine, cylinder heads are sealed to the tops of the cylinders by soft metal rings. The lubrication system feeds oil to the heads through the pushrods.

1.1.9 Exhaust Manifold

The exhaust manifold *(Figure 3-8)*, connects all of the engine cylinders to the rest of the exhaust system. On L-head engines, the exhaust manifold bolts to the side of the engine block, whereas on overhead-valve engines, it bolts to the side of the cylinder head. It is made of cast iron, lightweight aluminum, or stainless steel tubing. If the exhaust manifold is made properly, it can create a ***scavenging*** action that causes all of the cylinders to help each other get rid of the gases. Back pressure (the force that the pistons must exert to push out the exhaust gases) can be reduced by making the manifold with smooth walls and without sharp bends. Exhaust manifolds on vehicles today are constantly changing in design to allow the use of various types of emission controls. Each of these factors is taken into consideration when the exhaust manifold is designed, and the best possible manifold is manufactured to fit into the confines of the engine compartment.

Figure 3-8 – Exhaust manifold.

1.1.10 Intake Manifold

- The intake manifold can be made of cast iron, aluminum, or plastic. On a gasoline engine it carries the air-fuel mixture from the carburetor and distributes it to the cylinders. On a diesel engine, the manifold carries only air into the cylinders. The gasoline engine intake manifold *(Figure 3-9)*, is designed with the following functions in mind: Deliver the air-fuel mixture to the cylinders in equal quantities and proportions. This is important for smooth engine performance. The lengths of the passages should be as equal as possible to distribute the air-fuel mixture equally.

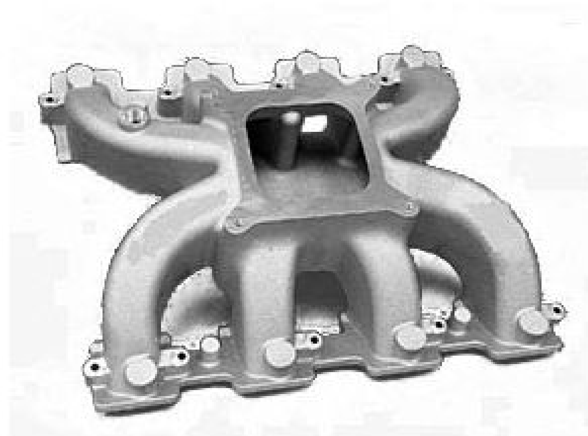

Figure 3-9 – Intake manifold.

- Help to keep the vaporized air-fuel mixture from condensing before it reaches the combustion chamber. The ideal air-fuel mixture should be vaporized completely as it enters the combustion chamber. This is very important. The manifold passages are designed with smooth walls and a minimum of bends that collect fuel to reduce the condensing of the mixture. Smooth flowing intake manifold passages also increase volumetric efficiency.
- Aid in the vaporization of the air-fuel mixture. The intake manifold has a controlled system of heating that must heat the mixture enough to aid in vaporization—without heating it to the point of reducing volumetric efficiency.

The intake manifold on an L-head engine is bolted to the block, whereas the overhead-valve engine has the intake manifold bolted to the side of the cylinder head.

Intake manifolds can be designed to provide optimum performance for a given speed range by varying the length of the passages. The inertia of the moving intake mixture causes it to bounce back and forth in the intake manifold passage from the end of one intake stroke to the beginning of the next intake stroke. If the passage is the proper length so the next intake stroke is just beginning as the mixture is rebounding, the inertia of the mixture causes it to ram itself into the cylinder. This increases the volumetric efficiency of the engine in the designated speed range. It should be noted that the ram manifold serves no purpose outside its designated speed range.

As stated earlier, providing controlled heat for the incoming mixture is very important for good performance. The heating of the mixture may be accomplished by doing one or both of the following:

- Directing a portion of the exhaust through a passage in the intake manifold. The heat from the exhaust transfers and heats the mixture. The amount of exhaust that is diverted into the intake manifold heat passage is controlled by the manifold heat control valve.
- Directing the engine coolant, which is heated by the engine, through the intake manifold on its way to the radiator.

1.1.11 Oil Pan

The lower part of the crankcase is the oil pan *(Figure 3-10)*, which is bolted at the bottom. The oil pan is made of cast aluminum or pressed steel and holds the lubricating oil for the engine. Since the oil pan is the lowest part of the engine, it must be strong enough to withstand blows from flying stones and obstructions sticking up from the road surface.

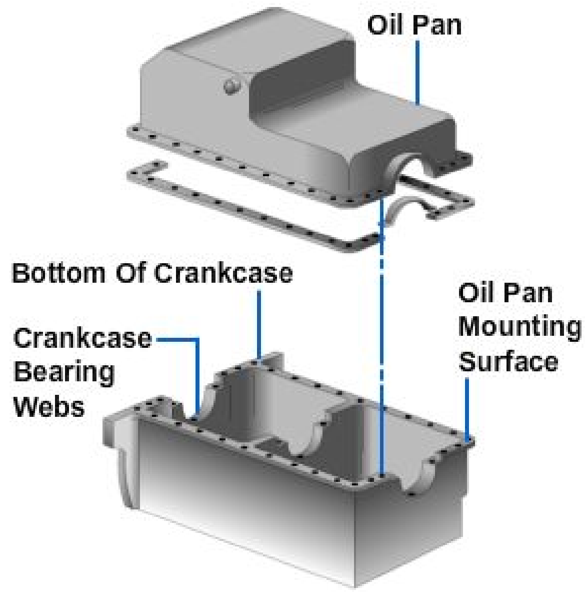

Figure 3-10 – Oil pan.

1.1.12 Cylinder Head Gasket

Usually, a head gasket can be installed only one way. If it is installed backwards, coolant and oil passages may become blocked, causing serious problems. Markings usually indicate the front or top of the head gasket. The gasket may be marked with the word "top" or "front" or it may have a line to show installation direction. Metal dowels are often provided to align the head gasket.

Most modern, Teflon ®-coated, permanent-torque (retorquing is not needed after engine operation) cylinder head gaskets should be installed clean and dry. Sealer is not recommended. However, some head gaskets may require retorquing and sealer. When in doubt, refer to manufacturer's instructions.

1.1.13 Intake and Exhaust Gaskets

There are three types of manifold gaskets, the intake manifold, the exhaust manifold and a combination of the two. Each type of manifold gasket has its own sealing characteristics and problems. Therefore, be sure to follow the manufacturer's instructions when installing them.

1.1.14 Oil Pan Gasket

An oil pan gasket seals the joint between the oil pan and the bottom of the block. The oil pan gasket might also seal the bottom of the timing cover and the lower section of the rear main bearing cap.

The oil pan gasket must resist hot, thin engine oil. The gasket is made of several types of material. A commonly used material is synthetic rubber, known for its long-term sealing ability. It is tough and durable, and resists hot engine oil.

1.1.15 Synthetic Rubber Seals

The synthetic rubber seal *(Figure 3-11)*, is the most common type of oil seal. It is composed of a metal case used to retain its shape and maintain rigidity. A rubber

Figure 3-11 – Synthetic rubber seal.

element is bonded to the case, providing a sealing lip or lips against the rotating shaft. A coil spring, sometimes called a garter spring, is used to hold the rubber element around the shaft with a controlled force. This allows the seal to conform to minor shaft run out. Some synthetic rubber seals fit into bores mounted around the shaft. This type is generally a split design and does not require a metal case or garter spring. The internal pressure developed during operations forces the sealing lips tighter against the rotating shaft. This type of seal operates effectively only against fluid pressure from one direction.

1.2.0 Moving Parts of an Engine

1.2.1 Piston Assembly

The piston transfers the pressure of combustion to the connecting rod and crankshaft. It must also hold the piston rings and piston pin while operating in the cylinder. Pistons,(*Figure 3-12*) are normally cast or forged from an aluminum alloy. Cast pistons are relatively soft and are used in slow-speed, low-performance engines. Forged pistons are commonly used in today's fuel-injected, turbocharged, and diesel engines. These engines expose the pistons to much higher stress loads, which could break cast aluminum pistons.

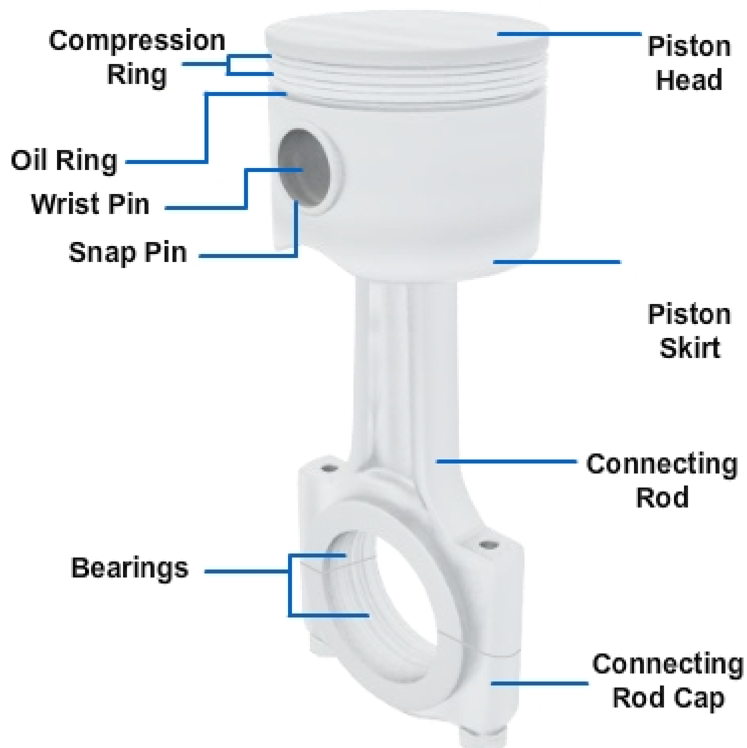

Figure 3-12 — Piston.

The piston must withstand incredible punishment under temperature extremes. The following are examples of conditions that a piston must withstand at normal highway speed:

- As the piston moves from the top of the cylinder to the bottom (or vice versa), it accelerates from a stop to a speed approximately 60 mph at midpoint, and then decelerates to a stop again. It does this approximately 80 times per second.
- The piston is subjected to pressures on its head in excess of 1,000 psi and temperatures well over 600°F.

The structural components of the pistons are the head, skirt, ring grooves, and lands (*Figure 3-13*); however, all pistons do not look like the typical one shown here. Some have differently shaped heads.

Figure 3-13 – Parts of a piston.

The piston head is the top of the piston and is exposed to the heat and pressure of combustion. This area must be thick enough to withstand these forces. It must also be shaped to match and work with the shape of the combustion chamber for complete combustion.

A piston skirt (*Figure 3-14*) is the side of the piston below the last ring. Without a skirt, the piston could tip and jam in the cylinder. A slipper skirt is produced when portions of the piston skirt below the piston ends are removed. The slipper skirt provides clearance between the piston and the crankshaft counterweights. This allows the piston to slide farther down in the cylinder without hitting the crankshaft. A straight skirt is flat across the bottom, a style no longer common in automotive engines.

Figure 3-14 – Piston skirts.

Piston ring grooves are slots machined in the piston for the piston rings. The upper two groves hold the compression rings. The lower piston groove holds the oil ring.

Piston oil holes in the bottom ring groove allow the oil to pass through the piston and onto the cylinder wall. The oil then drains back into the crankcase.

The piston ring lands are the areas between and above the ring grooves. They separate and support the piston rings as they slide on the cylinder.

The piston boss is a reinforced area around the piston pin hole. It must be strong enough to support the piston pin under severe loads.

A piston pin hole is machined through the pin boss for the piston pin. It is slightly larger than the piston pin.

The piston pin, also called the wrist pin, allows the piston to swing on the connecting rod. The pin fits through the hole in the piston and the connecting rod small end.

Piston clearance is the amount of space between the sides of the piston and the cylinder wall. Clearance allows a lubricating film of oil to form between the piston and the cylinder. It also allows for expansion when the piston heats up. The piston must always be free to slide up and down in the cylinder block.

A cam-ground piston (*Figure 3-15*) is slightly out-of-round when viewed from the top. The piston is machined a few thousandths of an inch larger in diameter perpendicular to the piston pin centerline.

Cam grinding is done to compensate for different rates of piston expansion due to differences in metal wall thickness. As the piston is heated by combustion, the thicker area around the pin boss causes the piston to expand more parallel to the piston pin.

The oval-shaped piston becomes round when hot, and there is still enough clearance parallel to the piston pin.

The cold cam-ground piston has the correct piston-to-cylinder clearance. The unexpanded piston will not slap, flop sideways, and knock in the cylinder because of too much clearance. However, the cam-ground piston will not become too tight in the cylinder when heated to full operating temperature.

Piston taper is also used to maintain the correct piston-to-cylinder clearance. The top of the piston is machined slightly smaller than the bottom. Since the piston head gets hotter than the skirt, it expands more. The piston taper makes the piston almost equal in size at the top and bottom at operating temperature.

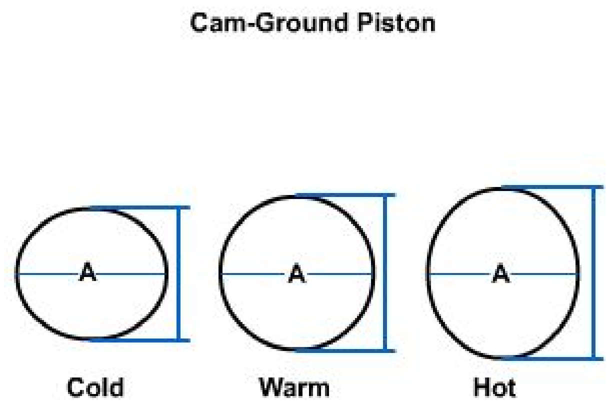

Figure 3-15 – Cam-ground piston.

Piston shape generally refers to the contour of the piston head. Usually, a piston head is shaped to match the shape of the head. A flat top piston implies it has a flat head, that it is parallel to the deck of the head. Valve reliefs are cut into the head of these types of pistons.

A dished piston has a head that is sunken. This type of piston can be used to lower compression like in a supercharged engine.

A domed piston, or pop-up piston, has a head that is convex, or curved upward. This type of piston is normally used with a hemi-type cylinder head and some four-valve heads.

Diesel engine pistons have combustion cups machined into their heads. The combustion cup shape causes the fuel to move in a turbulent pattern as it enters the combustion chamber, allowing a more thorough mixture for efficient combustion. Two typical combustion cup designs are the sombrero cup and the turbulence cup.

The piston rings seal the clearance between the outside of the piston and cylinder wall. They must keep combustion pressure from entering the crankcase. They must also keep oil from entering the combustion chamber.

Most pistons use three rings, two upper compression rings and one oil ring on the bottom. The compression rings prevent blow by (combustion pressure leaking into the engine crankcase). The oil rings prevent oil from entering the combustion chamber.

Diesel engine pistons typically use a four-ring design because they are more prone to blow by. The four-ring piston has three compression rings from the top, followed by one oil control ring. This is due to the much higher pressures generated during the power stroke.

1.2.2 Connecting Rods

Connecting rods connect the pistons to the crankshaft to convert ***reciprocating motion*** into ***rotary motion.*** They must be strong enough to transmit the thrust of the pistons to the crankshaft and to withstand the internal forces of the directional changes of the pistons. The connecting rods (*Figure 3-16*) are in the form of an I-beam. This design gives the highest overall strength and lowest weight. They are made of forged steel but may also be made of aluminum in smaller engines.

The upper end of the connecting rod is connected to the piston by the piston pin. The piston pin is locked in the pin bosses, or it floats in both piston and connecting rod. The upper hole of the connecting rod has a solid bearing (bushing) of bronze or similar material. As the lower end of the connecting rod revolves with the crankshaft, the upper end is forced to turn back and forth on the piston pin. Although the movement is slight, the bushing is necessary because the temperatures and pressures are high. If the piston pin is semi-floating, a bushing is not needed.

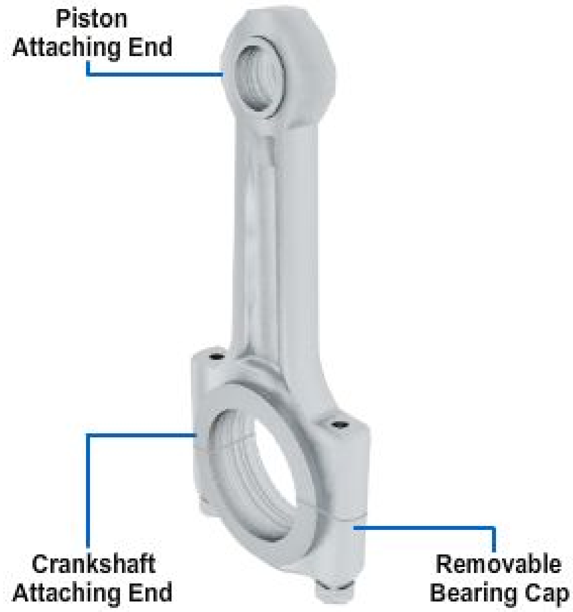

Figure 3-16 – Connecting rod.

The lower hole in the connecting rod is split so it can be clamped around the crankshaft. The bottom part, or cap, is made of the same type of material as the rod and is attached by two or more bolts. The surface that bears on the crankshaft is generally a bearing material in the form of a split shell, although in a few cases it may be spun or die-cast in the inside of the rod and cap during manufacture. The two parts of the separate bearing are positioned in the rod and cap by dowel pins and projections or by a short brass screw. The shell may be of Babbitt metal that is die-cast on a backing of bronze or steel.

The connecting rod bearings are fed a constant supply of oil through a hole in the crankshaft journal. A hole in the upper bearing half feeds a passage in the connecting rod to provide oil to the piston pin.

Connecting rod numbers are used to assure a proper location of each connecting rod in the engine. They all assure that the rod cap is installed on the rod body correctly. When connecting rod caps are being manufactured, they are bolted to the connecting rods. Then the lower end holes are machined in the rods. Since the holes may not be perfectly centered, rod caps must NOT be mixed up or turned around. If the cap is installed without the rod numbers in alignment, the bore will NOT be perfectly round. Connecting rod caps, crankshaft, and bearing damage will result.

In addition to the proper fit of the connecting rod bearings and the proper position of the connecting rod, the alignment of the rod itself must be considered. That is to say, the hole for the piston pin and the crankpin must be precisely parallel. EVERY connecting rod should be checked for proper alignment just before it is installed in the engine. Misalignment of connecting rods causes many hard to locate noises in the engine.

1.2.3 Crankshaft

As the pistons collectively might be regarded as the heart of the engine, so the crankshaft (*Figure 3-17*) may be considered its backbone. The crankshaft is located in the bottom of the engine and is the part of the engine that transforms the reciprocating motion of the piston to rotary motion. It transmits power through the flywheel, the clutch, the transmission, and the differential to drive your vehicle.

Crankshafts are usually made of cast iron or forged steel. Forged steel crankshafts are needed for heavy-duty applications, such as turbocharged or diesel engines. A steel crankshaft is stiffer and stronger than a cast iron crankshaft. It will withstand greater forces without flexing, twisting or breaking.

Oil passages leading to the rod and main bearings are either cast or drilled in the crankshaft. Oil enters the crankshaft at the main bearings and passes through holes in the main journals. It then flows through passages in the crankshaft and out to the connecting rod bearings.

With an inline engine, only one connecting rod fastens to each rod journal. With a V-type engine, two connecting rods bolt to each rod journal. The amount of rod journal offset controls the stroke of the piston. The journal surfaces are precision machined and polished to very accurate tolerances. It is common to have reduced journal, or crankpin, diameters in order to reduce friction in the bearings.

A fully counterweighted crankshaft has weights formed opposite every crankpin. A partially counterweighted crankshaft only has weights formed on the center area. A fully counterweighted crankshaft will operate with less vibration than a partially counterweighted crankshaft.

The crankshaft is supported in the crankcase and rotates in the main bearings (*Figure 3-17*). The connecting rods are supported on the crankshaft by the rod bearings. Crankshaft bearings are made as precision inserts that consist of a hard shell of steel or bronze with a thin lining of anti-frictional metal or bearing alloy. Bearings must be able to support the crankshaft rotation and deliver power stroke thrust under the most adverse conditions.

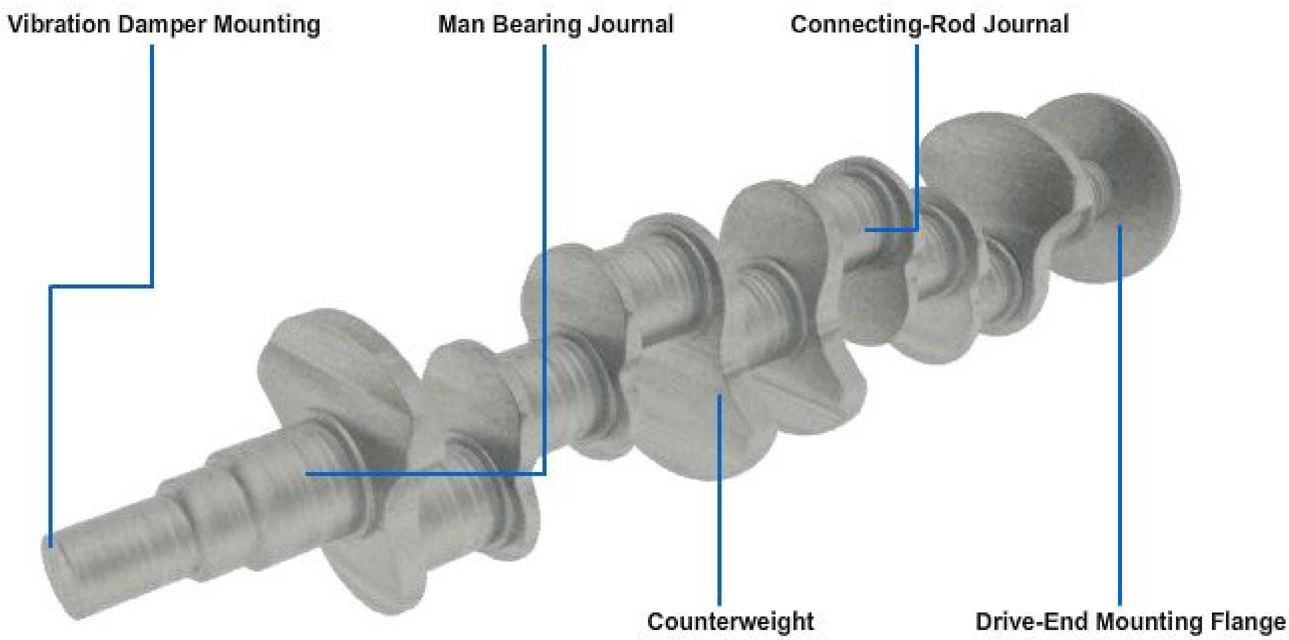

Figure 3-17 — Crankshaft.

The crankshaft rotates in the main bearings located at both ends of the crankshaft and at certain intermediate points. The upper halves of the bearing fit right into the crankcase and the lower halves fit into the caps that hold the crankshaft in place (*Figure 3-17*). These bearings often are channeled for oil distribution and may be lubricated with crankcase oil by pressure through drilled passages or by splash. Some main bearings have an integral thrust face that eliminates crankshaft end play. To prevent the loss of oil, place the seals at both ends of the crankshaft where it extends through the crankcase. When replacing main bearings, tighten the bearing cap to the proper tension with a torque wrench and lock them in place with a cotter pin or safety wire after they are in place.

Vibration due to imbalance is an inherent problem with a crankshaft that is made with offset throws. The weight of the throws tends to make the crankshaft rotate elliptically. This is aggravated further by the weight of the piston and the connecting rod. To eliminate the problem, position the weights along the crankshaft, placing one weight 180 degrees away from each throw. They are called counterweights and are usually part of the crankshaft but may be a separate bolt on items on small engines.

The crankshaft has a tendency to bend slightly when subjected to tremendous thrust from the piston. This deflection of the rotating member causes vibration. This vibration due to deflection is minimized by heavy crankshaft construction and sufficient support along its length by bearings.

Torsional vibration occurs when the crankshaft twists because of the power stroke thrusts. It is caused by the cylinders farthest away from the crankshaft output. As these cylinders apply thrust to the crankshaft, it twists and the thrust decreases. The twisting and unwinding of the crankshaft produces a vibration. The use of a vibration damper at the end of the crankshaft opposite the output acts to absorb torsional vibration.

1.2.4 Camshaft

The camshaft is also part of the valve train and will be discussed later in this chapter.

1.2.5 Valve Train

A valve train is a series of parts used to open and close the intake and exhaust ports. A valve is a movable part that opens and closes a passageway. A camshaft controls the movement of the valves, causing them to open and close at the proper time. Springs are used to close the valves.

1.2.6 Vibration Damper

A high frequency movement resulting from twisting and untwisting of the crankshaft is called harmonic vibration. Each piston and rod assembly can exert over a ton of downward force on its journal. This can actually flex the crank throws in relation to each other. If you do not control the vibration, serious damage can occur. A vibration damper or harmonic balancer *(Figure 3-18)*, is used to control this vibration. The damper also cuts load variation on the engine timing belt, chain, or gears so they last longer.

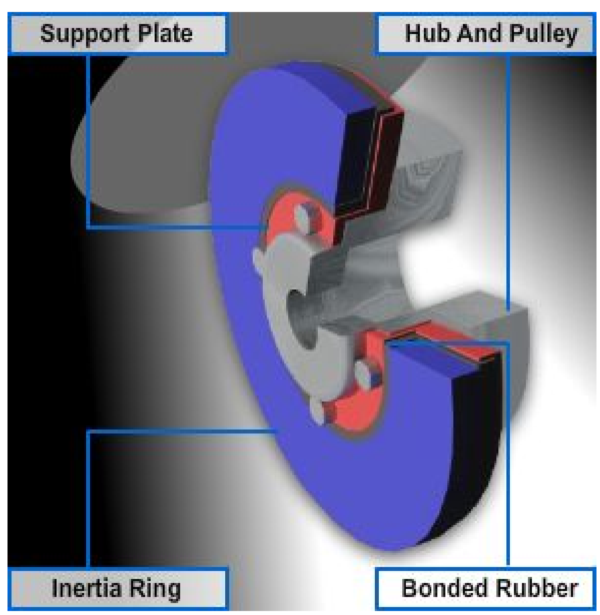

Figure 3-18 – Vibration damper.

The vibration damper is a heavy wheel mounted on a rubber ring to control harmonic vibration. It consists of two metal rings, the outer inertia ring and the inner sleeve, separated by a ring of rubber. The balancer is keyed to the crankshaft snout. This makes the damper spin with the crankshaft. The inertia ring and the rubber ring set up a damping action on the crankshaft as it tries to twist and untwist. This deadens vibration action. There is also a dual-mass harmonic balancer which has one weight mounted on the outside of the crankshaft pulley and another on the inside. The extra rubber-mounted weight helps reduce vibration at high engine speeds.

1.2.7 Flywheel

The flywheel (*Figure 3-19*) stores energy from the power strokes and smoothly delivers it to the drive train of the vehicle between the engine and the transmission. It releases this energy between power impulses, assuring fewer fluctuations in speed and smoother engine operation. The flywheel is mounted at the rear of the crankshaft near the rear main bearing. This is usually the longest and heaviest main bearing in the engine, as it must support the weight of the flywheel.

The flywheel on large, low-speed engines is usually made of cast iron. This is desirable because the heavy weight of the cast iron helps the engine maintain a steady speed. Small, high-speed engines usually use a forged steel or forged aluminum flywheel for the following reasons:

Figure 3-19– Flywheel.

- The cast iron is too heavy, giving it too much inertia for speed variations necessary on small engines.
- Cast iron, because of its weight, pulls itself apart at high speeds due to centrifugal force.

On a vehicle with a manual transmission, the flywheel serves to mount the clutch. With a vehicle that is equipped with an automatic transmission, the flywheel supports the front of the torque converter. In some configurations, the flywheel is combined with the torque converter. The outer edge of the flywheel carries the ring gear, either integral with the flywheel or shrunk on. The ring gear is used to engage the drive gear on the starter motor for cranking the engine.

1.3.0 Valve and Valve Mechanisms

There are two valves for each cylinder in most engines—one intake and one exhaust. Since these valves operate at different times, it is necessary that a separate operating mechanism be provided for each valve. Valves are held closed by heavy springs and by compression in the combustion chamber. The purpose of the valve actuating mechanism is to overcome spring pressure and open the valve at the proper time. The valve actuating mechanism includes the engine camshaft, the camshaft followers (tappets), the pushrods, and the rocker arms.

1.3.1 Camshaft

The camshaft provides for the opening and closing of the engine valves. The camshaft (*Figure 3-20*) is enclosed in the engine block. It has eccentric lobes (cams) ground on it for each valve in the engine. As the camshaft rotates, the cam lobe moves up under the valve tappet, exerting an upward thrust through the tappet against the valve stem or the pushrod. This thrust overcomes the valve spring pressure as well as the gas pressure in the cylinder, causing the valve to open. When the lobe moves from under the tappet, the valve spring pressure reseats the valve.

On L-, F-, or I-head engines, the camshaft is located to one side and above the crankshaft, while in V-type engines, it is located directly above the crankshaft. On the overhead camshaft engine, the camshaft is located above the cylinder head.

The camshaft of a four-stroke-cycle engine turns at one half of engine speed. It is driven off the crankshaft through timing gears or a timing chain. (The system of camshaft drive is discussed later in this chapter.) In a two-stroke-cycle engine, the camshaft must turn at the same speed as the crankshaft, so each valve opens and closes once in each revolution of the engine.

In most cases, the camshaft does more than operate the valve mechanism. It may have external cams or gears that operate the fuel pumps, the fuel injectors, the ignition distributor, or the lubrication pump.

Camshafts are supported in the engine block by journals in bearings. Camshaft bearing journals are the largest machined surfaces on the shaft. The bearings are made of bronze and are bushings, rather than split bearings. The bushings are lubricated by oil circulating through drilled passages from the crankcase. The stresses on the camshaft are small; therefore, the bushings are not adjustable and require little attention. The camshaft bushings are replaced only when the engine requires a complete overhaul.

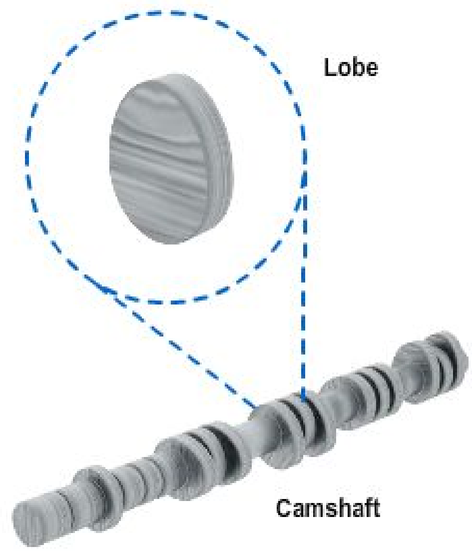

Figure 3-20 – Camshaft.

1.3.2 Followers

Camshaft followers are part of the valve actuating mechanism that contacts the camshaft. You will hear them called valve tappets or valve lifters. The bottom surface is hardened and machined to be compatible with the surface of the camshaft lobe. There are four types of followers—hydraulic, mechanical, roller and the OHC follower.

Hydraulic valve lifters (*Figure 3-21)* are common because they operate quietly by maintaining zero valve clearance. Zero valve clearance means that there is no space between valve train parts. With zero

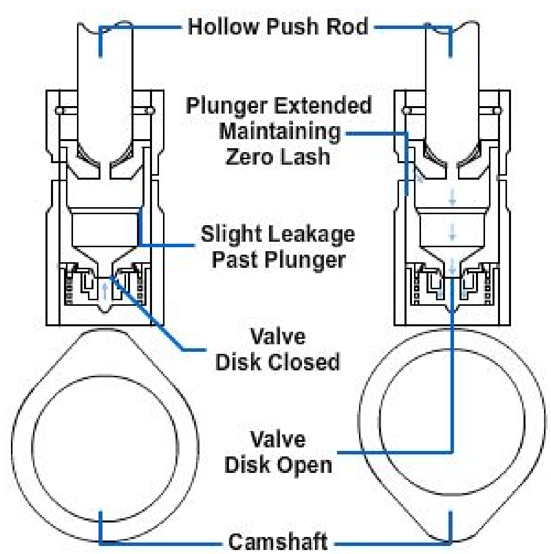

Figure 3-21 – Hydraulic lifters.

clearance, the valve train does not clatter when the engine is running. The hydraulic lifter adjusts automatically with temperature changes and part wear. During engine operation, oil pressure fills the inside of the hydraulic lifter with motor oil. The pressure pushes the lifter plunger up in its bore until all the play is out of the valve train. As the camshaft pushes on the lifter, the lifter check valve closes to seal oil inside the lifter. Since oil is not compressible, the lifter acts as a solid unit to open the valve.

Mechanical lifters (*Figure 3-22*), also called solid lifters, do not contain oil. They simply transfer cam lobe action to the push rod. Mechanical lifters are not self-adjusting and require periodic setting. A screw adjustment is normally provided at the rocker arm when solid lifters are used. Turning the adjustment screw down reduces any “play” in the valve train. Unscrewing, or backing off, the rocker arm adjustment increases clearance. A clattering or clicking noise is produced as the valves open and close.

Figure 3-22 – Mechanical lifters.

A roller lifter (*Figure 3-23)* has a small roller that rides on the camshaft lobe. This type of lifter can be either mechanical or hydraulic. The point where the lifter touches the camshaft is one of the highest friction points in the engine. The roller helps reduce this friction and wear. A roller lifter is also used to reduce frictional losses of power.

An OHC follower (*Figure 3-24)* fits between the camshaft and valve. The follower slides up and down in a bore machined in the head. Either an adjusting screw in the follower or shims of different thicknesses can be used to adjust valve clearance.

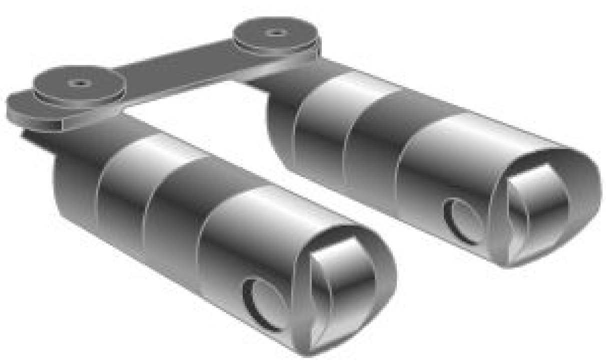

Figure 3-23 – Roller lifters.

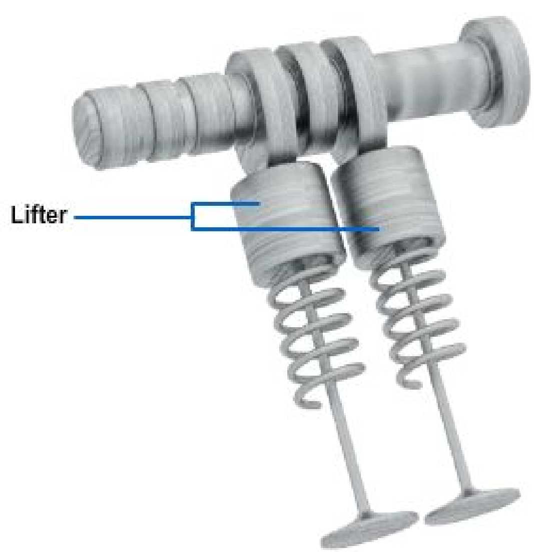

Figure 3-24 – OHC lifters.

1.3.3 Valve and Valve Seats

Each cylinder in a four-stroke-cycle engine must have one intake and one exhaust valve (*Figure 3-25*). The valve design that is commonly used is the poppet, a word derived from the popping action of the valve.

Figure 3-25 – Valves.

Construction and design considerations are very different for intake and exhaust valves. The difference is based on their temperature operating ranges. Intake valves are kept cool by the incoming intake mixture. Exhaust valves are subject to intense heat from the burnt gases that pass by it. The temperature of an exhaust valve can be in excess of 1300°F. Intake valves are made of nickel chromium alloy, whereas exhaust valves are made from silichrome alloy. In certain heavy-duty and most air-cooled engines, the exhaust valves are sodium-filled. During engine operation, the sodium inside the hollow valve melts. When the valve opens, the sodium splashes down into the valve head and collects heat. Then, when the valve closes, the sodium splashes up into the valve stem. Heat transfers out of the sodium into the stem, valve guide, and engine coolant. In this way, the valve is cooled. Sodium-filled valves are light and allow high engine rpm for prolonged periods.

In vehicles that use unleaded fuel, a stellite valve is preferred. A stellite valve has a special hard metal coating on its face. Lead additives in gasoline, other than increasing octane, act as a lubricant. The lead coats the valve face and seat to reduce wear. With unleaded fuel, the wear of the valve seat and valve face is accelerated. A stellite valve prevents this and prolongs valve service life.

Valve seats (*Figure 3-26*) are important, as they must match the face of the valve head to form a perfect seal. The seats are made so they are concentric with the valve guides, that is, the surface of the seat is an equal distance from the center of the guide all around. Although some earlier engines were designed with flat contact surface for the valve and valve seat, most are now designed with valve seat angles of 30 to 45 degrees. This angle helps prevent excessive accumulation of carbon on the contact surface of the seat—a condition that keeps the valve from closing properly. To further reduce carbon build up, there is an interference angle (usually 1 degree) between the valve and seat. In some cases, a small portion of the valve seat has an

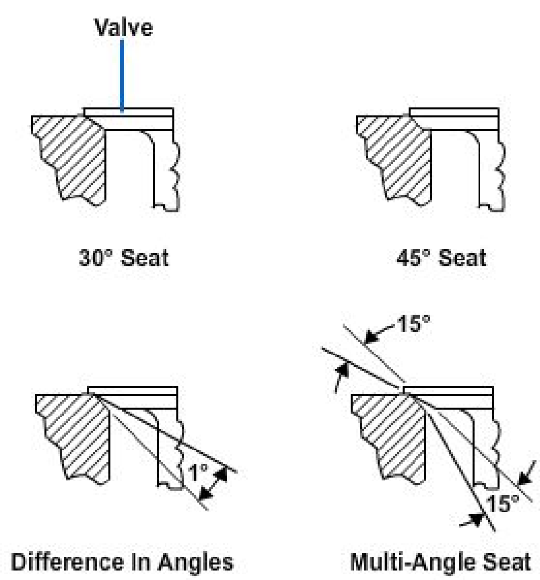

Figure 3-26 – Valve seats.

additional 15-degree angle ground into it to narrow the contact area of the valve face and seat. When you reduce the contact area, the pressure between the mating parts is increased, thereby forming a better seal.

The valve seats may be an integral part of the cylinder head or an insert pressed into the cylinder head. Valve seat inserts are commonly used in aluminum cylinder heads. Steel inserts are needed to withstand the extreme heat. When a valve seat insert is badly worn from grinding or pitting, it must be replaced.

1.3.4 Valve Guides

The valve guides (*Figure 3-27*) are the parts that support the valves in the cylinder head. They are machined to fit a few thousandths of an inch clearance with a valve stem. This close clearance is important for the following reasons:

- It keeps lubricating oil from getting sucked into the combustion chamber past the intake valve stem during the intake stroke.
- It keeps exhaust gases from getting into the crankcase area past the exhaust valve stem during the exhaust stroke.
- It keeps the valve face in perfect alignment with the valve seat.

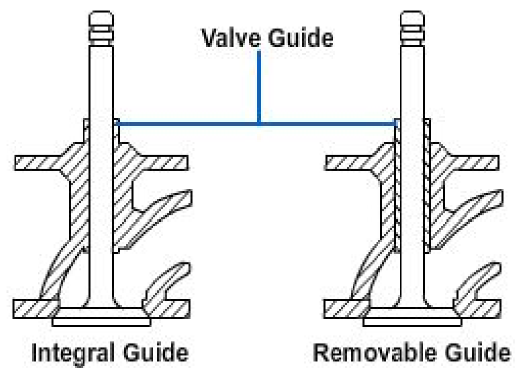

Figure 3-27 – Valve guides.

Valve guides may be cast integrally with the head, or they may be removable. Removable guides are press-fit into the cylinder head.

1.3.5 Valve Guide Service

Servicing of valve guides is an important but often neglected part of a good valve job. The guide must be clean and in good condition before a good valve seat can be made. Valve guide wear is a common problem; it allows the valve to move sideways in its guide during operation. This can cause oil consumption (oil leaks past the valve seal and through the guide), burned valves (poor seat to valve face seal), or valve breakage.

There are several satisfactory methods of checking for valve guide wear. One is to slide the valve into its guide, pull it open approximately 1/2 inch, then try and wiggle the valve sideways. If the valve moves sideways in any direction, the guide or stem is worn. Another checking procedure involves the use of a small hole gauge to measure the inside of the guide and a micrometer to measure the valve stem; the difference in the readings is the clearance. Check the manufacturer's manual for the maximum allowable clearance. When the maximum clearance is exceeded, the valve guide needs further servicing before you proceed with the rest of the job.

Servicing procedures depend on whether the guide is of the integral or replaceable type. If it is the integral type, it must be reamed to a larger size and a valve with an oversize stem installed. But if it is replaceable, it should be removed and a new guide installed.

1.3.6 Valve Seat Service

Valve seat service requires either replacement of the seat or reconditioning of the seat by grinding or cutting. Valve seat replacement is required when a valve seat is cracked, burned, or recessed (sunk) in the cylinder head. Normally, valve seats can be machined and returned to service.

To remove a replaceable pressed-in seat, split the old seat with a sharp chisel. Then pry out the old seat. New seat inserts should be chilled in dry ice for about 15 minutes to shrink them, so they can be driven into place easily. The seat expands when returned to room temperature, which locks the seat in place.

In most cases, the valve seats are not replaceable, so they must be ground. Before operating the valve seat grinding equipment in your shop, be sure to study the manufacturer's manual for specific instructions. The following procedure is typical for grinding valve seats:

1. Select and install the correct size pilot (metal shaft that fits into the guide and supports cutting stone or carbide cutter). The pilot should fit snugly in the valve guide and not wiggle.
2. Select the correct stone for the valve seat. It must be slightly larger in diameter than the seat and must have the correct face angle. Slip the stone-and-sleeve assembly over the pilot.
3. Insert the power head into the sleeve assembly. Support the weight of the power head. Grind only long enough to clean up pits in the seat. Check the progress often to ensure that you do not remove more material than necessary to get a good seat.

After grinding valve seats, it is recommended that you lap the contact surfaces of the valve and valve seat in order to check the location of the valve-to-seat contact point and to smooth the mating surfaces.

To lap the valve, dab grinding compound (abrasive paste) on the valve face. Install the valve into the cylinder head and rotate with a lapping stick (a wooden stick with a rubber plunger for holding the valve head). Rub your hands back and forth on the lapping stick to spin the valve on its seat. This rubs the grinding compound between the valve face and the seat. Remove the valve and check the contact point. A dull gray stripe around the seat and face of the valve indicates the valve-to-seat contact point. This helps you narrow or move the valve seat. A few manufacturers do **NOT** recommend valve lapping. Refer to the manufacturer's service manual for details.

CAUTION

Make sure you clean all of the valve grinding compound off the valve and cylinder head.The compound can cause rapid part wear.

Another way to check valve-to-seat contact is by spreading a thin coat of ***prussian blue*** on the valve face or putting lead pencil marks on the valve seat. If, when turning the valve on its seat, you see an even deposit of coloring on the valve seat or the pencil lines are removed, the seating is perfect. Do NOT rotate the valve more than one-eighth turn, as a high spot could give a false indication if turned one full revolution.

The seat should touch near the center of the valve face with the correct contact width. Typically, an intake valve should have a valve-to-seat contact width of about 1/16 of an inch. An exhaust valve should have a valve-to seat contact width of approximately 3/32 of an inch. Check the manufacturer's service manual for exact values.

When the valve seat does **NOT** touch the valve face properly (wrong width or location on the valve), regrind the seat using different angles, usually 15-degree and 60-degree stones. This is known as narrowing or positioning a valve.

To move the seat in and narrow it, grind the valve seat with a 15-degree stone. This removes metal from around the top of the seat. The seat face moves closer to the valve stem.

To move the seat out and narrow it, grind the valve seat with a 60-degree stone. This cuts away metal from the inner edge of the seat. The seat contact point moves toward the margin or outer edge of the valve.

1.3.7 Valve Spring Service

After prolonged use, valve springs tend to weaken, lose tension, or even break. During engine service, always test valve springs to make sure they are usable. Valve springs should be tested for uniformity and strength. The three characteristics to check are valve spring squareness, valve spring free height, and valve spring tension.

Valve spring squareness is easily checked with a combination square. Place each spring next to the square on a flat surface. Rotate the spring while checking for a gap between the side of the spring and the square. Replace any spring that is not square.

Valve spring free height can also be measured with a combination square or a valve spring tester. Simply measure the length of each spring in normal uncompressed condition. If it is too long or too short, replace the spring.

Valve spring tension, or pressure, is measured by using a spring tester. Compress the spring to specification height and read the scale on the tester. Spring pressure must be within specifications. If the reading is too low, the spring has weakened and must be replaced.

1.3.8 Timing Gears

Timing gears (*Figure 3-28*) are common in engines used for heavy-duty applications, such as taxi cabs or trucks. They are very dependable and long lasting. However, they are noisier than a chain or belt drive. Gears are primarily used for cam-in-block engines where the crankshaft is close to the camshaft.

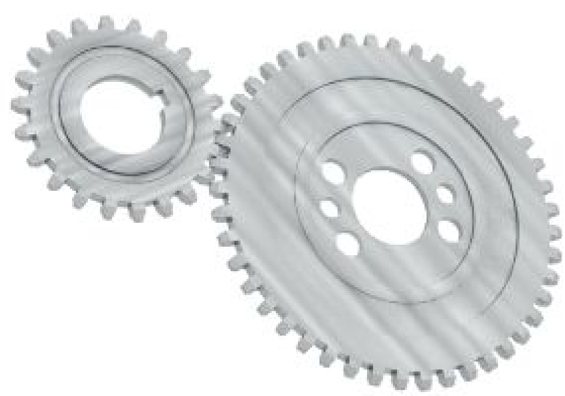

Figure 3-28 – Timing gears.

Two timing gears are used to drive the engine camshaft. A crank gear is keyed to the crankshaft snout. It turns a cam gear on the end of the camshaft. The cam gear is twice the size of the crank gear. This results in the desired 2:1 reduction.

Timing marks on the two gears show the technician how to install the gears properly. The marks may be circles, indentations, or lines on the gears. The timing marks must line up for the camshaft to be in time with the crankshaft.

1.4.0 Engine Bearings

Bearings (*Figure 3-29*) are installed in an engine where there is relative motion between parts. Camshaft bearings are called sleeve bearings because they are in the shape of a sleeve that fits around the rotating journal or shaft, as shown in *Figure 3-29, View A*. Connecting rod or crankshaft (main) bearings are of the split or half type, as shown in *Figure 3-29, View B*. On main bearings, as shown in *Figure 3-29, View C*, the upper half is installed in the counter bore in the cylinder block. The lower-bearing half is held in place by the bearing cap. On connecting rod bearings, the upper-bearing half is installed in the rod and the lower half is placed in the rod cap. The piston pin bearing in the connecting rod is of the full round or bushing type.

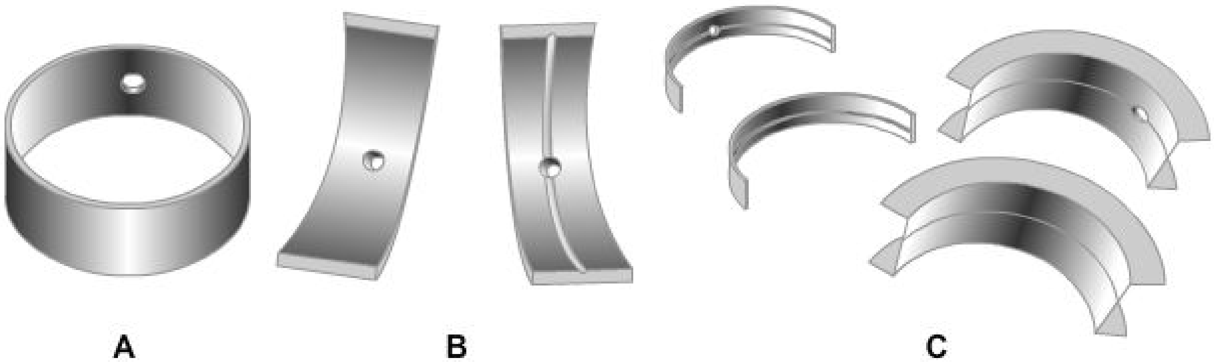

Figure 3-29 – Engine bearings.

1.4.1 Bearing Lubrication

The lubrication of bearings is very important to engine service life because it forces oil to high friction points within the engine. Without lubrication between parts, bearings overheat and score from friction.

The journal or shaft must be smaller in diameter than the bearing, so there is clearance (called oil clearance) between the two parts; oil circulates through the clearance. The oil enters through the oil hole and fills the oil groove in the bearing. From there, the rotating journal carries the oil around to all moving parts of the bearing. The oil works its way to the outer edges of the bearing. From there, it is thrown off and drops back into the oil pan. The oil thrown off helps to lubricate other engine parts, such as the cylinder walls, the pistons, and the piston rings.

As the oil moves across the faces of the bearings, it not only lubricates them but also helps keep them cool. The oil is relatively cool as it leaves the oil pan. It picks up heat in its passage through the bearing. This heat is carried down to the oil pan and released to the air passing around the oil pan. The oil also flushes and cleans the bearings. It tends to flush out particles of grit and dirt that may have worked into the bearing. The particles are carried back to the oil pan by the circulating oil. The particles then drop to the bottom of the oil pan or are removed from the oil by the oil screen or filter.

The greater the oil clearance, the faster the oil flows through the bearing; however, excessive oil clearance causes some bearings to fail from oil starvation. Here's the reason: If oil clearances are excessive, most of the oil passes through the nearest bearings. There is not enough oil for the most distant bearings; these bearings eventually fail from lack of oil. An engine with excessive bearing oil clearance usually has low oil pressure; the oil pump cannot build up normal pressure because of the excessive oil clearance in the bearings.

On the other hand, when the bearings have insufficient oil clearances, there is metal-to-metal contact between the bearings and the journal. Extremely rapid wear and quick failure is the end result. Also, there is not enough throw-off for adequate lubrication of cylinder walls, pistons, and rings.

1.4.2 Bearing Characteristics

Engine bearings must operate under tremendous loads, severe temperature variations, abrasive action, and corrosive surroundings. Essential bearing characteristics include the following:

- Bearing load strength is the ability of a bearing to withstand pounding and crushing during engine operations. The piston and rod can produce several TONS of downward force. The bearing must not fatigue, flatten, or split under these loads. If the bearing load resistance is too low, the bearing can smash, fail, and spin in its bore. This ruins the bore or the journal.
- Bearing conformability is the ability of a bearing to move, shift, conform to variations in shaft alignment, and adjust to imperfections in the surface of the journal. Usually, a soft metal is placed over hard steel. This lets the bearing conform to the defects in the journal.
- Bearing embedability refers to the ability of a bearing to permit foreign particles to become embedded in it. Dirt and metal are sometimes carried into the bearings. The bearing should allow the particles to sink beneath the surface into the bearing material. This prevents the particles from scratching, wearing, and damaging the surface of the crankshaft or camshaft journals.
- Bearing corrosion resistance is the ability of a bearing to resist corrosion from acid, water, and other impurities in the engine oil. Combustion blow-by gases cause engine oil contamination that can also corrode engine bearings. Aluminum-lead and other alloys are commonly being used because of their excellent corrosion resistance.

1.4.3 Bearing Materials

As discussed earlier, there are three basic types of engine bearings—connecting rod bearings, crankshaft main bearings, and camshaft bearings. The backing material (body of the bearing that contacts stationary parts) for engine bearings is normally steel. Softer alloys are bonded over the backing to form the bearing surface. Any one of three basic types of metal alloys can be plated over the top of the steel backing—Babbitt (lead-tin alloy), copper, or aluminum. These three metals may be used in different combinations to design bearings for light-, medium-, or heavy-duty applications. The engine designer selects the combination of ingredients that will best suit the engine.

Test your Knowledge (Select the Correct Response)

1. Why is aluminum not used as an engine block?

   A. Aluminum is cheaper than cast iron.
   B. Aluminum is more expensive than cast iron.
   C. Aluminum is too hard to mold.
   D. Aluminum is more tolerant to heat.

2. The brackets that hold the engine to the vehicle frame are mounted at a minimum of how many points?

   A. Four
   B. Three
   C. Two
   D. One

3. The three types of manifold gaskets are the intake, the exhaust and the ______.

   A. multiple
   B. extruded
   C. combination
   D. corregated

2.0.0 ENGINE ADJUSTMENT and TESTING

2.1.0 Valve Adjustment

Valve adjustment, also called tappet clearance adjustment or rocker adjustment, is critical to the performance and service life of an engine. If the valve train is too loose (has too much clearance), it can cause valve train noise (tapping or clattering from the rocker striking the valve stems). This can increase part wear and cause part breakage. Valves that are adjusted too tight (with inadequate clearance) may be held open or may not close completely. This can allow combustion heat to blow over and burn the valve.

Nonadjustable rocker arms are used on many push rod engines with hydraulic (self-adjusting) lifters. Hydraulic lifters automatically compensate for changes in valve train clearance and maintain zero valve lash. They adjust valve train clearance as parts wear, temperature changes, or oil thickness changes.

If adjustment is needed because of valve grinding, head milling, or other conditions, shorter or longer push rods can be installed with nonadjustable rocker arms. Refer to service manual for details.

2.1.1 Lifter Adjustment

Mechanical lifters, also called solid lifters, are adjusted to ensure proper valve train clearance. Since mechanical lifters cannot automatically compensate for changes in valve train clearance, they must be adjusted periodically. Check the vehicle's service manual for adjustment intervals and clearance specifications. Typical clearance is approximately 0.014" for the intake valves and 0.016" for the exhaust valves.

Unlike hydraulic lifters, mechanical lifters make a clattering or pecking sound during engine operation. This is normal. Mechanical lifters are used on heavy-duty and high-performance engines.

To adjust a mechanical lifter, position the lifter on its base circle (valve fully closed). This can be done by cranking the engine until the piston in the corresponding cylinder is at TDC on its compression stroke. With the piston at TDC on the compression stroke, all valves in the cylinder can be adjusted.

Slide a flat feeler gauge of the correct thickness between the rocker arm and the valve stem. When valve clearance is properly adjusted, the feeler gauge will slide between the valve and the rocker arm with a slight drag.

If needed, adjust the rocker to obtain the specified valve clearance. You will normally have to loosen a lock nut and turn an adjusting screw. Then tighten the lock nut and recheck the clearance. Repeat this procedure on the other lifters.

2.1.2 Overhead Cam Adjustment

There are several different methods of adjusting the valves on an overhead cam engine. In many overhead cam designs, the valves are adjusted like the mechanical lifters in a push rod engine. A rocker arm adjustment screw is turned until the correct size feeler gauge fits between the cam lobe and the follower, valve shim, or valve stem.

Valve adjusting shims may also be used on modern OHC engines to allow valve clearance adjustment. Measure valve clearance with a feeler gauge. Then, if needed, remove and change shim thickness.

2.1.3 Hydraulically Operated Valves

Hydraulic lifter adjustment is done to center the lifter plunger in its bore. This will let the lifter automatically take up or allow more valve train clearance. Some manuals recommend adjustment with the engine off. However, many technicians adjust hydraulic lifters with the engine running.

To adjust lifters with the engine off, turn the crankshaft until the lifter is on the camshaft base circle (not the lobe). The valve must be fully closed.

Loosen the rocker adjusting nut until you can wiggle the push rod up and down. Then slowly tighten the adjusting nut until all play is out of the valve train (you cannot wiggle the push rod).

To center the lifter plunger, tighten the adjusting nut about one more turn. Refer to service manual for exact details. The adjustment procedure can vary with engine design. Repeat adjustment procedure on the other rockers.

To adjust hydraulic lifters with the engine running, install special oil shrouds, clothespins, or other devices to catch oil spray off the rockers. Start the engine and allow it to reach operating temperature.

Tighten all rockers until they are quiet. One at a time, loosen a rocker until it clatters. Then tighten the rocker slowly until it quiets down. This will be zero valve lash.

To set the lifter plunger halfway down in its bore, tighten the rocker about one-half to one more turn. Tighten the rocker slowly to give the lifter time to leak down and prevent engine missing or stalling. Repeat the adjustment on the other rockers.

Other adjustment methods may also be recommended. Check the service manual for detailed information.

2.1.4 OHC Engine Valves

There are several different methods of adjusting the valves on an overhead cam (OHC) engine. Some OHC engines have an adjusting screw in each cam follower. Turning the screw changes valve clearance. Always refer to a shop manual for detailed directions.

2.2.0 Compression Test

A compression test is used to measure the amount of pressure developed during the engine compression stroke. It provides a means of testing the mechanical condition of the engine. It should be done when symptoms (engine miss, rough idle, puffing noise in induction or exhaust) point to major engine problems. Measure compression pressures of all cylinders with a compression gauge (*Figure 3-30*). Then compare them with each other and with the manufacturer's specifications for a new engine. This provides an accurate indication of engine condition.

Figure 3-30 – Compression gauge.

When gauge pressure is lower than normal, pressure is leaking out of the combustion chamber. Low engine compression can be caused by the following conditions:

- Blown head gasket (head gasket ruptured)
- Physical engine damage (hole in piston, broken valve, etc.)
- Burned valved seat (cylinder head seat damaged by combustion)
- Burned valve (valve face damaged by combustion heat)
- Worn rings or cylinders (part wear that prevents a ring-to-cylinder seal)
- Valve train troubles (valve adjusted with insufficient clearance, keeping the valve from fully closing; also, broken valve spring, seal, or retainer)
- Jumped timing chain or belt (loose or worn chain or belt that has jumped over teeth, upsetting valve timing)

2.2.1 Gasoline Engine Compression Test

To perform a compression test on a gasoline engine, use the following procedure:

1. Remove all spark plugs so the engine can rotate easily. Block open the carburetor or fuel injection pump throttle plate. This prevents restricted air flow into the engine.
2. Disable the ignition system to prevent sparks from arcing out of the disconnected spark plug wires. Usually, the feed wire going to the ignition coil can be removed to disable the system.
3. If the engine is equipped with electronic fuel injection, disable it as well to prevent fuel from spraying into the engine. Check the manufacturer’s manual for specific directions.
4. Screw the compression gauge into one of the spark plug holes. Some gauges have a tapered rubber-end plug and must be held by hand securely in the spark plug opening until the highest reading is obtained.
5. Crank the engine and let the engine rotate for about four to six compression strokes (compression gauge needle moves four to six times). Write down the

gauge readings for each cylinder and compare them to the manufacturer’s specifications.

2.2.2 Diesel Engine Compression Test

The compression test for a diesel engine is similar to that of a gasoline engine; however, do not use the compression gauge intended for a gasoline engine. It can be damaged by the high-compression-stroke pressure. Use a diesel gauge that reads up to approximately 600 psi.

To perform a diesel compression test, use the following procedure:

1. Remove all injectors or glow plugs. Refer to the manufacturer’s manual for instructions.
2. Install the compression gauge in the recommended opening.
3. Use a heat shield to seal the gauge when it is installed in place of the injector.
4. Disconnect the fuel shut-off solenoid to disable the fuel injection pump.
5. Crank the engine and note the highest reading on the gauge.

2.2.3 Wet Compression Testing

A wet compression test should be used when the cylinder pressure reads below the manufacturer's specifications. It helps you to determine what engine parts are causing the problem. Pour approximately 1 tablespoon of 30-weight motor oil into the cylinder through the spark plug or injector opening, and then retest the compression pressure.

If the compression reading *GOES UP* with oil in the cylinder, the piston rings and cylinders may be worn and leaking pressure. The oil will temporarily coat and seal bad compression rings to increase pressure; however, if the compression reading *STAYS ABOUT THE SAME,* then engine valves or head gaskets may be leaking. The engine oil seals the rings, but does **NOT** seal a burned valve or a blown head gasket. In this way, a wet compression test helps diagnose low-compression problems.

Do **NOT** put too much oil into the cylinder during a wet compression test or a false reading may result. With excessive oil in the cylinder, compression readings go up even if the compression rings and cylinders are in good condition.

CAUTION

Some manufacturers warn against performing a wet compression test on diesel engines. If too much oil is squirted into the cylinder, hydraulic lock and part damage may result, because oil does NOT compress in the small cylinder volume.

Compression readings for a gasoline engine should run around 125 to 175 psi. The compression should not vary over 15 to 20 psi from the highest to the lowest cylinder. Readings must be within 10 to 15 percent of each other. Diesel engine compression readings average approximately 275 to 400 psi, depending on the design and compression ratio. Compression levels must not vary more than about 10 to 15 percent (30 to 50 psi). Look for cylinder variation during an engine compression check. If some cylinders have normal pressure readings and one or two have low readings, engine performance is reduced. If two adjacent cylinders read low, it might point to a blown head gasket between the two cylinders. If the compression pressure of a cylinder is low for the first few piston strokes and then increases to near normal, a sticking valve is indicated. Indications of valve troubles by compression test may be confirmed by taking vacuum gauge readings.

2.3.0 Vacuum Gauge Test

When an engine has an abnormal compression reading, it is likely that the cylinder head must be removed to repair the trouble. Nevertheless, the technicians should test the vacuum of the engine with a gauge. The vacuum gauge provides a means of testing intake manifold vacuum, cranking vacuum, fuel pump vacuum, and booster pump vacuum. The vacuum gauge does **NOT** replace other test equipment, but rather supplements it and diagnoses engine trouble more conclusively.

Vacuum gauge readings are taken with the engine running and must be accurate to be of any value; therefore, the connection between the gauge and the intake manifold must be leak-proof. Also, before the connection is made, see that the openings to the gauge and the intake manifold are free of dirt or other restrictions.

When a test is made at an elevation of 1,000 feet or less, an engine in good condition, idling at a speed of about 550 rpm, should give a steady reading from 17 to 22 inches on the vacuum gauge. The average reading will drop approximately 1 inch of vacuum per 1,000 feet at altitudes of 1,000 feet or higher above sea level.

When the throttle is opened and closed suddenly, the vacuum reading should first drop about 2 inches with the throttle open, and then come back to a high of about 24 inches before settling back to a steady reading as the engine idles. This is normal for an engine in good operating condition.

If the gauge reading drops to about 15 inches and remains there, it indicates compression leaks between the cylinder walls and the piston rings or power loss caused by incorrect ignition timing. A vacuum gauge pointer indicating a steady 10 inches, for example, usually means that valve timing of the engine is incorrect. Below normal readings that change slowly between two limits, such as 14 and 16 inches, could indicate a number of problems, among them improper carburetor idling adjustment, maladjusted or burned breaker points, and spark plugs with the electrodes set too closely.

A sticking valve could cause the gauge pointer to bounce from a normal steady reading to a lower reading and then bounce back to normal. A broken or weak valve spring can cause the pointer to swing widely as the engine is accelerated. A loose intake manifold or leaking gasket between the carburetor and manifold shows a steady low reading on the vacuum gauge.

A vacuum gauge test only helps to locate the trouble. It is not conclusive, but as you gain experience in interpreting the readings, you can usually diagnose engine behavior.

2.4.0 Cylinder Leakage Test

Another aid in locating compression leaks is the cylinder leakage tester. The principle involved is that of simulating the compression that develops in the cylinder during operation. Compressed air is introduced into the cylinder through the spark plug or injector hole, and by listening and observing at certain key points, you can make some basic deductions.

In making a cylinder leakage test, remove all spark plugs, so each piston can be positioned without the resistance of compression of the remaining cylinders. Next, place the piston at TDC between the compression and power strokes. Then you can introduce the compressed air into the cylinder. Note that the engine tends to spin. By listening at the carburetor, the exhaust pipe, and the oil filler pipe (crankcase), and by observing the coolant in the radiator, when applicable, you can pinpoint the area of air loss. A loud hissing of air at the carburetor indicates a leaking intake valve or valves. Excessive hissing of air at the oil filler tube (crankcase) indicates an excessive air leak past the piston rings. Bubbles observed in the coolant at the radiator indicate a leaking head gasket.

As in vacuum testing, indications are not conclusive. For instance, a leaking head gasket may prove to be a cracked head, or bad rings may be a scored cylinder wall. The important thing is that you have pinpointed the source of the trouble to a specific area, and can make a fairly broad, accurate estimate of repairs or adjustments required without dismantling the engine.

Test your Knowledge (Select the Correct Response)

4. To adjust a valve, the piston must be _______.

   A. at BDC
   B. at TDC
   C. before TDC
   D. before BDC

5. Hydraulic lifters have what valve lash?

   A. Three
   B. Two
   C. One
   D. Zero

Summary

Your knowledge of the internal combustion engine and its many parts will enable you to become a better mechanic. Your ability to identify the stationary and moving parts of an internal combustion engine, to know the basic testing procedures used in its construction, and to understand the operating principles of stationary and moving parts will help you throughout your career as a mechanic. Basic techniques involved with the installation of certain parts are a valuable skill you will finely tune while working on different types of internal combustion engines. During your career as a Construction Mechanic, you will apply these and other skills every day.

Review Questions (Select the Correct Response)

1. The cylinder block, the cylinder head, the exhaust and intake manifolds are considered to be what part of the engine?

   A. Rotational
   B. Stationary
   C. Frame
   D. Backbone

2. Other than cast iron, what other type of metal is used to construct an engine block?

   A. Aluminum
   B. Tin
   C. Plastic
   D. Copper

3. Core hole plugs are also called _____ plugs.

   A. hot
   B. wet
   C. cold
   D. freeze

4. What are the two types of cylinder sleeves used in an engine block?

   A. Wet and dry
   B. Cold and hot
   C. Wet and hot
   D. Dry and cold

5. What condition causes most cylinder sleeve casualties?

   A. Lack of maintenance
   B. Lack of use
   C. Too much use
   D. Too much maintenance

6. The piston attaches to the crankshaft by what means?

   A. Push rod
   B. Connecting rod
   C. Wrist pin
   D. Rocker arm

7. What part is the backbone of an internal combustion engine?

A. Camshaft
B. Engine block
C. Crankshaft
D. Piston

8. In a diesel engine, what is machined in the head of the piston?

A. Compression chamber
B. Combustion cup
C. Dome
D. Power cup

9. What type of bearings support the crankshaft in the block?

A. Connecting
B. Main
C. Rod
D. Torsion

10. Intake manifolds can change engine performance when they are made by varying the length of what?

A. Bolts
B. Passages
C. Orifaces
D. Tubs

11. Cylinder heads on air-cooled engines are made of what material?

A. Argon
B. Cast iron
C. Tin
D. Aluminum

12. An internal combustion engine has a minimum of how many valves for each cylinder?

A. Four
B. Three
C. Two
D. One

13. What type of lifter is a zero clearance lifter?

A. Roller
B. Hydraulic
C. Mechanical
D. Floating

14. The three characteristics to check on a valve spring are the squareness, height and _______.

A. torsion
B. elasticity
C. color
D. tension

15. Timing gears are used in which type of engine?

A. Overhead cam
B. Cam-in-block
C. Dual overhead cam
D. All of the above

16. Typical clearance for mechanical lifters is_______.

A. 0.014” Intake and 0.014” Exhaust
B. 0.014” Intake and 0.016” Exhaust
C. 0.016” Intake and 0.014” Exhaust
D. 0.016” Intake and 0.016” Exhaust

17. **(True or False)** Hydraulically operated valves can be adjusted when the engine is running.

A. True
B. False

18. The two basic types of valve seats are integral and _____.

A. pressed
B. replaceable
C. contact
D. loose

19. When you perform a wet compression test and the reading goes up, what is the most likely problem?

A. Good piston rings
B. Bad piston rings
C. Bad valve seat
D. Good valve seat

20. If you make a vacuum gauge test at sea level with the engine idling at 550 rpm and get a reading of 10 inches, what is the most probable cause?

A. Incorrect valve timing
B. Bad piston rings
C. Incorrect carburetor idle adjustment
D. Sticking valve

21. When performing a cylinder leakage test, you notice a loud hissing of air from the carburetor. This is an indication of what type of problem?

A. Hole in the piston
B. Bad piston rings
C. Incorrect carburetor idle adjustment
D. Leaking intake valve

22. The structural components of a piston are the head, skirt, ring grooves, and______.

A. wrist pin
B. lands
C. connecting rod
D. bearings

23. The piston is subjected to extreme heat and pressure each time it moves, with a maximum pressure of ____ psi, and maximum heat of____ degrees F.

A. 2000, 800
B. 1000, 800
C. 2000, 600
D. 1000, 600

24. Piston clearance is the space between the piston and the_____.

A. head
B. cam shaft
C. crank shaft
D. cylinder wall

25. The connecting rods are made in the shape of a/an ____ beam.

A. I
B. A
C. D
D. E

26. Some crankshaft main bearings have an integral thrust face to eliminate ______.

A. vibration
B. heat
C. end play
D. lubrication

27. Tortional vibration occurs when the crankshaft twists because of what stroke?

A. Intake
B. Compression
C. Power
D. Exhaust

28. The flywheel on large slow moving engines is made of what material?

A. Cast iron
B. Steel
C. Spun copper
D. Aluminum

Trade Terms Introduced in this Chapter

Cylinder	The space in which a piston travels.
Air-cooled	The heat generated by the engine is released directly into the air.
Scavenging	The process of pushing exhaust gases out of the cylinder and drawing in fresh air ready for the next cycle.
Reciprocating motion	An up and down or back and forth motion.
Rotary motion	A circular motion.
Prussian blue	A dye used in metalworking to aid in marking out parts for further machining.

Additional Resources and References

This chapter is intended to present thorough resources for task training. The following reference works are suggested for further study. This is optional material for continued education rather than for task training.

Modern Automotive Technology Seventh Edition, James E. Duffy, The Goodheart-Willcox Company, Inc., 2009. (ISBN 978-1-59070-956-6)

Automotive Technology, A systems Approach Fourth Edition, Jack Erjavec, The Thomson-Delmar Learning Company, Inc., 2005. (ISBN 1-4018-4831-1)

Diesel Technology Seventh Edition, Andrew Norman and John “Drew” Corinchock, The Goodheart-Wilcox Company, Inc., 2007. (ISBN-13: 978-1-59070-770-8)

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Chapter 4

Gasoline Fuel Systems

Topics

To hear audio, click on the box.

Overview

As a Construction Mechanic, you will be working with different types of fuel systems for the internal combustion engine. It is important to know how these components function to provide fuel to the engine and how to service those systems. You will need to be able to identify the properties of gasoline and the components of a fuel system. The information provided in this chapter will help you identify the different systems and understand how they operate.

Objectives

When you have completed this chapter, you will be able to do the following:

1. Understand the different types of gasoline fuel systems, including how the components function to provide fuel to the engine in proper quantities and how to service the gasoline fuel systems.
2. Identify the properties of gasoline.
3. Identify the components of a fuel system.
4. Identify and understand the different gasoline fuel injection systems.
5. Identify components of the exhaust and emission control systems.
6. Understand the operation of the exhaust and emission control systems.

Prerequisites

None

This course map shows all of the chapters in Construction Mechanic Basic. The suggested training order begins at the bottom and proceeds up. Skill levels increase as you advance on the course map.

Automotive Chassis and Body	↑	C
Brakes		M
Construction Equipment Power Trains		
Drive Lines, Differentials, Drive Axles, and Power Train Accessories		
Automotive Clutches, Transmissions, and Transaxles		
Hydraulic and Pneumatic Systems		
Automotive Electrical Circuits and Wiring		B A
Basic Automotive Electricity		S
Cooling and Lubrication Systems		I
Diesel Fuel Systems		C
Gasoline Fuel Systems		
Construction of an Internal Combustion Engine		
Principles of an Internal Combustion Engine		
Technical Administration		

Features of this Manual

This manual has several features which make it easy to use online.

- Figure and table numbers in the text are italicized. The figure or table is either next to or below the text that refers to it.
- The first time a glossary term appears in the text, it is bold and italicized. When your cursor crosses over that word or phrase, a popup box displays with the appropriate definition.
- Audio and video clips are included in the text, with italicized instructions telling you where to click to activate it.
- Review questions that apply to a section are listed under the Test Your Knowledge banner at the end of the section. Select the answer you choose. If the answer is correct, you will be taken to the next section heading. If the answer is incorrect, you will be taken to the area in the chapter where the information is for

review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.

- Review questions are included at the end of this chapter. Select the answer you choose. If the answer is correct, you will be taken to the next question. If the answer is incorrect, you will be taken to the area in the chapter where the information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.

1.0.0 GASOLINE FUEL SYSTEMS

The function of the fuel system is to supply a combustible mixture of air and fuel to the engine. Major elements of the gasoline fuel supply system include the following: fuel tank and cap, fuel system ***emissions*** controls, fuel lines, fuel pump, fuel filter, carburetor or fuel injection system, air cleaner, and exhaust system. Before learning about these components of a gasoline fuel system, you should understand the composition and properties of gasoline.

1.1.0 Gasoline

Gasoline is a highly volatile, flammable liquid hydrocarbon mixture used as a fuel for internal combustion engines. A comparatively economical fuel, gasoline is the primary fuel for automobiles worldwide. Chemicals called additives such as lead, detergents, and anti-oxidants, are mixed into gasoline to improve its operating characteristics.

Antiknock additives are used to slow down the ignition and burning of gasoline. This action helps to prevent engine ping or knock. Leaded gasoline has lead antiknock additives. The lead allows a higher engine compression ratio to be used without the fuel igniting prematurely. Leaded gasoline is designed to be used in older vehicles that have little or no emission controls.

The fuel used today is unleaded gasoline. Unleaded gasoline, also called no-lead or lead-free, does NOT contain lead antiknock additives. Congress has passed laws requiring that all vehicles meet strict emission levels. As a result, manufacturers began using catalytic converters and unleaded fuel.

1.2.0 Properties of Gasoline

For a gasoline fuel system to function properly, the fuel must have the right qualities to burn evenly no matter what the demands of the engine are. To help you recognize the qualities required of gasoline used for fuel, let’s examine the three properties of gasoline and their effects on the operation of the engine.

1.2.1 Volatility

The ease with which gasoline vaporizes is called volatility. A high volatility gasoline vaporizes very quickly. A low volatility gasoline vaporizes slowly. A good gasoline should have the right volatility for the climate in which the gasoline is used.

If the gasoline is too volatile, it will vaporize in the fuel system. The result will be a condition called vapor lock. Vapor lock is the formation of vapor in the fuel lines in a quantity sufficient to prevent the flow of gasoline through the system. Vapor lock causes the vehicle to stall from lack of fuel. In the summer and in hot climates, fuels with low volatility lessen the tendency toward vapor lock.

1.2.2 Antiknock Quality

In modern high compression gasoline engines, the air-fuel mixture tends to ignite spontaneously or to explode instead of burning rather slowly and uniformly. The result is a knock, a ping, or a detonation. For this reason, gasoline refiners have various ways to make gasoline that does not detonate easily.

1.2.3 Octane Rating

A gasoline that detonates easily is called low octane gasoline. A gasoline that resists detonation is called high octane gasoline.

The octane rating of a gasoline is a measurement of the ability of the fuel to resist knock or ping. A high octane rating indicates the fuel will NOT knock or ping easily. It should be used in a high compression or turbocharged engine. A low octane gasoline is suitable for a low compression engine.

Octane numbers give the antiknock value of gasoline. A higher octane number (91) will resist ping better than a gasoline with a low octane number (83). Each manufacturer recommends an octane number for its engine.

1.3.0 Air-Fuel Ratio

For proper combustion and engine performance, the right amounts of air and fuel must be mixed together. If too much fuel or too little fuel is used, engine power, fuel economy, and efficiency are reduced.

For a gasoline engine, the perfect air-fuel ratio is 14.7:1 (14.7 parts air to 1 part fuel by weight). Under constant engine conditions, this ratio can help assure that all fuel is burned during combustion. The fuel system must change the air-fuel ratio with the changes in engine-operating conditions.

1.3.1 Lean Air-Fuel Mixture

A lean air-fuel mixture contains a large amount of air. For example, 20:1 would be a very lean mixture. A slightly lean mixture is desirable for high gas mileage and low exhaust emissions. Extra air in the cylinder ensures that all the fuel will be burned; however, too lean of a mixture can cause poor engine performance (lack of power, missing) and even engine damage.

1.3.2 Rich Air-Fuel Mixture

A rich air-fuel mixture contains a little more fuel mixed with the air. For gasoline, 8:1(8 parts air to 1 part fuel) is a very rich mixture. A slightly rich mixture tends to increase power; however, it also increases fuel consumption and exhaust emissions. An overly rich mixture will reduce engine power, foul ***spark plugs***, and cause incomplete burning (black smoke at engine exhaust).

1.4.0 Gasoline Combustion

For gasoline or any other fuel to burn properly, it must be mixed with the right amount of air. The mixture must then be compressed and ignited. The resulting combustion produces heat, expansion of the gases, and pressure.

1.4.1 Normal Combustion

Normal gasoline combustion occurs when the spark plug ignites the fuel and burning progresses smoothly through the fuel mixture. Maximum cylinder pressure should be produced after a few degrees of crank rotation after the piston passes TDC on the power stroke.

Normal combustion takes only about 3/1,000 of a second. This is much slower than an explosion. Dynamite explodes in about 1/50,000 of a second. Under some undesirable conditions, however, gasoline can be made to bum quickly, making part of the combustion like an explosion.

1.4.2 Abnormal Combustion

Abnormal combustion occurs when the flame does NOT spread evenly and smoothly through the combustion chamber. The lean air-fuel mixture, high operating temperatures, low octane, and unleaded fuels used today make abnormal combustion a major problem that creates unfavorable conditions, such as the following:

- Detonation results when part of the unburned fuel mixture explodes violently. This is the most severe engine-damaging type of abnormal combustion. Engine knock is a symptom of detonation because pressure rises so quickly that parts of the engine vibrate. Detonation sounds like a hammer hitting the side of the engine. It can crack cylinder heads, blow head gaskets, burn pistons, and shatter spark plugs.
- Pre-ignition results when an overheated surface in the combustion chamber ignites the fuel mixture. Termed surface ignition, a hot spot (overheated bit of carbon, sharp edge, and hot exhaust valve) causes the mixture to burn prematurely. A ping or mild knock is a light tapping noise that can be heard during pre-ignition. Pre-ignition is similar to detonation, but the action is reversed. Detonation begins after the start of normal combustion, and pre-ignition occurs before the start of normal combustion. Pre-ignition is common to modern vehicles. Some manufacturers say that some pre-ignition is normal when accelerating under a load.
- Dieseling, also called after-running or run on, is a problem when the engine keeps running after the key is turned off. A knocking, coughing, or fluttering noise may be heard as the fuel ignites and the crankshaft spins. When dieseling, the engine ignites the fuel from heat and pressure, somewhat like a diesel engine. With the key off, the engine runs without voltage to the spark plugs. The most common causes of dieseling are high idle speed, carbon deposits in the combustion chambers, low octane fuel, overheated engine, or spark plugs with too high of a heat range.
- Spark knock is another combustion problem caused by the spark plug firing too soon in relation to the position of the piston. The spark timing is advanced too far, causing combustion to slam into the upward moving piston. This causes maximum cylinder pressures to form before TDC, not after TDC as it should. Spark knock and pre-ignition both produce about the same symptoms—pinging under load. To find its cause, first check ignition timing. If ignition timing is correct, check other possible causes.

1.5.0 Gasoline Fuel System Components

A gasoline fuel system draws fuel from the tank and forces it into the fuel-metering device (carburetor, gasoline injectors), using either a mechanical (engine-driven) or electric fuel pump. The basic parts of a fuel supply system include the following:

- Fuel tank (stores gasoline)
- Fuel pump (draws fuel from the tank and forces it to the fuel-metering device)
- Fuel filters (remove contaminants in the fuel)
- Fuel lines (carry fuel between the tank, the pump, and other parts)

1.5.1 Fuel Tank

An automotive fuel tank must safely hold an adequate supply of fuel for prolonged engine operation. The location of the fuel tank should be in an area that is protected from flying debris, shielded from collision damage, and not subjected to bottoming (*Figure 4-1*). A fuel tank can be located just about anywhere in the vehicle that meets these requirements.

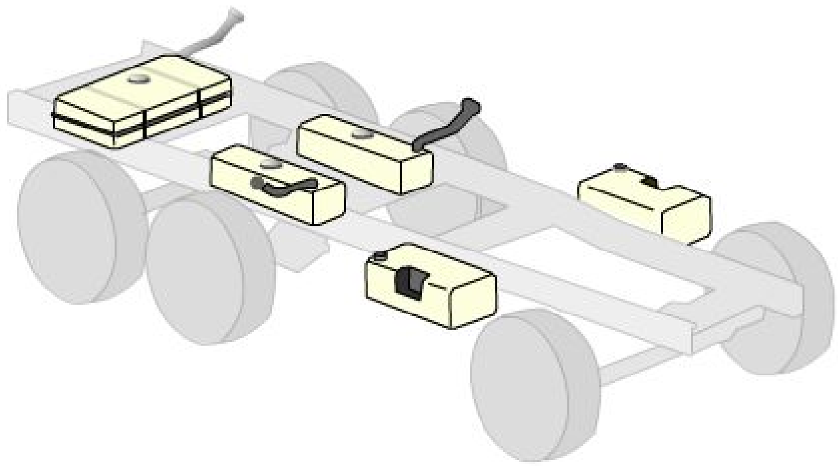

Figure 4-1— Common fuel tank locations.

Figure 4-2 shows the general construction of a fuel tank used on automotive equipment. Fuel tanks are usually made of thin sheet metal or plastic. The main body of a metal tank is made by soldering or welding two formed pieces of sheet metal together. Other parts (filer neck, fuel tank cap, and baffles) are added to the form to complete the fuel tank assembly. A lead-tin alloy is normally plated to the sheet metal to prevent the tank from rusting.

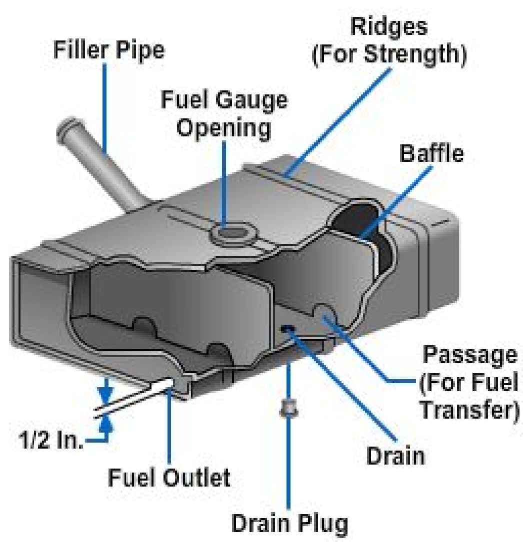

Figure 4-2— Fuel tank construction.

The fuel tank filler neck is an extension on the tank for filling the tank with fuel. The filler cap fits on the end of the filler neck. The neck extends from the tank through the body of the vehicle. A flexible hose is normally used as part of the filler neck to allow for tank vibration without breakage.

In vehicles requiring unleaded fuel, a fuel neck restrictor is used inside the filler neck. This prevents the accidental use of leaded gasoline in an engine designed for unleaded. The restrictor is too small to accept the larger leaded fuel type pump nozzle.

WARNING

If the restrictor is removed and leaded fuel is used in a vehicle designed for unleaded fuel, the catalytic converter will be damaged. This action is a violation of federal law; therefore, NEVER remove the filler neck restrictor.

Modern fuel tank caps are sealed to prevent escape of fuel and fuel vapors (emissions) from the tank. The cap has pressure and vacuum valves that open only under abnormal conditions of high pressure or vacuum.

Fuel tank baffles are placed inside the tank to prevent the fuel from sloshing or splashing around in the tank. The baffles are metal plates that restrict fuel movement when the vehicle accelerates, decelerates, or turns corners.

Fuel tanks give little or no trouble, and generally require no servicing other than an occasional draining and cleaning.

WARNING

If a fuel tank is punctured or develops leaks, it should NOT be welded or repaired with or near an open flame until all traces of fuel and fuel vapors have been completely removed from the tank. Before attempting to make any repairs to a fuel tank, consult with the shop supervisor for specific instructions on all safety precautions to be observed.

1.5.2 Fuel Gauges

The fuel gauge indicates the fuel level in the fuel tank. It is a magnetic indicating system that can be found on either an analog or digital instrument panel.

The fuel sending unit is combined with the fuel pump assembly and consists of a variable resistor controlled by the level of an attached float mechanism in the tank. When the fuel is low, resistance in the sender is low; therefore movement of lift of the gauge is low. When the resistance is high, such as with a full tank, the indicator is high, showing the gauge higher up the scale on the instrument panel.

1.5.3 Fuel Filters

The fuel injection system is highly sensitive to foreign particles. Fuel filters prevent water, dirt, and rust particles from entering the system. ***Contaminated*** fuel can cause incomplete combustion, smoky exhaust, engine knocking, and difficulties starting the engine. Most heavy equipment has a fuel pressure gauge that indicates when the filters are dirty.

The fuel filter operates by passing fuel through a porous element that removes particles large enough to cause problems in the system (*Figure 4-3*). Particles are often measured in microns. A micron is one millionth of a meter.

Some filters serve as sediment bowls. These types of filters separate water and larger particles from the fuel. After separation, the water and particles settle to the bottom of the bowl, where they can be removed through a drain plug.

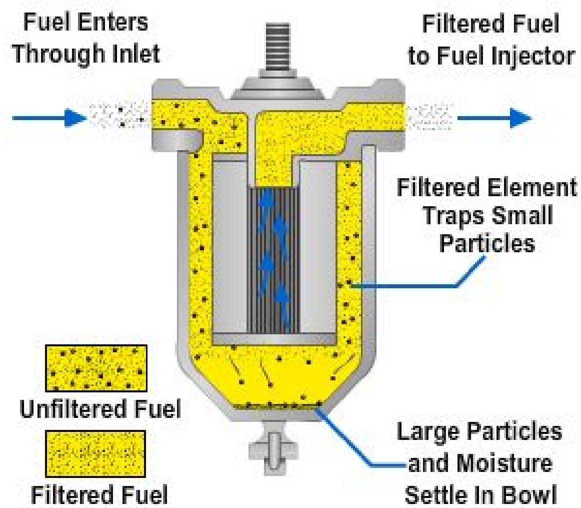

Figure 4-3— Fuel filter operation.

Filter elements can be made of ceramic, treated paper, sintered bronze or metal screen (*Figure 4-4*). Some filter elements are made of laminated disks that are spaced 0.0003 inches apart. Foreign matter is blocked out as the fuel passes between the disks.

Figure 4-4— Fuel filter elements.

1.5.4 Fuel Pump

A fuel pump is the device that draws the fuel from the tank to the engine's injection system. All late model vehicles use an electric fuel pump.

The fuel pump can be located either inside the tank or in the fuel system after the tank. There are four types of fuel pumps: the diaphragm, plunger, bellows, and impeller or rotary pump. The in-tank electric pump is usually a rotary pump. The others are usually of the demand style, meaning that when the ignition is turned on, the fuel pump starts and when the pressure in the system is correct, it shuts off. When more fuel is required, the pump starts again.

Most vehicles have an in-tank fuel pump. Some other vehicles also have a secondary pump along the fuel line. Fuel pumps are mounted in the tank to help keep the pump cool.

Nearly all electric fuel pump circuits have some sort of rollover protection. Typically this protection includes the installation of an inertia switch that shuts off the fuel pump if the vehicle rolls over or is in an accident.

1.5.5 Fuel Lines and Hoses

Fuel lines and hoses carry fuel from the tank to the filter and fuel injection assembly. They can be made from either metal tubing or flexible nylon or synthetic rubber hoses. The latter must be able to resist gasoline. The hoses must be nonpermeable so gas and gas vapors cannot evaporate through the hose.

Fuel supply lines from the tank to the injectors usually follow the frame of the vehicle along the underchassis. Generally, rigid lines are used from the tank to the fuel pump or filter. To absorb vibration, these lines can be joined with short lengths of flexible hose.

Many tanks also have vent hoses to allow air in the tank to escape when the tank is being filled. Vent hoses are usually routed alongside the filler neck.

Faulty fuel lines and hoses are a common source of fuel leaks. Fuel hoses can become hard and brittle after being exposed to the engine heat and the elements. Engine oil can soften and swell them. Always inspect hoses closely and replace any in poor condition. Metal fuel lines rarely cause problems; however, they should be replaced if they become smashed, kinked, rusted, or leaky. Remember these rules when working with fuel lines and hoses:

- Place a rag around the fuel line fitting during removal to keep fuel from spraying on you or on a hot engine. Use a flare nut or tubing wrench on fuel line fittings.

- Use only approved double wall steel tubing for fuel lines. NEVER use copper or plastic tubing.
- Make smooth bends when forming a new fuel line. Use a bending spring or bending tool.
- Form double lap flares on the ends of fuel lines. A single lap flare is NOT approved for fuel lines.
- Reinstall fuel line hold-down clamps and brackets. If not properly supported, the fuel line can vibrate and fail.
- Route all fuel lines and hoses away from hot or moving parts. Double-check the clearance after installation.
- Use only approved synthetic rubber hoses in a fuel system. Vacuum hose is NOT to be used as fuel hose.
- Make sure fuel hoses completely cover their fittings or lines before installing clamps. Pressure in the fuel system could force a hose off if not installed properly.
- Double-check all fittings for leaks. Start the engine and inspect the connections closely.

CAUTION

Most fuel injection systems have very high fuel pressure. Follow recommended procedures for bleeding or releasing pressure before disconnecting a fuel line or fitting. This action will prevent fuel spray from possibly causing injury or a fire.

1.5.6 Fuel Pressure Regulator

The fuel pressure regulator controls the amount of pressure entering the injector valves. When sufficient pressure is attained, the regulator returns excess fuel to the tank. This maintains a preset amount of fuel pressure for injector valve operation.

1.5.7 Fuel Injectors

Fuel injection systems can have one or more fuel supply devices called fuel injectors (*Figure 4-5*). Fuel injectors are controlled by an ECM. The computer system sends an electrical current to activate the solenoid inside the injector. When the solenoid is activated, the injector nozzle opens and squirts atomized fuel in a cone-shaped pattern. The computer system controls the fuel-air ratio by varying the length of time that the injector nozzle remains open.

In gasoline engines injectors squirt fuel into the intake manifold. In diesel engines, fuel is delivered directly into the combustion chamber. Spring pressure closes the injector nozzle when the solenoid is deactivated.

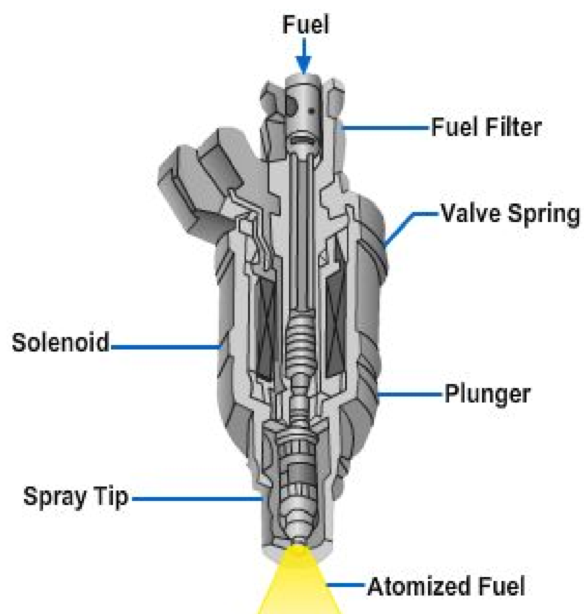

Figure 4-5— Fuel injector.

1.6.0 Air Cleaner

Air cleaners are used to prevent foreign matter, such as sand, dust, and lint, from entering the intake system (*Figure 4-6*). Contaminated air in the intake system can cause engine wear, poor combustion, and engine breakdown. In addition to supplying clean air, air cleaners reduce vibration sounds and other noises caused by air entering the intake system.

Figure 4-6 — Air cleaners.

Test your Knowledge (Select the Correct Response)

1. Which of the following is NOT a property of gasoline?

   A. Volatility
   B. Antiknock quality
   C. Cetane number
   D. Octane rating

2. Which of the following air-fuel ratios is considered to be perfect for a gasoline engine?

   A. 20:1
   B. 14.7:1
   C. 17.4:1
   D. 18.8:1

3. The fuel pressure regulator controls the amount of pressure entering the ______.

   A. intake
   B. valves
   C. injectors
   D. pump

2.0.0 GASOLINE FUEL INJECTION SYSTEMS

A modern gasoline injection system uses pressure from an electric fuel pump to spray fuel into the engine intake manifold. Like a carburetor, it must provide the engine with the correct air-fuel mixture for specific operating conditions. Unlike a carburetor, however, PRESSURE, not engine vacuum, is used to feed fuel into the engine. This makes the gasoline injection system very efficient. A gasoline injection system has several possible advantages over a carburetor type of fuel system. Some advantages are as follows:

- Improved atomization. Fuel is forced into the intake manifold under pressure that helps break fuel droplets into a fine mist.
- Better fuel distribution. Each cylinder receives an equal flow of fuel vapors.
- Smoother idle. Lean fuel mixture can be used without rough idle because of better fuel distribution and low-speed atomization.
- Lower emissions. Lean, efficient air-fuel mixture reduces exhaust pollution.
- Better cold weather drivability. Injection provides better control of mixture enrichment than a carburetor.
- Increased engine power. Precise metering of fuel to each cylinder and increased air flow can result in more horsepower output.
- Fewer parts. Simpler, late model, electronic fuel injection systems have fewer parts than modern computer-controlled carburetors.

There are many types of gasoline injection systems. Before studying the most common ones, you should have a basic knowledge of the different classifications. Systems are classified as either single- or multi-point injection and as either indirect or direct injection.

The point or location of fuel injection is one way to classify a gasoline injection system. A single-point injection system, also call throttle body injection (TBI), has the injector nozzles in a throttle body assembly on top of the engine. Fuel is sprayed into the top center of the intake manifold.

A multi-point injection system, also called port injection, has an injector in the port (air-fuel passage) going to each cylinder. Gasoline is sprayed into each intake port and toward each intake valve. Thereby, the term multi-point (more than one location) fuel injection is used.

An indirect injection system sprays fuel into the engine intake manifold. Most gasoline injection systems are of this type. Direct injection forces fuel into the engine combustion chambers.

There are several basic configurations of gasoline fuel injection we will discuss the timed, and throttle body.

2.1.0 Timed Fuel Injection System

Timed fuel injection systems for gasoline engines inject a measured amount of fuel in timed bursts that are ***synchronized*** to the intake strokes of the engine. Timed injection is the most precise form of fuel injection but is also the most complex. There are two basic forms of timed fuel injection: mechanical and electronic.

The basic operation of a mechanical-timed injection system (*Figure 4-7*) is as follows:

A high-pressure electric pump draws fuel from the fuel tank and delivers it to the metering unit. A pressure relief valve is installed between the fuel pump and the metering unit to regulate fuel line pressure by bleeding off excess fuel back to the tank.

The metering unit is a pump that is driven by the engine camshaft. It is always in the same rotational relationship with the camshaft so it can be timed to feed the fuel to the injectors just at the right moment.

Each injector contains a spring-loaded valve that is opened by fuel pressure, injecting fuel into the intake at a point just before the intake valve opens.

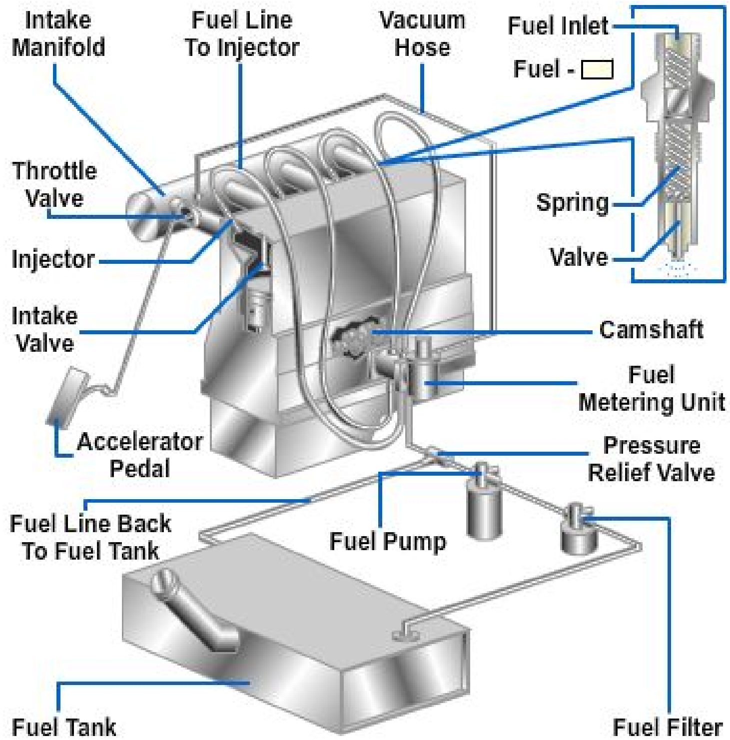

Figure 4-7 — Mechanical-timed injection system.

The throttle valve regulates engine speed and power output by regulating manifold vacuum, which, in turn, regulates the amount of fuel supplied to the injectors by the metering pump.

The more common type of timed fuel injection is the electronic-timed fuel injection, also known as electronic fuel injection, or EFI (*Figure 4-8*). An electronic fuel injection system can be divided into four subsystems:

- Fuel delivery system
- Air induction system
- Sensor system
- Computer control system

The fuel delivery system of an EFI system includes an electric fuel pump, a fuel filter, a pressure regulator, the injector valves, and the connecting lines and hoses.

The electric fuel pump draws fuel out of the tank and forces it into the pressure regulator.

The fuel pressure regulator controls the amount of

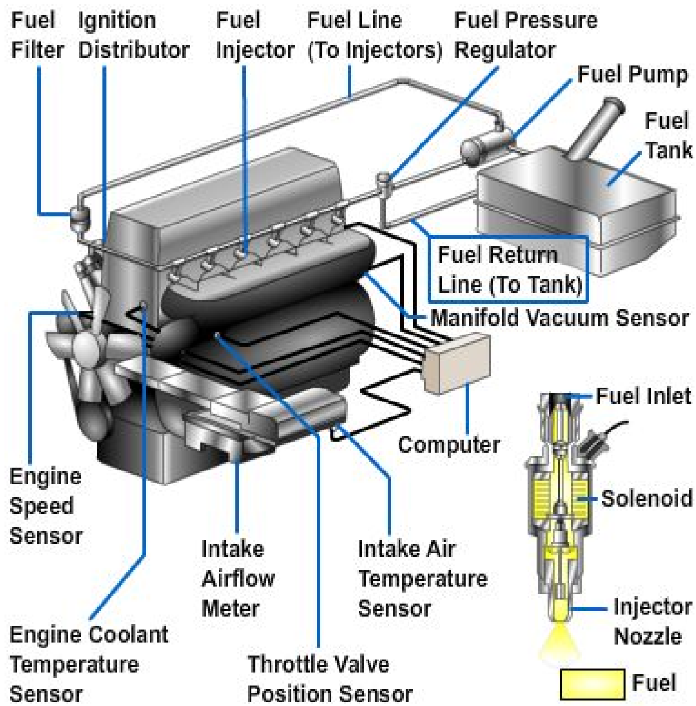

Figure 4-8 — Electronic fuel injection.

pressure entering the injector valves. When sufficient pressure is attained, the regulator returns excess fuel to the tank. This maintains a preset amount of fuel pressure for injector valve operation.

The fuel injector for an EFI system is a coil or ***solenoid***-operated fuel valve. When not energized, spring pressure keeps the injector closed, keeping fuel from entering the engine. When current flows through the injector coil or solenoid, the magnetic field attracts the injector armature. The injector opens, squirting fuel into the intake manifold under pressure.

The air induction system for the EFI typically consists of a throttle valve, sensors, an air filter, and connecting ducts.

The throttle valve regulates how much air flows into the engine. In turn, it controls engine power output. Like the carburetor throttle valve, it is connected to the gas pedal. When the pedal is depressed, the throttle valve swings open to allow more air to rush into the engine.

The EFI sensor system monitors engine operating conditions and reports this information to the computer. A sensor is an electrical device that changes circuit resistance or voltage with a change in a condition (temperature, pressure, position of parts, etc.). For example, the resistance of a temperature sensor may decrease as temperature increases. The computer can use the increased current flow through the sensor to calculate any needed change in the injector valve opening. Typical sensors for an EFI system include the following:

- Exhaust gas or oxygen sensor
- Manifold pressure sensor
- Throttle position sensor
- Engine temperature sensor
- Air flow sensor
- Inlet air temperature sensor
- Crankshaft position sensor

Since some of these sensors were discussed in the section on computerized carburetor systems, we will concentrate only on the sensors that are particular to the EFI system. These sensors are as follows:

The throttle position sensor is a variable resistor connected to the throttle plate shaft.

When the throttle swings open for more power or closes for less power, the sensor changes resistance and signals the computer. The computer can then enrich or lean the mixture as needed.

The air flow sensor is used in many EFI systems to measure the amount of outside air entering the engine. It is usually an air flap or door that operates a variable resistor. Increased air flow opens the air flap more to change the position of the resistor. Information is sent to the computer indicating air inlet volume.

The inlet air temperature sensor measures the temperature of the air entering the engine. Cold air is denser, requiring a little more fuel. Warm air is not as dense as cold, requiring a little less fuel. The sensor helps the computer compensate for changes in outside air temperature and maintain an almost perfect air-fuel mixture ratio.

The crankshaft position sensor is used to detect engine speed. It allows the computer to change injector openings with changes in engine rpm.

The signal from the engine sensors can be either a digital or an analog type output. Digital signals are on/off signals. An example is the crankshaft position sensor that shows engine rpm. Voltage output or resistance goes from maximum to minimum, like a switch. An analog signal changes in strength to let the computer know about a change in condition. Sensor internal resistance may smoothly increase or decrease with temperature, pressure, or part position. The sensor acts as a variable resistor.

Basic operation of an electronic-timed injection system is as follows:

Fuel is fed by a high-pressure electric fuel pump to the injectors that are connected in parallel to a common fuel line.

The fuel pressure regulator is installed in line with the injectors to keep fuel pressure constant by diverting excess fuel back to the tank.

Each injector contains a solenoid valve and is normally in a closed position. With a pressurized supply of fuel behind it, each injector will operate individually whenever electric current is applied to the solenoid valve.

The electronic computer sends the electric impulses and provides the proper amount of fuel. The computer receives a signal for the ignition distributor to establish the timing sequence.

By sending electric current impulses to the injectors in a sequence timed to coincide with the needs of the engine, the system will supply fuel to the engine as it should.

2.2.0 Throttle Body Injection System

The throttle body injection (TBI) system uses one or two injector valves mounted in a throttle body assembly (*Figure 4-9*). The injectors spray fuel into the top of the throttle body air horn The TBI fuel spray mixes with the air flowing through the air horn. The mixture is then pulled into the engine by intake manifold vacuum. The throttle body injection assembly typically consists of the following: throttle body housing, fuel injectors, fuel pressure regulator, Idle air control sensor, throttle position sensor, and throttle plates.

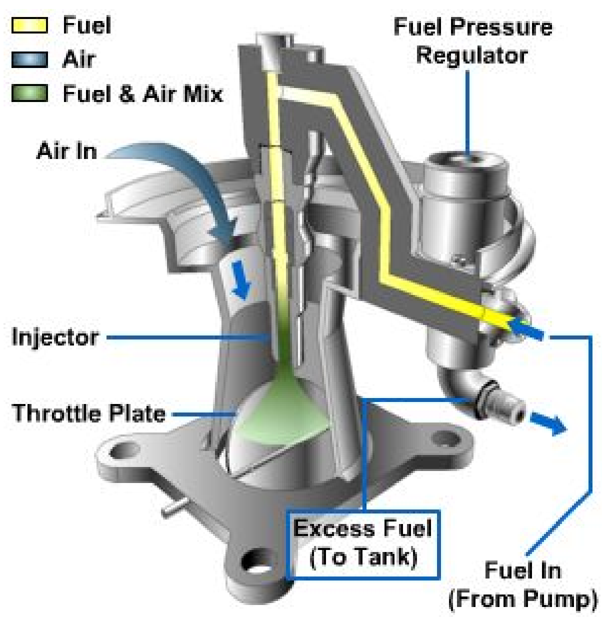

Figure 4-9 — Throttle body injection.

The throttle body housing, like a carburetor body, bolts to the pad on the intake manifold.

It houses the metal castings that hold the injectors, the fuel pressure regulator, and the throttle plates. The throttle plates are located in the lower section of the body. A linkage or cable connects the throttle plates with the accelerator pedal. An inlet fuel line and an outlet return line connect to the fittings on the body.

The throttle body injector consists of an electric solenoid coil, armature or plunger, ball or needle valve and seat, and injector spring. Wires from the computer connect to terminals on the injectors. When the computer energizes the injectors, a magnetic field is produced in the injector coil. The magnetic field pulls the plunger and valve up to open the injector. Fuel can then squirt through the injector nozzle and into the engine.

The throttle body pressure regulator consists of a fuel valve, a diaphragm, and a spring. When fuel pressure is low, the spring holds the fuel valve closed, causing pressure to build as fuel flows into the regulator from the fuel pump. When a preset pressure is reached, pressure acts on the diaphragm. The diaphragm compresses the spring and opens the fuel valve. Fuel can then flow back to the fuel tank, limiting the maximum fuel pressure at the injectors.

Although throttle body injection does not provide the precise fuel distribution of the direct port injection, it is much cheaper to produce and provides a much higher degree of precision fuel metering than a carburetor.

2.3.0 Multi-Port Injection

Multi-port injection systems use a computer, engine sensors, and one solenoid injector for each cylinder. This is the most common fuel injection system in late model vehicles. The multi-port injection system operates similar to that of a throttle body injection system, except that the fuel is injected at each intake port instead of at the top of the intake manifold.

A fuel rail feeds fuel to the injectors. It connects the main fuel line to the inlet of each injector. The injector is pressure fit into a port in the intake manifold. Each injector is aimed to spray fuel toward the engine's intake valve. Each injector is connected to the computer and is electronically fired just before the intake valve is to open.

2.4.0 Direct Injection

Direct injection has been around for many years on a diesel engine. With gasoline direct injection (GDI), the gasoline is injected directly into the combustion chamber (*Figure 4-10*). To make this possible, specially designed injectors deliver fuel into the high pressures and temperatures in the cylinders. To prevent heat from igniting the fuel in the injector, the injectors are designed to completely seal after the fuel is sprayed. The injectors must also be able to spray the fuel at a higher pressure than what is in the cylinder.

GDI allows for very lean operation during cruising. When the engine is operating under heavy loads, the system provides near perfect air-fuel mixture. The ability to run at such lean mixtures allows for increased fuel economy, nearly 30%.

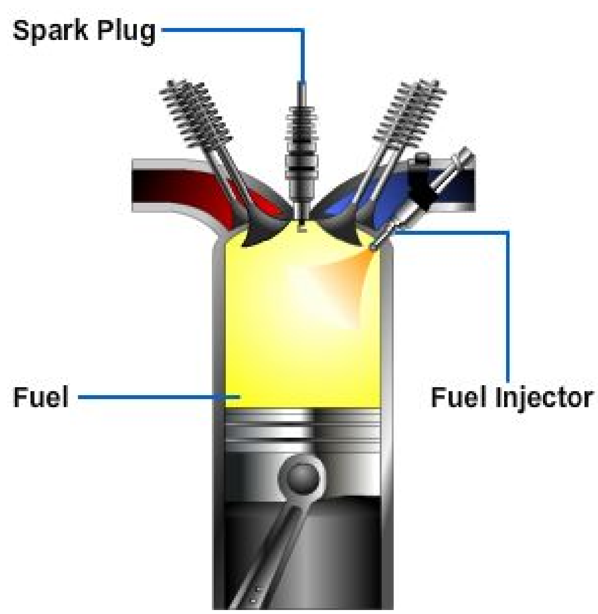

Figure 4-10 — Gasoline direct injection.

Spraying the fuel directly into the cylinder also increases volumetric efficiency. GDI decreases an engine's tendency to knock, allowing for a higher compression ratio without the need for a higher octane gasoline.

With GDI, fuel can be injected at any time, not just during intake. The injectors can pulse twice during the transition from the compression stroke to combustion. The two pulses promote complete combustion when the PCM senses operating conditions may prevent a complete burning of fuel.

The fuel is injected into the cylinder under enormous pressure, typically between 400 and 1,500 psi. The injector delivers a relatively small, precisely shaped burst of fuel around the spark plug just before ignition. This means only the area around the spark plug has air and fuel to begin combustion; the rest of the chamber is filled with air.

The fuel pump that delivers this high pressure is driven by the engine. The pump is fed by an in-tank electric fuel pump. A PCM controls the timing of injection and ignition for each cylinder.

Test your Knowledge (Select the Correct Response)

4. A gasoline injection system has all these advantages over a carburetor, except which one?

   A. Improved atomization
   B. Better fuel distribution
   C. Lower horse power
   D. Lower emissions

5. What gasoline fuel injection system is the most precise and also the most complex?

   A. Hydraulic-timed
   B. Throttle body fuel
   C. Timed fuel
   D. Continuous fuel

3.0.0 EXHAUST and EMISSION CONTROL SYSTEMS

Over the past several years, exhaust and emission control has greatly increased because of stringent anti-pollution laws and EPA guidelines. This has made the exhaust and emission control systems of vehicles invaluable and a vital part of today's vehicles.

The waste products of combustion are carried away from the engine to the rear of the vehicle by the exhaust system where they are expelled to the atmosphere. The exhaust system also serves to dampen engine noise. The parts of a typical exhaust system include the following: exhaust manifold, header pipe, catalytic converter, intermediate pipe, muffler, tailpipe, hangers, heat shields, and muffler clamps.

The control of exhaust emissions is a difficult job. The ideal situation would be to have the fuel combine completely with the oxygen from the intake air. The carbon would then combine with the oxygen to form carbon dioxide (CO_2), the hydrogen would combine to form water (H_2O), and the nitrogen present in the intake would stand alone. The only other product present in the exhaust would be the oxygen from the intake air that was not used in the burning of the fuel. In a real life situation, however, this is not what happens. The fuel never combines completely with the oxygen, and undesirable exhaust emissions are created as a result.

The most dangerous of the emissions is carbon monoxide (CO), which is a poisonous gas that is colorless and odorless. CO is formed as a result of insufficient oxygen in the combustion mixture and combustion chamber temperatures that are too low. Other exhaust emissions that are considered major pollutants are as follows:

Hydrocarbons (HC) are unburned fuel. They are particulate (solid) in form, and, like carbon monoxide, are manufactured by insufficient oxygen in the combustion mixture and combustion chamber temperatures that are too low. Hydrocarbons are harmful to all living things. In any urban area where vehicular traffic is heavy, hydrocarbons in heavy concentrations react with the sunlight to produce a brown fog known as photochemical smog.

Oxides of nitrogen (NO_x) are formed when nitrogen and oxygen in the intake air combine when subjected to high temperatures of combustion. Oxides of nitrogen are harmful to all living things.

The temperatures of the combustion chamber would have to be raised to a point that would melt pistons and valves to eliminate carbon monoxide and carbon dioxide emissions. Furthermore, oxides of nitrogen emissions go up with any increase in the combustion chamber temperature. Knowing these facts, you can see why emission control devices are necessary.

3.1.0 Exhaust Manifold

The exhaust manifold connects all the engine cylinders to the exhaust system. It is usually made of cast iron. If the exhaust manifold is properly formed, it can create a scavenging action that will cause all of the cylinders to help each other get rid of exhaust gases. Back pressure (the force that the pistons must exert to push out the exhaust gases) can be reduced by making the manifold with smooth walls and without any sharp bends. All these factors are taken into consideration when the exhaust manifold is designed, and the best possible manifold is manufactured to fit into the confines of the engine compartment.

3.2.0 Catalytic Converters

It is impossible to keep carbon monoxide and hydrocarbon emissions at acceptable levels by controlling them in the cylinder without shortening engine life considerably. The most practical method of controlling these emissions is outside the engine using a catalytic converter. The catalytic converter is similar in appearance to the muffler and is positioned in the exhaust system between the engine and muffler. As the engine exhaust passes through the converter, carbon monoxide and hydrocarbons are oxided (combined with oxygen), changing them into carbon dioxide and water.

The catalytic converter contains a material (usually platinum or palladium) that acts as a catalyst. The catalyst is something that causes a reaction between two substances without actually getting involved. In the case of the catalytic converter, oxygen is joined chemically with carbon monoxide and hydrocarbons in the presence of its catalyst. Because platinum and palladium are both very precious metals and the catalyst must have a tremendous amount of surface area in order to work properly, it has been found that the following internal structures work best for catalytic converters:

Pellet type is filled with aluminum oxide pellets that have a very thin coating of catalytic material (*Figure 4-11, View A*). Aluminum oxide has a rough outer surface, giving each pellet a tremendous amount of surface area. The converter contains baffles to ensure maximum exposure of the exhaust to the pellets.

Monolithic type uses a one-piece ceramic structure in a honeycomb style form (*Figure 4-11, View B*). The structure is coated thinly with a catalytic material. The honeycomb shape has a tremendous surface area to ensure maximum exposure of exhaust gases to the catalyst.

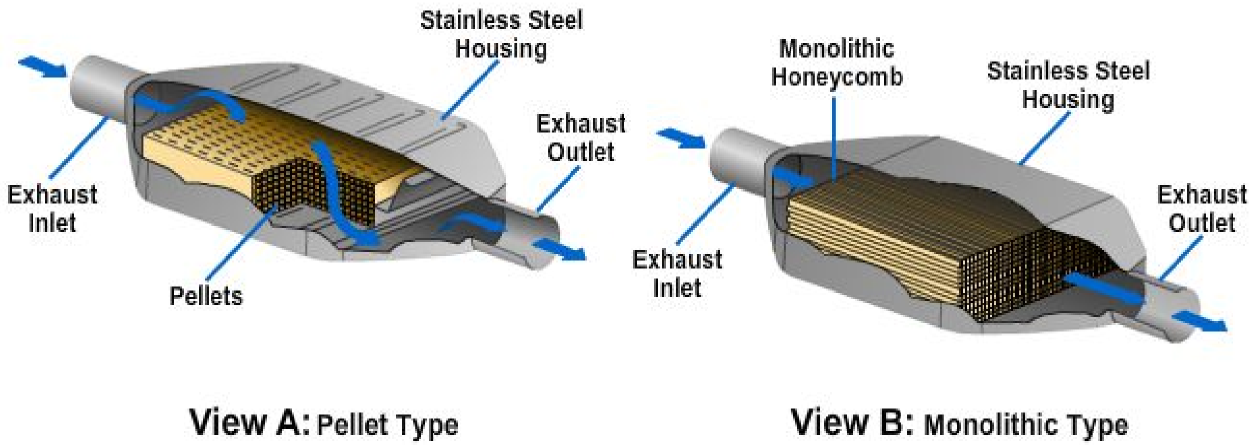

Figure 4-11— Catalytic converter.

An adequate amount of oxygen must be present in the exhaust system for the catalytic converter to operate; therefore, a supporting system, such as an air injection system, usually is placed on catalytic converter-equipped engines to dilute the exhaust stream with fresh air.

3.3.0 Muffler

The muffler reduces the acoustic pressure of exhaust gases and discharges them to the atmosphere with a minimum of noise (*Figure 4-12*). The muffler usually is located at about midpoint in the vehicle with the exhaust pipe between it and the exhaust manifold, and the tailpipe leading from the muffler to the rear of the vehicle.

The inlet and outlet of the muffler usually are slightly larger than their connecting pipes so that they may hook up by slipping over them. The muffler is then secured to the exhaust pipe and tailpipe by clamps.

A typical muffler has several concentric chambers with openings between them. The gas enters the inner chamber and expands as it works its way through a series of holes in the other chambers and finally to the atmosphere. They must be designed also to quiet exhaust noise while creating minimum back pressure. High back pressure could cause loss of engine power and economy as well as overheating.

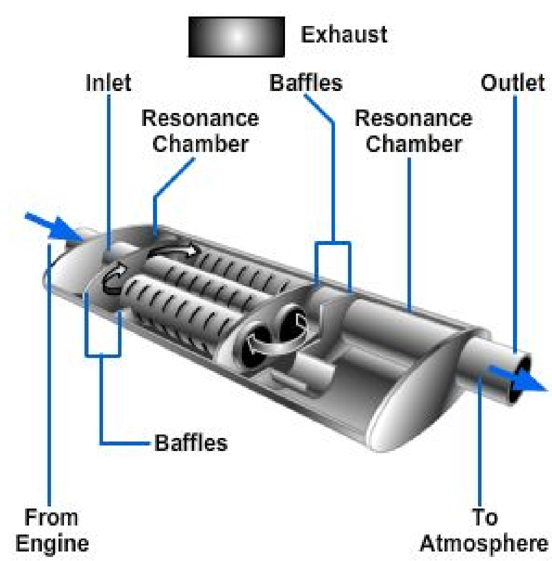

Figure 4-12 — Muffler.

Exhaust system components usually are made of steel. They are coated with aluminum or zinc to retard corrosion. Stainless steel also is used in exhaust systems in limited quantities due to its high cost. A stainless steel exhaust system will last indefinitely.

3.4.0 Air Injection System

An air injection system forces fresh air into the exhaust ports of the engine to reduce HC and CO emissions (*Figure 4-13*). The exhaust gases leaving an engine can contain unburned and partially burned fuel. Oxygen from the air injection system causes this fuel to continue to burn. The major parts of the system are the air pump, the diverter valve, the air distribution manifold, and the air check valve.

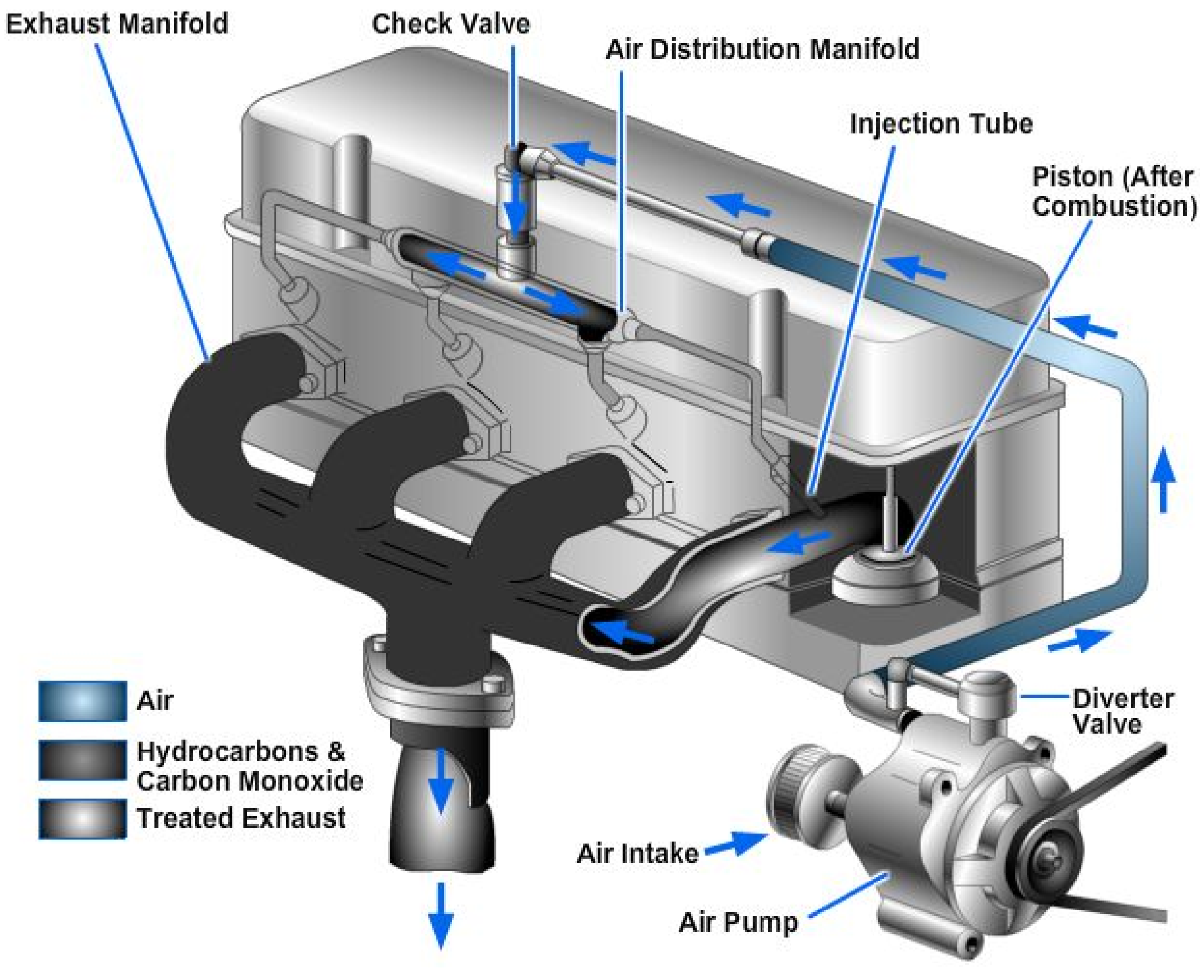

Figure 4-13 — Air injection system.

The air pump is belt-driven and forces air at low pressure into the system. A hose is connected to the output of the diverter valve.

The diverter valve keeps air from entering the exhaust system during deceleration. This prevents backfiring in the exhaust system. Also, the diverter valve limits maximum system air pressure when needed, releasing excessive pressure through a silencer or a muffler.

The air distribution manifold directs a stream of fresh air toward each engine exhaust valve. Fittings on the air distribution manifold screw into a threaded hole in the exhaust manifold or cylinder head.

The air check valve is usually located in the line between the diverter valve and the air distribution manifold. It keeps exhaust gases from entering the air injection system.

Basic operation of the air injection system is as follows:

When the engine is running, the spinning vanes of the air pump force air into the diverter valve. If the engine is not decelerating, the air is forced through the diverter valve, the check valve, the air injection manifold, and into the engine. The fresh air blows on the exhaust valves.

During periods of deceleration, the diverter valve blocks air flow into the engine exhaust manifold. This prevents a possible backfire that could damage the exhaust system of the vehicle. When needed, the diverter valve will release excess pressure in the system.

3.5.0 Positive Crankcase Ventilation (PCV) System

The positive crankcase ventilation system uses manifold vacuum to purge the crankcase blow-by fumes. The fumes are then aspirated back into the engine where they are reburned.

A hose is tapped into the crankcase at a point that is well above the engine oil level. The other end of the hose is tapped into the intake manifold.

An inlet breather is installed on the crankcase in a location that is well above the level of the engine oil. The inlet breather also is located strategically to ensure complete purging of the crankcase fresh air. The areas of the crankcase where the vacuum hose and inlet breather are tapped have baffles to keep motor oil from leaving the crankcase.

A flow control valve is installed in the line that connects the crankcase to the manifold. It is called a positive crankcase ventilation (PCV) valve (*Figure 4-14*) and serves to avoid the air-fuel mixture by doing the following:

Any periods of large throttle opening will be accompanied by heavy engine loads. Crankcase blow-by will be at its maximum during heavy engine loads. The PCV valve will react to the small amount of manifold vacuum that also is present during heavy engine loading by opening fully through the force of its control valve spring. In this way, the system provides maximum effectiveness during maximum blow-by periods.

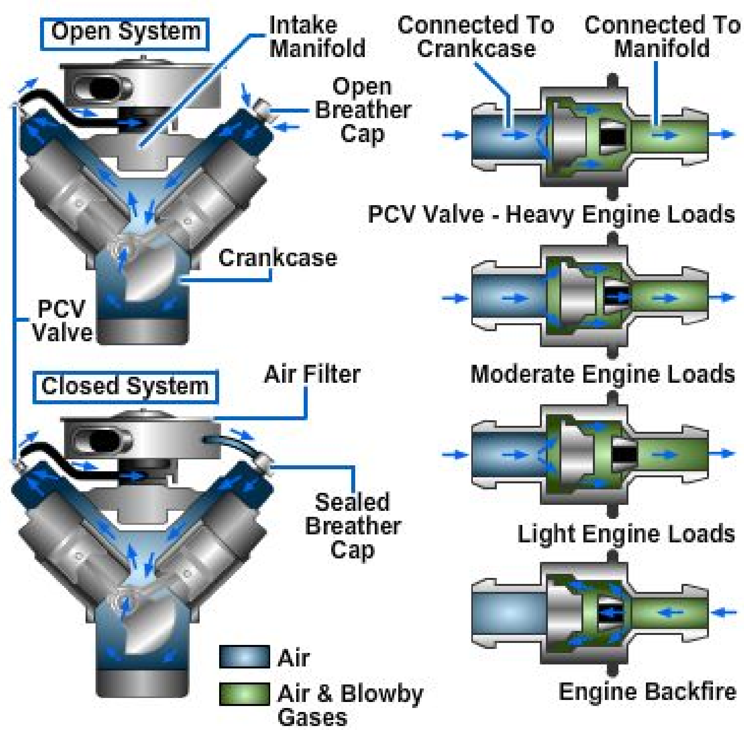

Figure 4-14 — Positive crankcase ventilation system.

Any period of small throttle opening will be accompanied by small engine loads, high manifold vacuum, and a minimum amount of crankcase blow-by. During these periods, the high manifold vacuum will pull the PCV valve to its position of minimum opening. This is important to prevent an excessively lean air-fuel mixture.

In the event of engine backfire (flame traveling back through the intake manifold), the reverse pressure will push the rear shoulder of the control valve against the valve body.

This will seal the crankcase from the backfire which could otherwise cause an explosion.

A PCV system keeps the inside of the engine clean and reduces air pollution. Older engines used an open PCV system. This system is no longer in use. The closed system uses a sealed oil filler cap, a sealed dip stick, ventilation hoses, and either a PCV valve or flow restrictor. The gases are drawn into the engine and burned. The system stores the gases when the engine is not being run.

3.6.0 Exhaust Gas Recirculation (EGR) System

The exhaust gas recirculation system allows burned gases to enter the engine intake manifold to help reduce oxides of nitrogen (NO_x) emissions. When exhaust gases are added to the air-fuel mixture, they decrease peak combustion temperatures (maximum temperature produced when the air-fuel mixture burns). For this reason, an exhaust gas recirculation system lowers the amount of NO_x in the engine exhaust. EGR systems can be controlled by engine vacuum or by the engine control module.

Vacuum controlled EGR systems use engine vacuum to operate the EGR valve (*Figure 4-15*). This system is found on older vehicles.

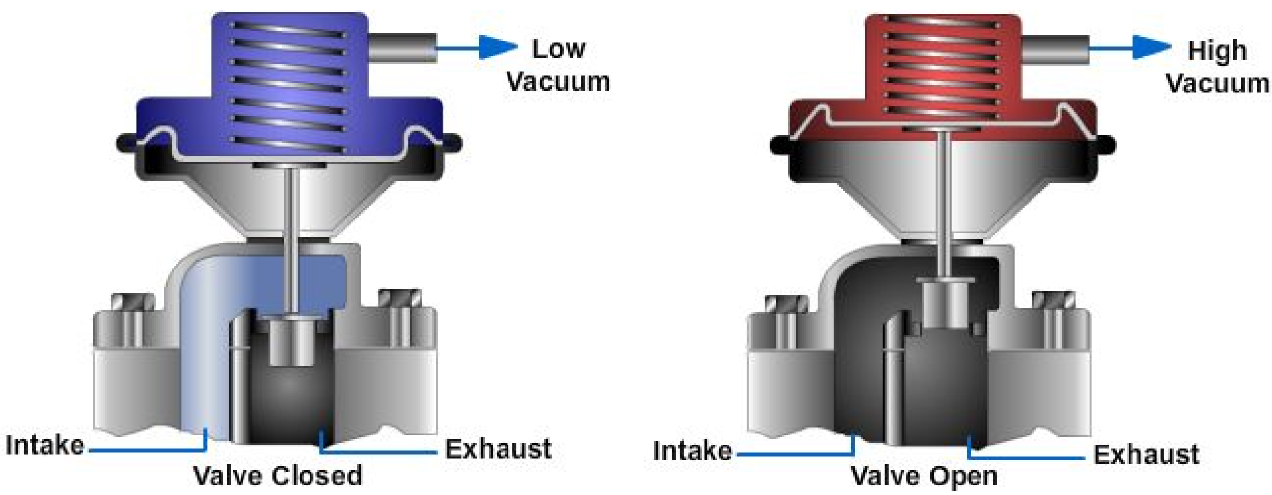

Figure 4-15 — Vacuum controlled EGR valve.

The basic vacuum EGR system consists of a vacuum-operated EGR valve and a vacuum line from the throttle body or carburetor. The EGR valve is bolted to the engine intake manifold to control the air-fuel ratio and reduce exhaust emissions. Exhaust gases are routed through the cylinder head and intake manifold to the EGR valve.

The EGR valve consists of a vacuum diaphragm, spring, plunger, exhaust gas valve, and diaphragm housing. It is designed to control exhaust flow into the intake when the throttle is opened and the increased vacuum pulls the diaphragm open on the EGR valve, in turn opening the exhaust outlet to allow exhaust gas into the intake manifold.

An electronic-vacuum EGR valve uses both engine vacuum and electronic control for better exhaust gas metering. An EGR position sensor is located on top of the EGR valve. This sensor sends data to the ECM and allows the computer to determine how far to open the EGR valve.

Electronic EGR systems use vehicle sensors, the ECM, and a solenoid-operated EGR valve. This is the most common type of EGR system used on late model engines.

The ECM uses data from the EGR position sensor, engine coolant temperature sensor, mass airflow sensor, throttle position sensor, crankshaft position sensor, and various other sensors to control the air fuel ratio and reduce exhaust emission. The data collected will determine the duty cycle for the EGR valve to allow certain amounts of gases to be recirculated for maximum efficiency.

3.7.0 Fuel Evaporation Control System

The fuel evaporization control system prevents vapors from the fuel tank and carburetor from entering the atmosphere (*Figure 4-16*). Older, pre-emission vehicles used vented fuel tank caps. Carburetor bowls were also vented to the atmosphere. This caused a considerable amount of emissions. Modern vehicles commonly use fuel evaporization control systems to prevent this source of pollution. The major components of the fuel evaporization control systems are the sealed fuel tank cap, fuel air dome, liquid-vapor separator, rollover valve, fuel tank vent line, charcoal canister, carburetor vent line, and the purge line.

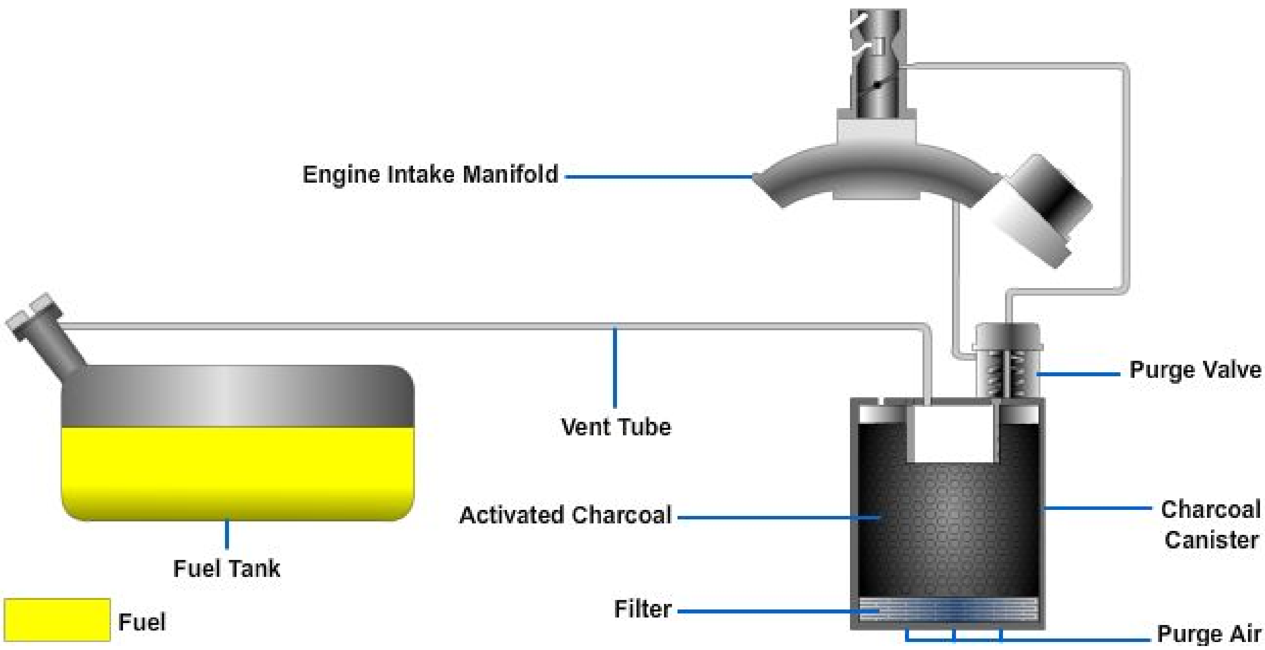

Figure 4-16 — Fuel evaporation system.

The sealed fuel tank cap is used to keep fuel vapors from entering the atmosphere through the tank filler neck. It may contain pressure and vacuum valves that open in extreme cases of pressure or vacuum. When the fuel expands (from warming), tank pressure forces fuel vapors out a vent line or line at the top of the fuel tank, not out of the cap.

The fuel air dome is a hump designed into the top of the fuel tank to allow for fuel expansion. The dome normally provides about 10 percent air space to allow for fuel heating and volume increase.

The liquid-vapor separator is frequently used to keep liquid fuel from entering the evaporation control system. It is simply a metal tank located above the main fuel tank. Liquid fuel condenses on the walls of the separator and then flows back into the fuel tank.

The roll-over valve is sometimes used in the vent line from the fuel tank. It keeps liquid fuel from entering the vent line after an accident where the vehicle rolled upside down. The valve contains a metal ball or plunger valve that blocks the vent line when the valve is turned over.

The fuel tank vent line carries fuel vapors up to a charcoal canister in the engine compartment.

The charcoal canister stores fuel vapors when the engine is not running. The metal or plastic canister is filled with activated charcoal granules capable of absorbing fuel vapors.

The purge line is used for removing or cleaning the stored vapors out of the charcoal canister. It connects the canister and the engine intake manifold.

Basic operation of a fuel evaporization control system is as follows:

When the engine is running, intake manifold vacuum acts on the purge line, causing fresh air to flow through the filter at the bottom of the canister. The incoming fresh air picks up the stored fuel vapors and carries them through the purge line. The vapors enter the intake manifold and are pulled into the combustion chambers for burning.

When the engine is shut off, engine heat produces excess vapors. These vapors flow through the vent line and into the charcoal canister for storage. The vapors that form in the tank flow through the liquid vapor separator into the tank vent line to the charcoal canister. The charcoal canister absorbs these fuel vapors and holds them until the engine is started again.

3.8.0 Oxygen Sensor

The oxygen sensor monitors the exhaust gases for oxygen content. The amount of oxygen in the exhaust gases is a good indicator of the engine's operational state. The oxygen sensor's voltage output varies with any changes in the exhaust's oxygen content. For example, an increase in oxygen, which would indicate a lean mixture, will make the sensor output voltage decrease. A decrease in oxygen which occurs during rich mixture conditions causes the sensor output voltage to increase.

In this way, the oxygen sensor supplies data to the computer. The computer can then alter the opening and closing of the injectors to maintain a correct air-fuel ratio for maximum efficiency.

3.8.1 Pre Oxygen Sensor

A pre oxygen (O2) sensor is the O2 sensor located in front of the catalytic converter. The signal from the pre O2 sensor indicates whether the engine's air-fuel mixture is too lean or too rich.

3.8.2 Post Oxygen Sensor

The post oxygen sensor is located further down the exhaust system after the catalytic converter. It checks the oxygen content of the exhaust gases to determine if the converter is working properly. If the oxygen content after the converter is the same as before, it will send a signal to the trouble light on the dash board to let the operator know there is a problem with the catalytic converter.

3.8.3 Heated Oxygen Sensor

The heated oxygen sensor (HO2) uses an electrical heating element to warm the sensor to normal operating temperature. This element will stabilize the temperature and operation of the sensor. The heating element allows the computer system to utilize the sensor's input sooner since the sensor operates at a higher temperature.

Test your Knowledge (Select the Correct Response)

6. Of the following chemical compounds, which one is the most dangerous emission?

   A. Carbon dioxide
   B. Carbon monoxide
   C. Hydrocarbons
   D. Oxides of nitrogen

7. The exhaust gas recirculation system allows burned gases to enter the engine intake manifold to help reduce what gas?

   A. Carbon dioxide
   B. Carbon monoxide
   C. Hydrocarbons
   D. Oxides of nitrogen

Summary

Your knowledge of the gasoline fuel system will enable you to evaluate certain engine problems with confidence. The ability to diagnose a gasoline fuel system will help the environment because your ability to determine that the problem is in the exhaust system will alleviate some of the pollutants being dispersed into the atmosphere. Technicians and engineers have developed automobile parts and various systems to help extend fuel economy, gain horsepower, and lower emissions.

Review Questions (Select the Correct Response)

1. What types of additives are used in gasoline to slow down ignition?

   A. Antiping
   B. Antiknock
   C. Anticombustion
   D. Antioxidants

2. Which property is NOT a property of gasoline?

   A. Volatility
   B. Antiknock quality
   C. Cetane number
   D. Octane rating

3. What term refers to the measurement of the ability of a fuel to resist knock or ping?

   A. Air-fuel ratio
   B. Cetane number
   C. Volatility
   D. Octane rating

4. An air-fuel mixture that is too lean will cause which condition?

   A. Increased power
   B. Increased fuel consumption
   C. Poor engine performance
   D. Decreased exhaust emissions

5. Which is NOT a condition of abnormal combustion?

   A. Detonation
   B. Dieseling
   C. Pre-ignition
   D. Spark ping

6. Which factor can cause dieseling in a gasoline engine?

   A. Low octane fuel
   B. Low heat range spark plugs
   C. Incorrect timing
   D. Hot exhaust valve

7. What device is used in the filler neck of a gasoline fuel tank to prevent the accidental use of leaded fuel?

   A. Fuel valve
   B. Restrictor
   C. Vacuum valve
   D. Fuel nozzle

8. What is the function of the baffles in a fuel tank?

   A. To reinforce the bottom of the fuel tank
   B. To reinforce the sides of the fuel tank
   C. To prevent the fuel from sloshing and splashing
   D. To prevent the escape of fuel and fuel vapors from the tank

9. Fuel filters are NOT made of which material?

   A. Sintered brass
   B. Ceramic
   C. Treated paper
   D. Metal screen

10. What is the function of the fuel pump?

   A. To measure the amount of fuel that enters the carburetor or fuel injectors
   B. To deliver the fuel from the tank to the engine under pressure
   C. To pump fuel from the carburetor to the intake manifold
   D. To pump fuel from the carburetor through the fuel filter into the manifold

11. Fuel line tubing is normally made of what material?

   A. Single-wall steel
   B. Double-wall steel
   C. Single-wall copper
   D. Double-wall copper

12. Which attribute is NOT an advantage of a gasoline injection system over a carburetor type system?

   A. Improved atomization
   B. Better fuel distribution
   C. Richer fuel mixture
   D. Lower emissions

13. In a gasoline indirect injection system, fuel is sprayed into what part?

   A. Precombustion chamber
   B. Cylinder
   C. Combustion chamber
   D. Intake manifold

14. Of the gasoline fuel injection systems, what system is the most precise and also the most complex?

    A. Hydraulic-timed injection
    B. Throttle body fuel injection
    C. Timed fuel injection
    D. Continuous fuel injection

15. In a mechanical-timed injection system, the throttle valve regulates engine speed and power output by regulating the _______.

    A. intake pressure
    B. manifold vacuum
    C. exhaust pressure
    D. metering pump vacuum

16. Which is NOT a subsystem of an electronic-timed fuel injection system?

    A. Fuel delivery system
    B. Air induction system
    C. Computer control system
    D. Fuel metering system

17. In an electronic fuel injection system, what sensor measures the amount of outside air entering the engine?

    A. Air flow
    B. Inlet air temperature
    C. Manifold pressure
    D. Oxygen

18. In an electronic fuel injection system, where does the fuel pressure regulator divert the excess fuel?

    A. Back to the fuel tank
    B. To the inlet side of the fuel filter
    C. To the inlet side of the fuel pump
    D. Back to the inlet side of the fuel line

19. What component of a throttle body injection system contains the fuel pressure regulator?

    A. Throttle air horn
    B. Throttle body housing
    C. Throttle positioner
    D. Throttle fuel mixture valve

20. In a multi port fuel injection system, what component supplies fuel to the injectors?

A. Fuel tube
B. Fuel rail
C. Siphon pipe
D. Pressure regulator

21. Of the following chemical compounds, which is the most dangerous emission?

A. Carbon dioxide
B. Carbon monoxide
C. Hydrocarbons
D. Oxides of nitrogen

22. Exhaust manifolds are made from what type of material?

A. Aluminum
B. Steel
C. Cast iron
D. Iron alloy

23. What device is used to reduce the acoustic pressure of exhaust gases and discharge the gases into the atmosphere?

A. Resonator
B. Catalytic converter
C. Muffler
D. Exhaust manifold

24. The catalytic converter changes carbon monoxide and hydrocarbons into carbon dioxide and _____.

A. hydrogen
B. oxygen
C. methane
D. water

25. What two materials that act as a catalyst can be found inside a catalytic converter?

A. Silver and bronze
B. Bronze and platinum
C. Silver and palladium
D. Platinum and palladium

26. In an air injection system, what device is used to prevent air from entering the exhaust system during deceleration?

    A. Air distribution manifold
    B. Air check valve
    C. Air pump
    D. Diverter valve

27. What device keeps exhaust gases from entering the air injection system?

    A. Air check valve
    B. Diverter valve
    C. Air distribution manifold
    D. Air pump

28. **(True or False)** The open type positive crankcase ventilation system has a sealed breather that is connected to the air filter by a hose.

    A. True
    B. False

29. To control the formation of oxides of nitrogen, the exhaust gas recirculation system recirculates a portion of the exhaust gases back through the _______.

    A. intake manifold
    B. exhaust manifold
    C. muffler
    D. catalytic converter

30. At idle, engine vacuum is blocked off so it cannot act on the EGR valve. This is accomplished by a closed _______.

    A. diverter valve
    B. vacuum diaphragm
    C. throttle plate
    D. heat control valve

31. What valve prevents fuel from entering the fuel tank vent line in the event of a accident in which the vehicle turns over?

    A. Purge
    B. Fuel tank
    C. Roll-over
    D. Spillage

32. **(True or False)** The charcoal canister does NOT store fuel vapors when the engine is running.

    A. True
    B. False

33. What component connects the charcoal canister to the engine intake manifold and is used to clean out stored fuel vapors from the charcoal canister?

A. Purge line
B. Carburetor vent line
C. Fuel tank vent line
D. Liquid-vapor separator

Trade Terms Introduced in this Chapter

Emissions	Any release of toxic substances into the environment.
Spark plugs	A device that emits an electrical arc at the tip to ignite the air-fuel mixture if an engine.
Contaminated	The intrusion of a foreign substance that ruins the quality of the original element.
Synchronized	The coordination of events to operate a system in unison.
Solenoid	A loop of wire, often wrapped around a metallic core, which produces a magnetic field when an electric current is passed through it. It can create a controlled magnetic field and can be used as an electromagnet.

Additional Resources and References

This chapter is intended to present thorough resources for task training. The following reference works are suggested for further study. This is optional material for continued education rather than for task training.

Modern Automotive Technology Seventh Edition, James E. Duffy, The Goodheart-Willcox Company, Inc., 2009. (ISBN 978-1-59070-956-6)

Automotive Technology, A systems Approach Fourth Edition, Jack Erjavec, The Thomson-Delmar Learning Company, Inc., 2005. (ISBN 1-4018-4831-1)

Diesel Technology Seventh Edition, Andrew Norman and John “Drew” Corinchock, The Goodheart-Wilcox Company, Inc., 2007. (ISBN-13: 978-1-59070-770-8)

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