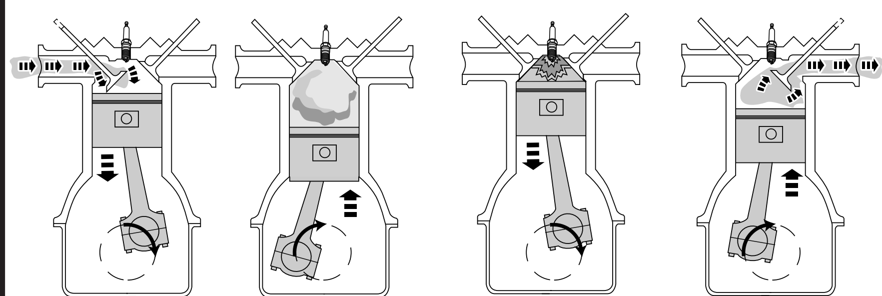
Technical Service Training

Global Fundamentals

Curriculum Training – TF1010009S

Engine Operation



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Global fundamentals training overview

The goal of the Global Fundamentals Training is to provide students with a common knowledge base of the theory and operation of automotive systems and components. The Global Fundamentals Training Curriculum (FCS-13203-REF) consists of nine self-study books. A brief listing of the topics covered in each of the self-study books appears below.

- Shop Practices (FCS-13202-REF) explains how to prepare for work and describes procedures for lifting materials and vehicles, handling substances safely, and performing potentially hazardous activities (such as welding). Understanding hazard labels, using protective equipment, the importance of environmental policy, and using technical resources are also covered.
- Brake Systems (FCS-13201-REF) describes the function and operation of drum brakes, disc brakes, master cylinder and brake lines, power-assist brakes, and anti-lock braking systems.
- Steering and Suspension Systems (FCS-13196-REF) describes the function and operation of the power-assisted steering system, tires and wheels, the suspension system, and steering alignment.
- Climate Control (FCS-13198-REF) explains the theories behind climate control systems, such as heat transfer and the relationship of temperature to pressure. The self-study also describes the function and operation of the refrigeration systems, the air distribution system, the ventilation system, and the electrical control system.
- Electrical Systems (FCS-13197-REF) explains the theories related to electricity, including the characteristics of electricity and basic circuits. The self-study also describes the function and operation of common automotive electrical and electronic devices.
- Manual Transmission and Drivetrain (FCS-13199-REF) explains the theory and operation of gears. The self-study also describes the function and operation of the drivetrain, the clutch, manual transmissions and transaxles, the driveshaft, the rear axle and differential, the transfer case, and the 4x4 system.
- Automatic Transmissions (FCS-13200-REF) explains the function and operation of the transmission and transaxle, the mechanical system, the hydraulic control system, the electronic control system, and the transaxle final drive. The self-study also describes the theory behind automatic transmissions including mechanical powerflow and electro-hydraulic operation.
- Engine Operation (FCS-13195-REF) explains the four-stroke process and the function and operation of the engine block assembly and the valve train. Also described are the lubrication system, the intake air system, the exhaust system, and the cooling system. Diesel engine function and operation are covered also.
- Engine Performance (FCS-13194-REF) explains the combustion process and the resulting emissions. The self-study book also describes the function and operation of the powertrain control system, the fuel injection system, the ignition system, emissions control devices, the forced induction systems, and diesel engine fuel injection. Read Engine Operation before completing Engine Performance.

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Objectives

Upon completion of this lesson, you will be able to:

- Explain the purpose and function of the internal combustion engine.
- Describe the types of internal combustion engines.
- Explain the process by which burning fuel is turned into rotary motion.
- Explain the purpose of an engine.
- Identify the major components and systems of an internal combustion engine.
- Explain the process by which rotary motion is transferred from the engine to the vehicle wheels.
- Describe the four-stroke cycle.

Purpose and function

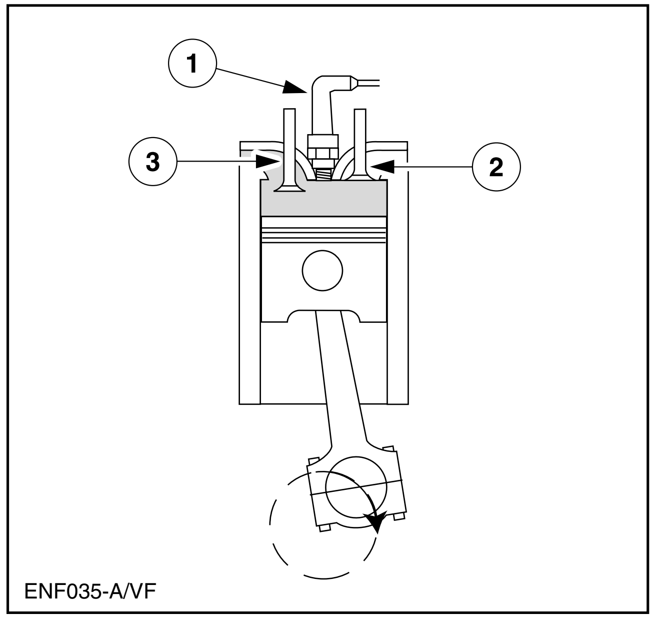
The internal combustion engine provides power to move the vehicle. A typical internal combustion engine is either a gasoline or diesel design. The type of fuel used in gasoline and diesel engines is different because of the method used for ignition of the fuel. The mechanical operation of each engine is nearly identical. In an engine, fuel is burned to create mechanical motion. The major components of the internal combustion engine include:

- Cylinder block assembly
- Valve train
- Intake system
- Exhaust system
- Lubrication system
- Cooling system

Gasoline internal combustion engine

The combustion process

Combustion is the process of igniting a mixture of air and fuel. In the combustion process a mixture of air and fuel is drawn into a cylinder and compressed by a moving piston. The compressed mixture is ignited to create energy for vehicle motion.



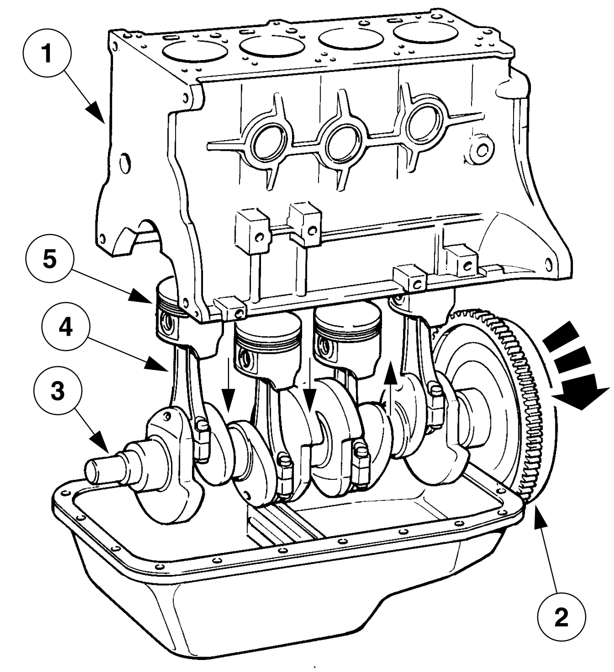
Intake stroke

1 Spark plug
2 Exhaust valve (closed)
3 Intake valve (open)

Creating mechanical motion

When combustion occurs, the gases from the burning air-fuel mixture expand in the cylinder with very high pressure. The high pressure pushes the piston down in the cylinder. The piston is connected to a connecting rod, which is connected to the crankshaft. Because the piston is connected in this way to the crankshaft, the crankshaft begins to rotate with the motion of the piston. The connecting rod and crankshaft convert the up and down motion of the piston into rotary motion.

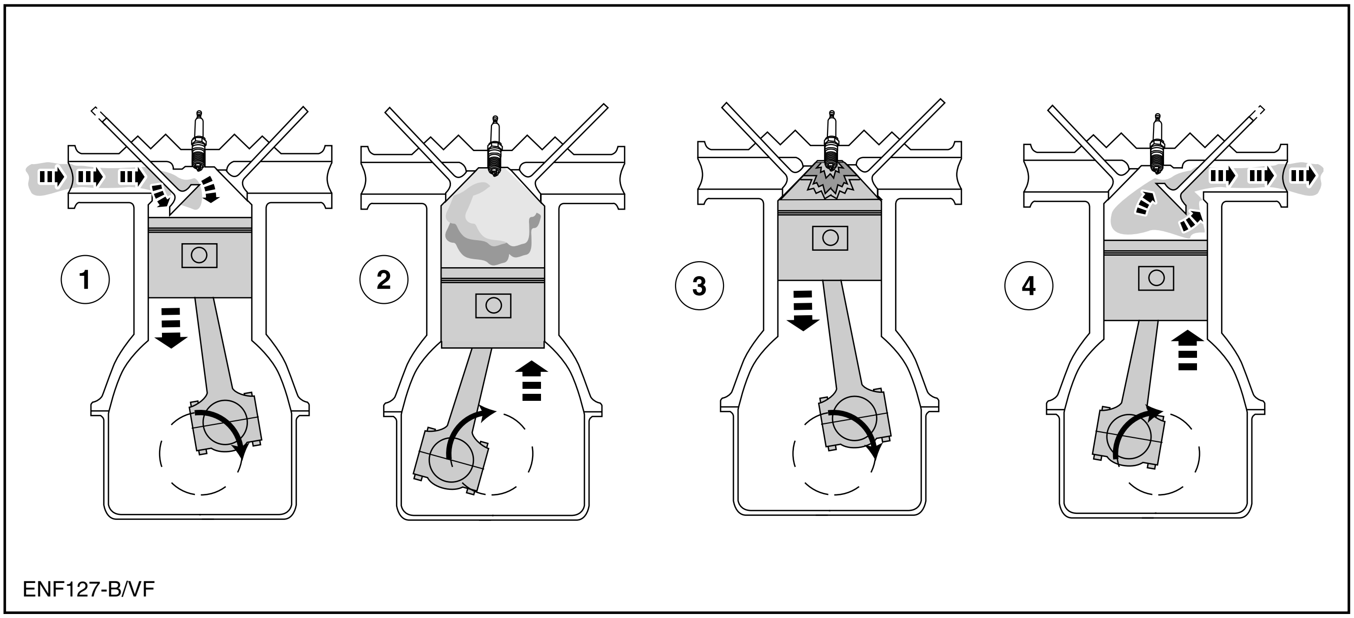
As combustion occurs in each cylinder, pulses of energy are transferred from the pistons to the crankshaft. The flywheel, which is a heavy round metal plate attached to one end of the crankshaft, helps smooth out the power pulses and keeps the crankshaft rotating smoothly. The rotary motion from the engine is transferred to the wheels through the transmission and drivetrain.



Mechanical motion

1 Engine block
2 Flywheel
3 Crankshaft
4 Connecting rod
5 Piston

The four-stroke cycle



The four-stroke cycle

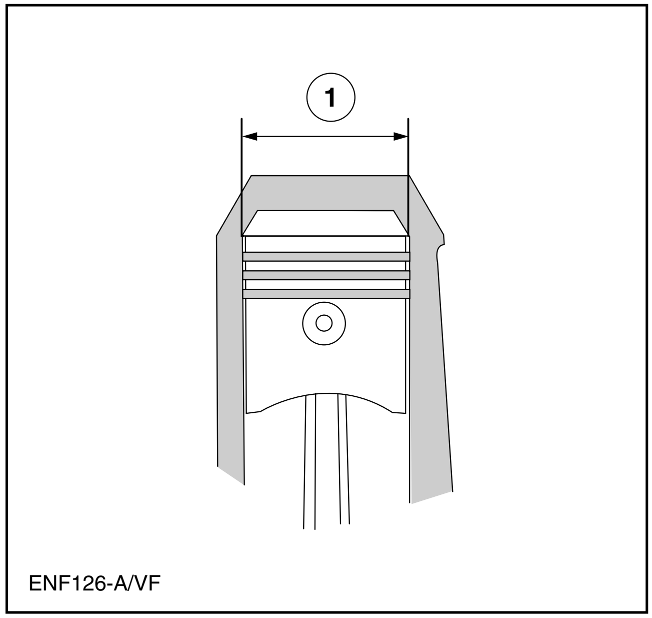
1 Intake stroke
2 Compression stroke
3 Power stroke
4 Exhaust stroke

Nearly all modern vehicle engines are four-stroke cycle engines. Four-stroke means the piston moves the length of the cylinder four times in order to complete one combustion cycle.

Bore, stroke and displacement

Cylinder bore

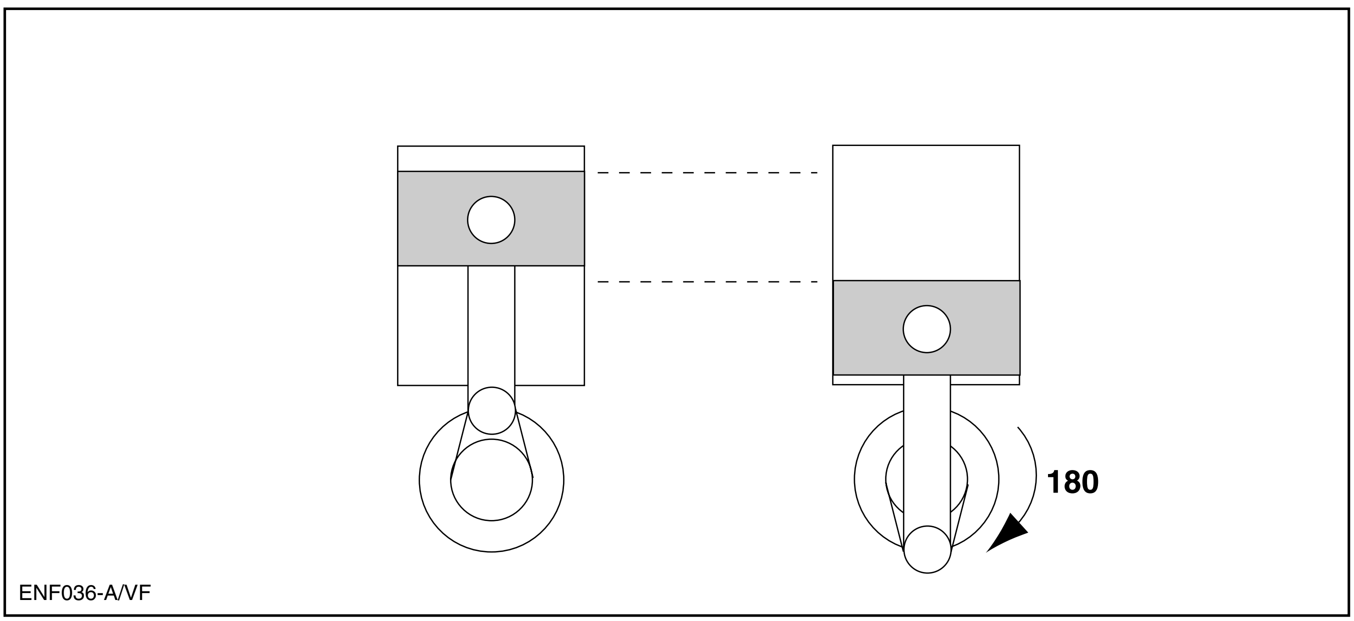
In automotive engine terminology, bore refers to cylinder bore. Cylinder bore is the diameter of the cylinder.



Cylinder bore measurement

1 Cylinder bore

Stroke

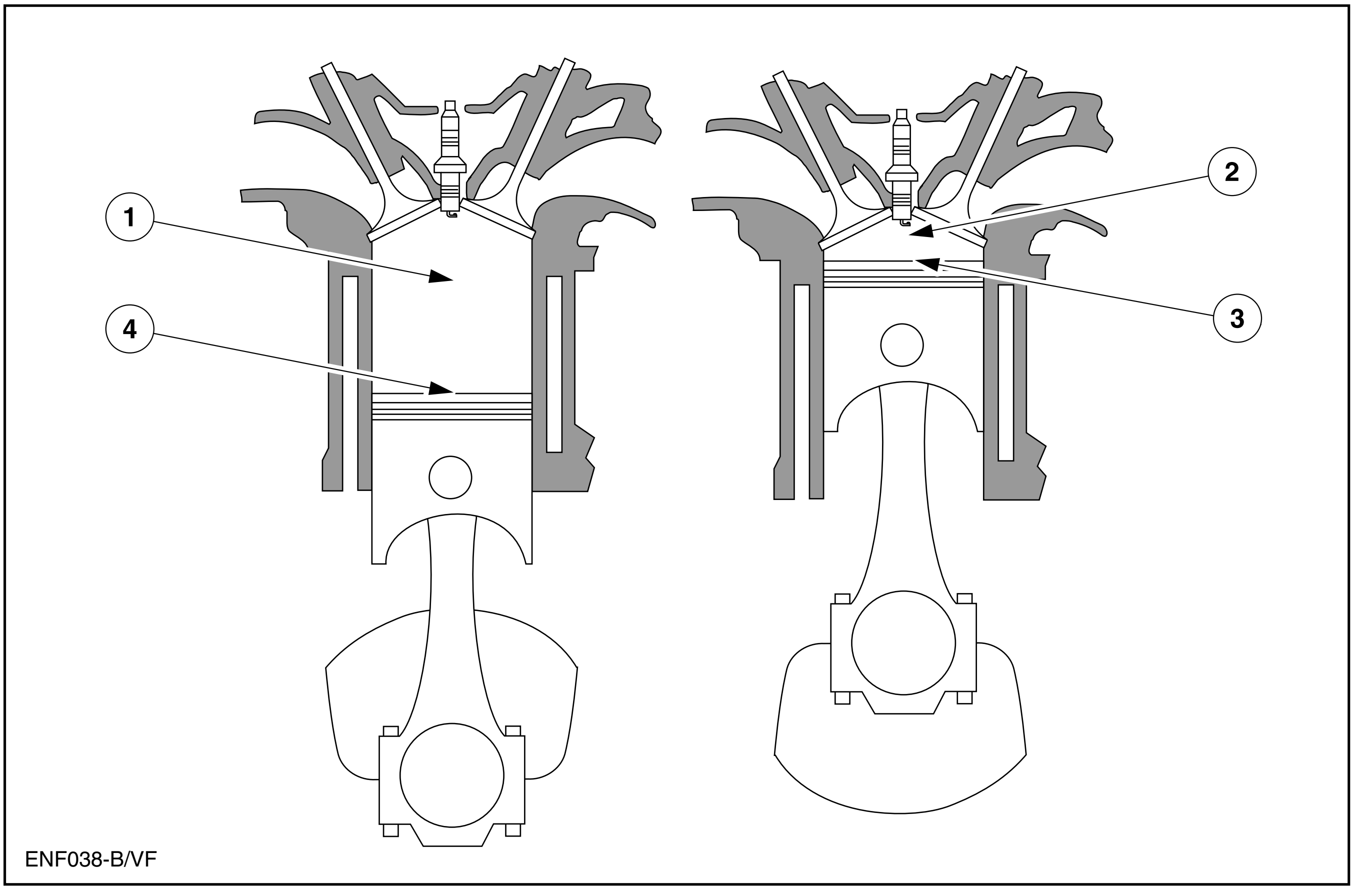


Piston stroke

Stroke refers to piston stroke. Piston stroke is a measurement of the distance a piston travels in the cylinder during crankshaft rotation. The stroke is equal to the distance the piston travels in the cylinder from the lowest point to the highest point.

The highest point of the piston in the cylinder is called top dead center (TDC). The lowest point of the piston in the cylinder is called bottom dead center (BDC). One stroke of a piston takes one half-turn of the crankshaft, or 180 degrees rotation.

Displacement



Displacement

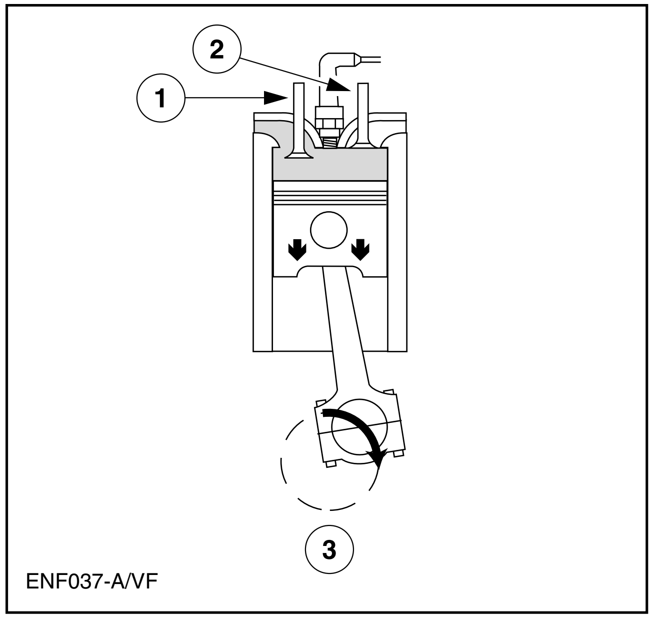
1 Cylinder and combustion chamber volume at BDC
2 Cylinder and combustion chamber volume at TDC
3 Top of piston at TDC
4 Top of piston at BDC

The term displacement refers to two related concepts. Cylinder displacement is the amount of air that is moved or displaced by the piston in a single cylinder when it moves from BDC to TDC in the cylinder. Displacement is expressed as a volume in liters (L), cubic centimeters (cc), or cubic inches (ci).

Total engine displacement is equal to the displacement of one piston multiplied by the total number of cylinders in the engine. For example, each cylinder of a certain four-cylinder engine has a displacement of 0.500 liter. Therefore, total engine displacement is equal to cylinder displacement (0.500 liter) times the number of cylinders (4), or 2.0 liters.

Intake stroke

The intake stroke is considered the first of the four cycles. The rotating crankshaft pulls the piston down from TDC toward BDC. The exhaust valve is closed and the intake valve is open. As the piston moves down, the air-fuel mixture is drawn into the cylinder through the intake valve.



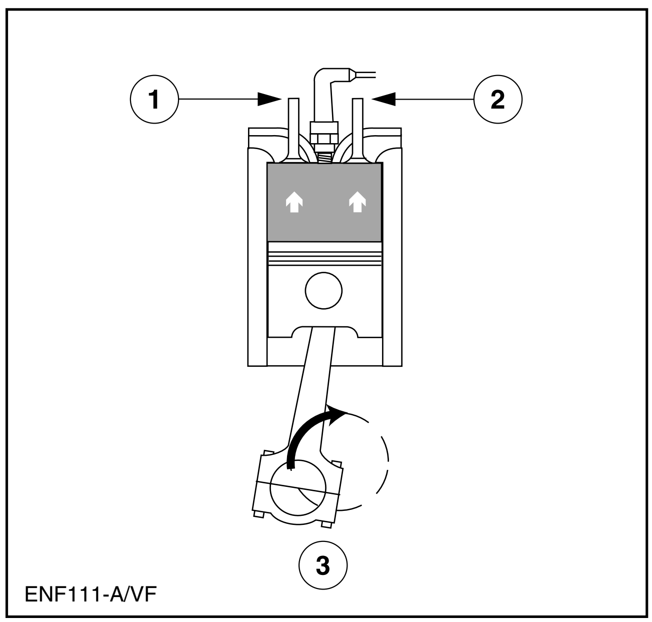
Piston and valves during intake stroke

1 Intake valve open
2 Exhaust valve closed
3 Piston moves downward

Compression stroke

When the piston reaches BDC, the intake stroke ends and the compression stroke begins. The intake valve closes and the exhaust valve stays closed. The crankshaft motion sends the piston back up the cylinder toward TDC. The air-fuel mixture is trapped in the cylinder and is compressed between the piston and cylinder head.

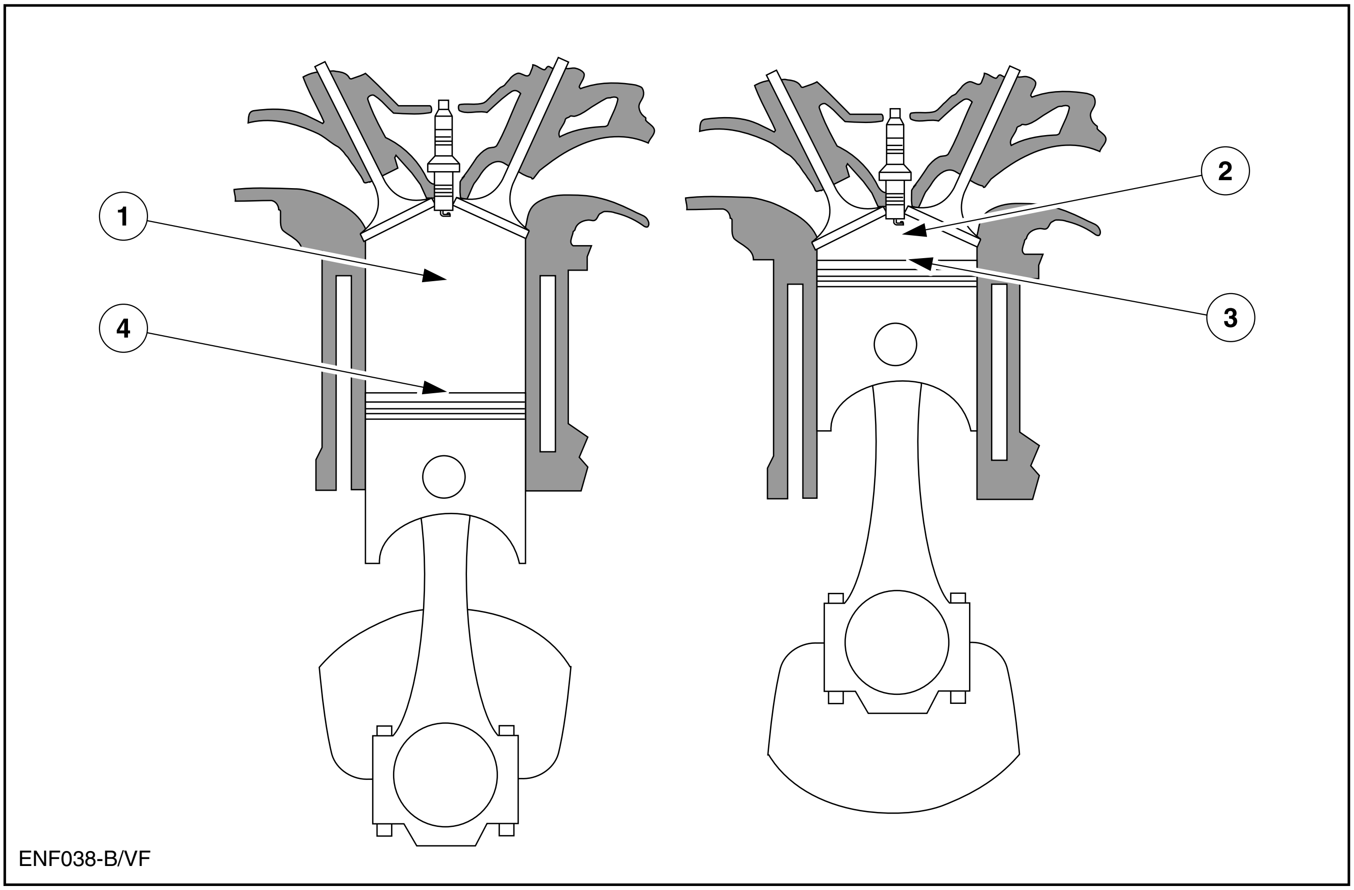
Compression of the air-fuel mixture is very important for developing power. The greater the compression, the more power the mixture creates during combustion. Compression also "pre-heats" the mixture, which helps combustion.



Piston and valves during compression stroke

1 Intake valve closed
2 Exhaust valve closed
3 Piston moves upward

Compression ratio



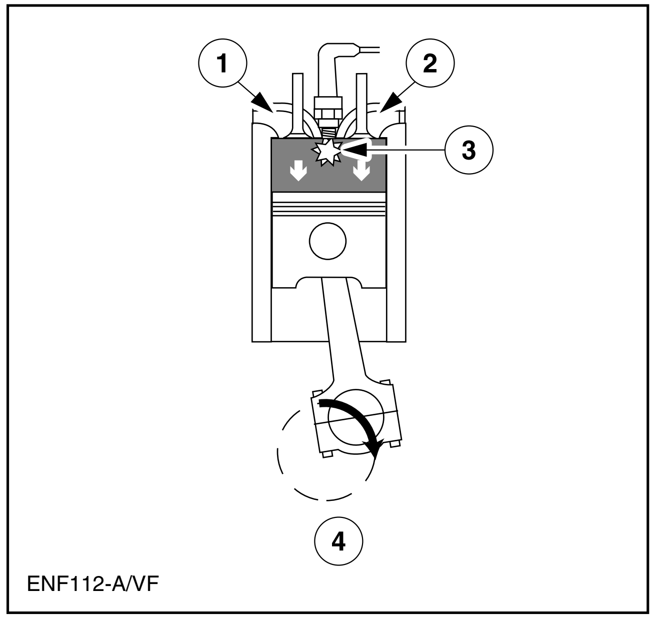
Compression ratio

1 Volume before compression
2 Volume after compression
3 Piston at TDC
4 Piston at BDC

The compression ratio indicates how much the air-fuel mixture is squeezed during the compression stroke. The compression ratio is the volume at TDC compared to the volume at BDC during the compression stroke. For example, a compression ratio of 8 to 1 means the volume at BDC is eight times larger than the volume when the piston is at TDC. Higher compression ratios allow for greater potential power output.

Power stroke

Just before the piston reaches TDC, a spark from the spark plug ignites the air-fuel mixture and the power stroke begins. The burning gases expand rapidly, creating very high pressure on top of the piston as the piston rotates past TDC and moves down the cylinder toward BDC. The intake and exhaust valves remain tightly closed, so all the force is pushing the piston down in the cylinder to turn the crankshaft.



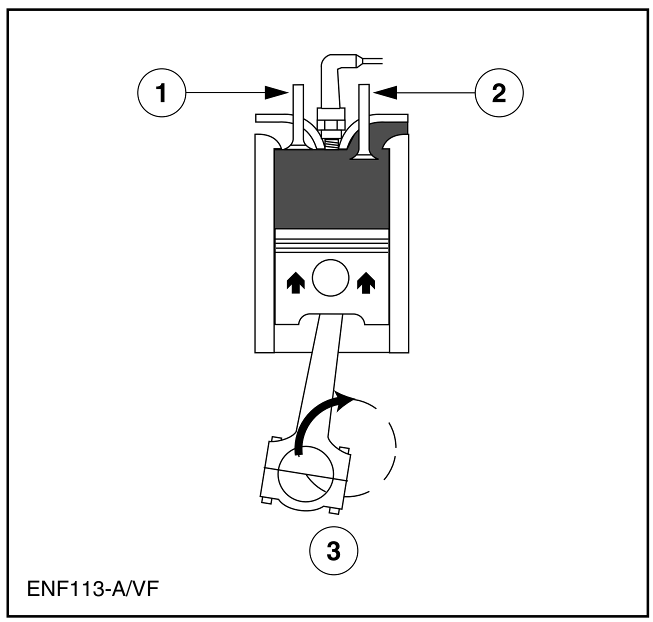
Piston and valves during power stroke

1 Intake valve closed
2 Exhaust valve closed
3 Combustion
4 Piston moves downward

Exhaust stroke

As the piston nears BDC on the power stroke, the exhaust valve begins to open. As the piston passes BDC, the rotating crankshaft pushes the piston back up the cylinder toward TDC and the exhaust valve is fully opened. The piston pushes the burned gases out the exhaust valve, through the cylinder head exhaust port and out the exhaust system.

As the piston passes TDC, the four-stroke cycle begins again with the intake stroke. The exhaust valve stays open momentarily at the beginning of the intake stroke, allowing the momentum of the gases to empty the cylinder completely.



Piston and valves during exhaust stroke

1 Intake valve closed
2 Exhaust valve open
3 Piston moves upward

Summary

We have illustrated the four-stroke cycle in only one cylinder. Remember, the four strokes are continuously repeated in all the cylinders in an alternating pattern. The four strokes of the cycle — intake, compression, power, and exhaust —require two full rotations of the crankshaft. However, the piston receives direct combustion pressure only during the power stroke, or about one quarter of the cycle.

When you realize that no power is being generated during three of the four strokes, you can see why the flywheel is so important. The flywheel “stores” the energy that is generated. The flywheel uses the stored energy to keep the crankshaft rotating smoothly.

Objectives

Upon completion of this lesson, you will be able to:

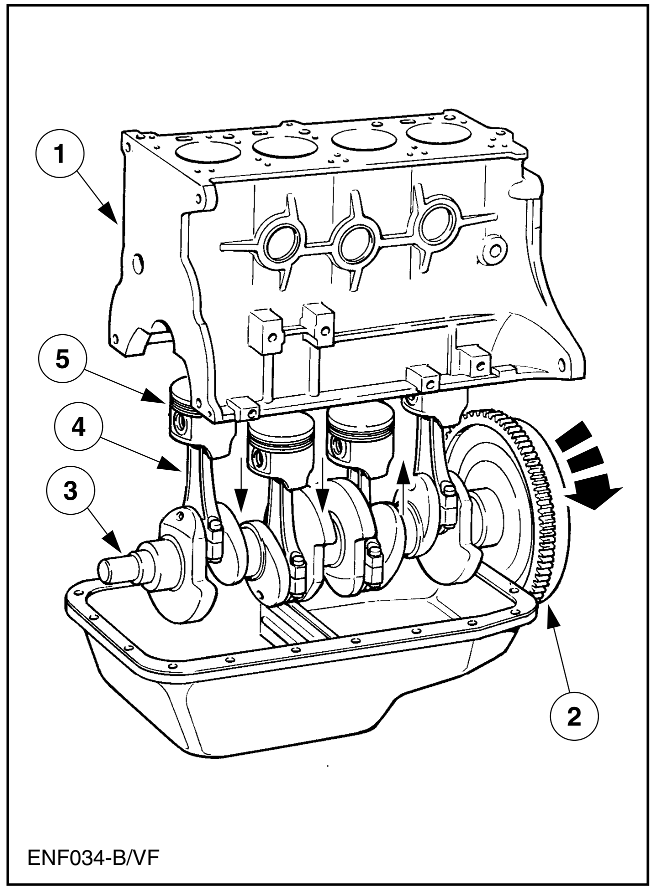
- Explain the purpose and function of the engine block assembly.
- Describe the different types of engine block assemblies.
- Identify the major components of the engine block assembly.
- Explain the theory and operation of the engine block assembly.

Engine block assembly

The engine block is the main supporting member of the engine. Almost every other engine component is either connected to or supported by the engine block. The pistons, connecting rods, and crankshaft work inside the engine block.

The engine block may be either an in-line or “V” type design depending upon the arrangement of the individual cylinders in the block.

The engine block contains the cylinders, internal passages for coolant and oil, and mounting surfaces for attaching engine accessories, such as the oil filter and coolant pump. The cylinder head is mounted on top of the engine block, and the oil pan is mounted on the bottom.



Engine block assembly

1 Engine block
2 Flywheel
3 Crankshaft
4 Connecting rod
5 Piston

Major components

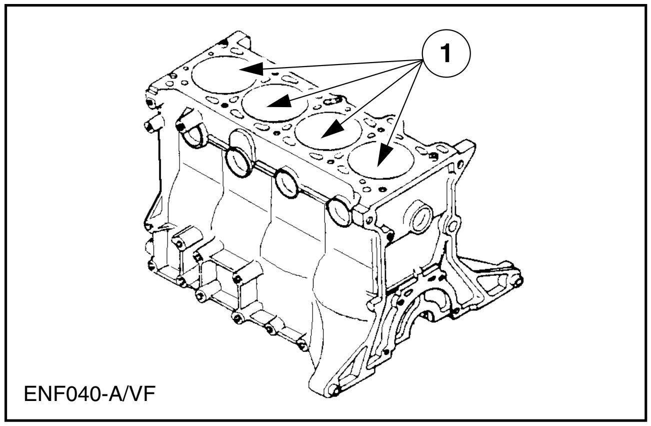
In-line engine block design

In-line engines commonly have 3, 4, 5 or 6 cylinders.

V-Type engine block design

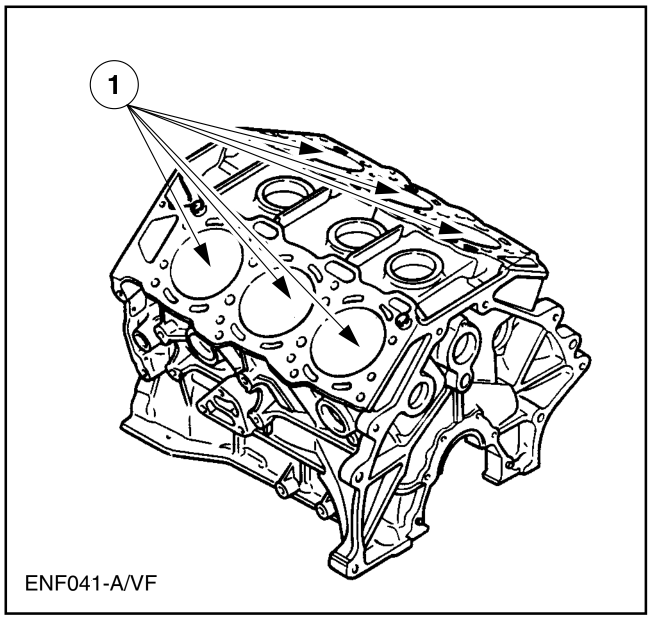
A V-Type engine design has two banks of cylinders arranged in a “V” pattern. Even though the cylinders are in two banks, they are still connected to a common crankshaft.

V-configuration engines commonly have 6, 8, and occasionally 12 cylinders.



Four-cylinder in-line engine block

1 Cylinders



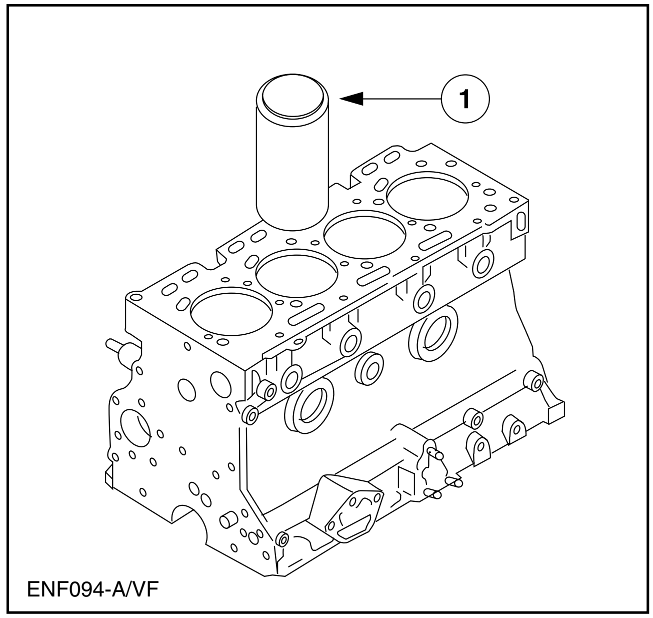
V-6 engine block

1 Cylinders

Engine block and liner

Cylinder liners

Some engine designs use cylinder liners. A cylinder liner is a hardened steel cylinder which is inserted into the engine block. A liner is not required in all engine blocks. Liners are made of a hard material to contain combustion inside the cylinders and reduce wear from piston ring movement. There are two types of cylinder liners: wet liners, and dry liners.

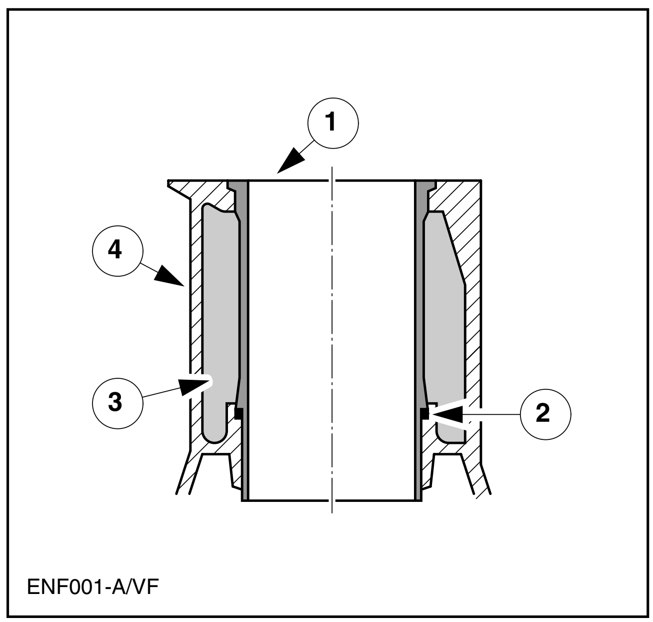


Engine block and liner

1 Cylinder liner

Wet liners

Wet liners are so named because they come into direct contact with engine coolant in the block. Seals are used to prevent coolant from reaching the crankcase. Wet liners are easy to repair since they can be fairly easily changed. This makes it unnecessary to machine the cylinder and eliminates the need for oversized pistons. Wet liners have an increased chance for corrosion because of their design.



Wet liner

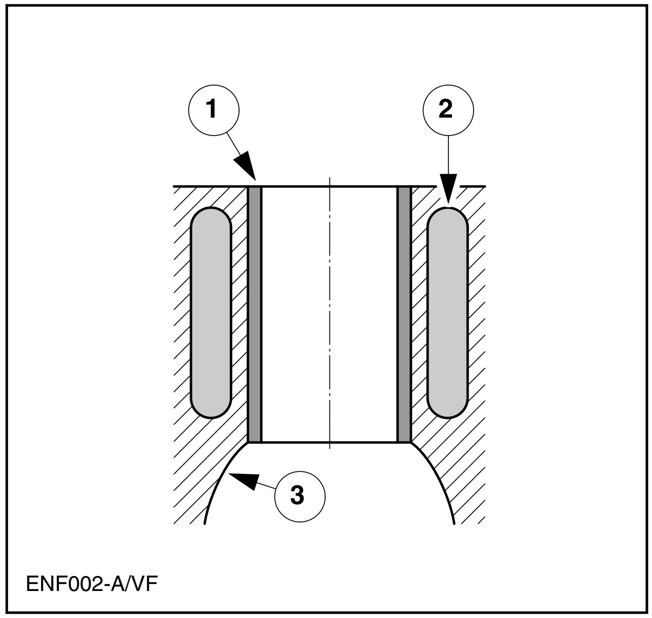
1 Liner
2 Seal
3 Coolant
4 Engine block

Engine block and liner (continued)

Dry liners

Dry liners do not come into direct contact with engine coolant. Dry liners are installed in an engine block by either pressing or shrinking.

The process of shrink-fitting uses the property of metals that allows them to shrink when cold and expand when hot. The dry liner is cooled and the engine block is heated, then the liner is inserted into the block. This method makes it easier to replace the liners.

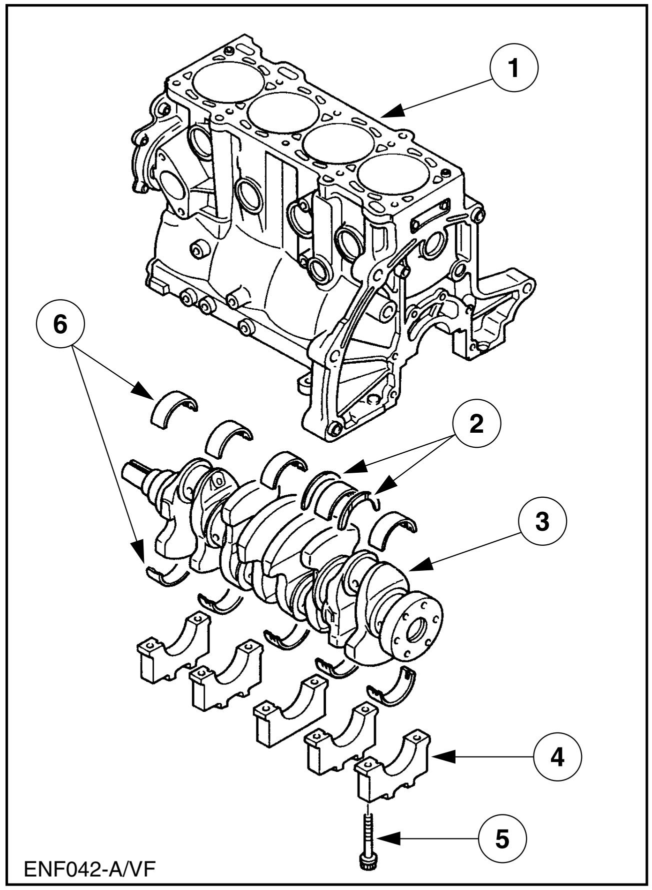


Dry liner

1 Liner
2 Coolant
3 Engine block

Crankcase

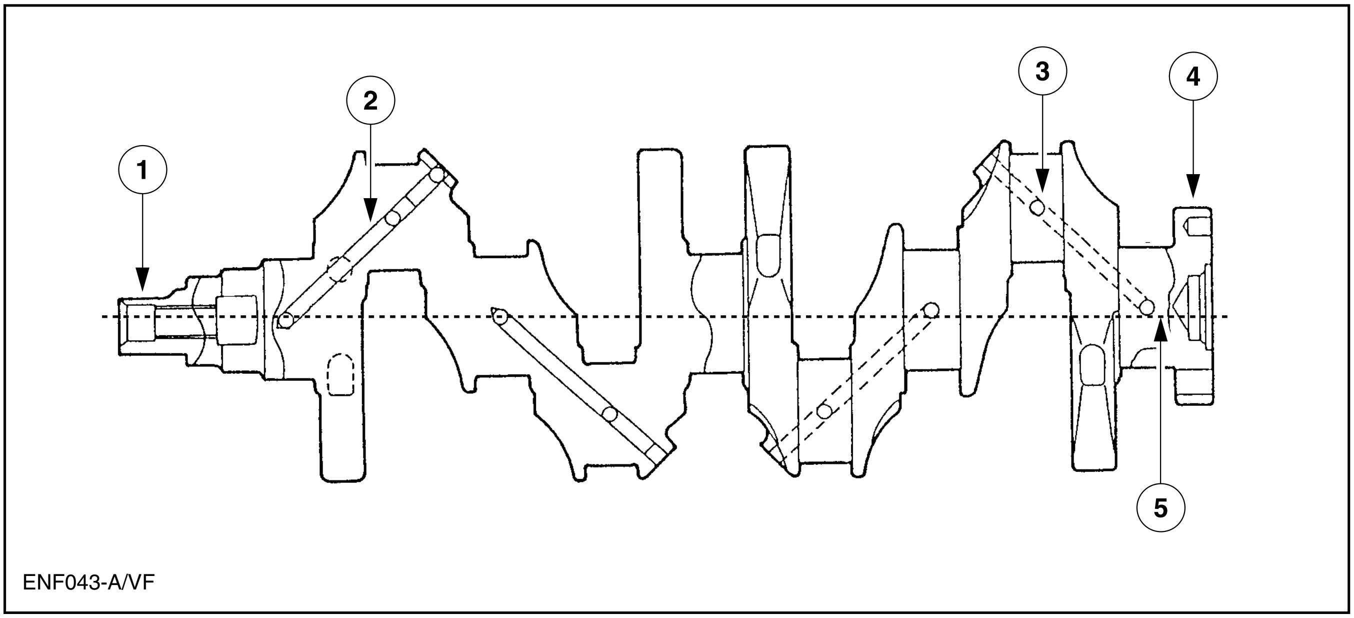
The crankcase supports the crankshaft and main bearings. The bottom of the engine block forms the upper part of the crankcase. The oil pan attached to the bottom of the engine block forms the bottom part of the crankcase. The crankcase includes several support surfaces for the crankshaft. The number of supports varies depending on the length of the crankshaft and cylinder layout. For example, a four-cylinder engine usually has five of these support surfaces. The crankshaft mounts on insert bearings that are installed on the support surfaces and attached with bearing caps. The supports have oil passages that lubricate the crankshaft as it spins against the bearings. These passages align with oil holes in the bearings. The engine block includes a groove for the rear main oil seal, which keeps oil from leaking out at the rear of the crankshaft. The term “main” refers to bearings, seals, and other mounting hardware used on the crankshaft. “Main” distinguishes these mounting parts from other mounting parts that connect to the crankshaft, such as connecting rod bearings.



Crankcase components

1 Engine block
2 Thrust bearings
3 Crankshaft
4 Main bearing caps
5 Main bearing cap mounting bolt
6 Main bearings

Crankshaft



Crankshaft (typical)

1 Front end
2 Oil passage
3 Connecting rod journal
4 Flywheel end
5 Main bearing journal

The crankshaft changes the up-and-down motion of the pistons into the rotational motion needed to drive the wheels of the vehicle. The crankshaft is mounted in the engine block on “U” shaped supports that are cast into the engine block assembly. Caps called main bearing caps are bolted onto the supports to secure the crankshaft onto the block. Between the crankshaft and its mounting surfaces are bearings in which the crankshaft is held and is able to spin. When the block is manufactured, main bearing surfaces are machined to be exactly parallel to the crankshaft. For this reason, main bearing caps must never be interchanged.

The crankshaft withstands the tremendous forces of the pistons’ power strokes. The crankshaft is usually made of heavy, high-strength cast iron. Crankshafts made for high performance or heavy-duty applications usually are made of forged steel. Some crankshafts have counterweights cast opposite the crankpins. Counterweights help balance the crankshaft and prevent vibration during high-speed rotation.

Main bearing journals

Main bearing journals on a crankshaft are highly polished and manufactured to exact roundness so they rotate properly in the bearing inserts. Oil passages drilled into the main journals receive oil flow from the supports in the engine block. Slanted oil passages are drilled from the main journals to the crankpin journals to lubricate the connecting rod bearings.

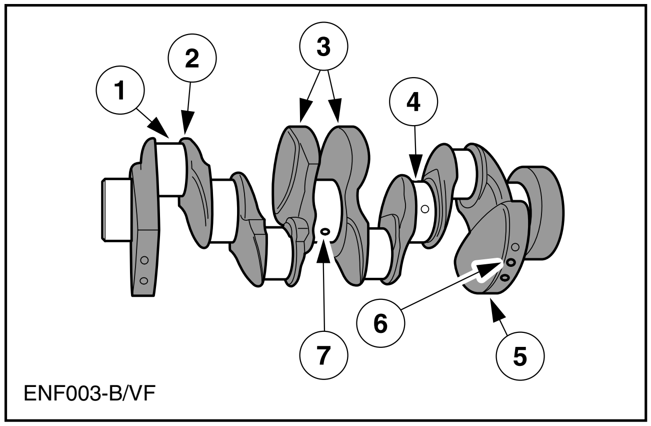
Thrust bearings

In addition, one of the main journals (usually in the middle or rear) is machined with a thrust surface. This surface rides against a special thrust bearing to limit front-to-rear movement of the crankshaft.

Crankshaft journals

The journals on a crankshaft are those areas which serve as bearing surfaces for the crankshaft itself, or the connecting rods which are attached to the crankshaft. The journals for crankshaft bearings are referred to as main bearing journals. The journals for connecting rods are referred to as connecting rod journals.

A common design for an in-line 4-cylinder engine has five main bearing journals and four connecting rod journals. One piston is connected to each connecting rod journal using a connecting rod. V-type cylinder design engines attach two connecting rods to each connecting rod journal.



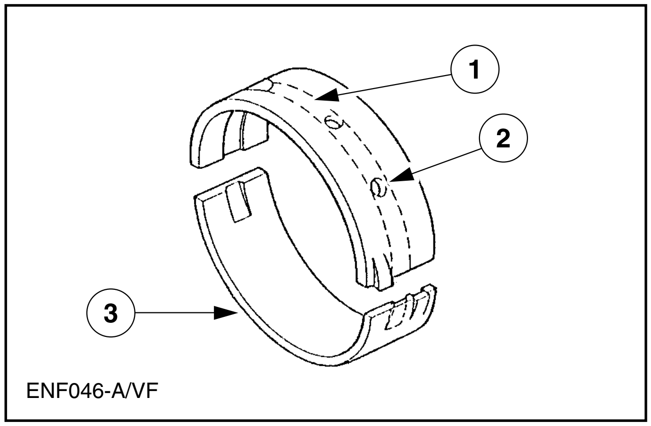
Crankshaft journals

1 Connecting rod journal
2 Crank web
3 Crankshaft counterweights
4 Main bearing journal
5 Balance weight
6 Balance hole
7 Oil bore

Main bearing journals (continued)

Main bearings

Main bearings support the crankshaft into the main bearing journals and main bearing caps. Crankshaft main bearings are split circular sleeves that wrap around the crankshaft main journals. The upper half of the bearing has one or more oil holes which allow lubricant to coat the inside surface of the bearing. The upper bearing fits into a main support on the bottom of the engine block. The lower half of the bearing fits into the bearing cap. The wear surfaces of the bearings are made of softer material than the crankshaft. The softer material reduces friction, and it tends to mold itself around any uneven areas on the main journal. In addition, if wear does occur, it affects the bearing, which is cheaper to replace than the crankshaft.

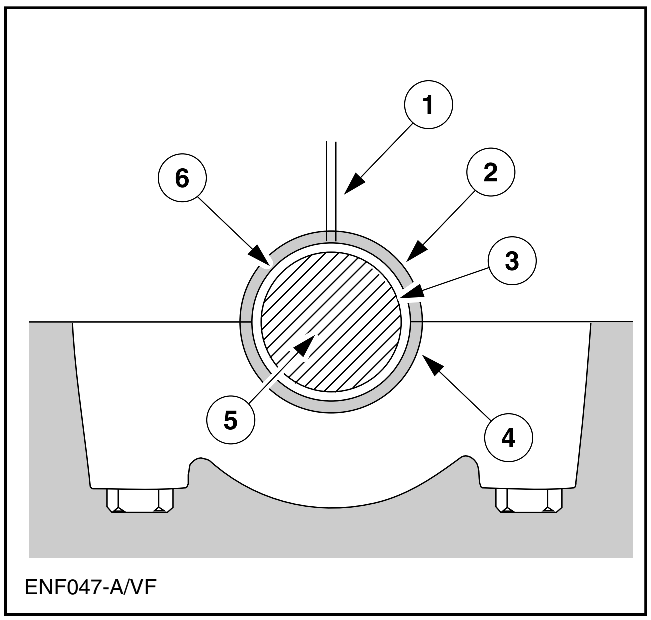


Crankshaft main bearings

1 Upper main bearing
2 Oil hole
3 Lower main bearing

Bearing lubrication

In most engines, the upper and lower bearings are not interchangeable. The upper bearing usually has an oil passage hole in it, allowing oil to flow to the bearing surface of the main journal. Since the crankshaft main journal diameter is a few hundredths of a millimeter smaller than the inside diameter created by the bearings, oil can coat the entire bearing surface.



Crankshaft main bearings installed

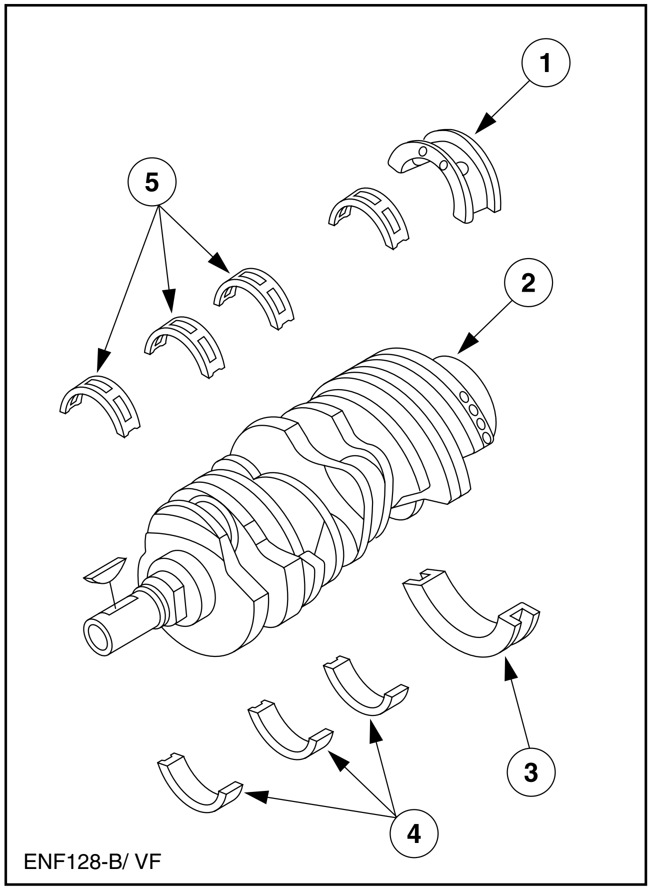
1 Oil passage upper main bearing
2 Upper main bearing
3 Oil film
4 Lower main bearing
5 Crankshaft main journal
6 Bearing clearance

Bearing clearance

The gap between the bearings and crankshaft journal is called bearing clearance. Clearance is one of the most critical measurements in the engine. The oil that lubricates the bearings does not actually stay in a continuous film. As the crankshaft turns, the oil works its way to the outer edges of the bearings, where it is thrown off into the crankcase. New oil constantly feeds through the oil hole to replace the oil thrown off. The constant flow of oil over the bearings helps cool them and flush away grit and dirt from the bearing surfaces. If the clearance is too small, not enough oil is allowed in to lubricate the bearings. The resulting friction wears out the bearings quickly. If the clearance is too large, too much oil flows through the bearings. Oil pressure drops and the crankshaft journal may start to pound against the bearing rather than spin inside it. To prevent damage to the bearings and crankshaft, bearing clearances are set precisely whenever the bearings or crankshaft are repaired.

Thrust bearings

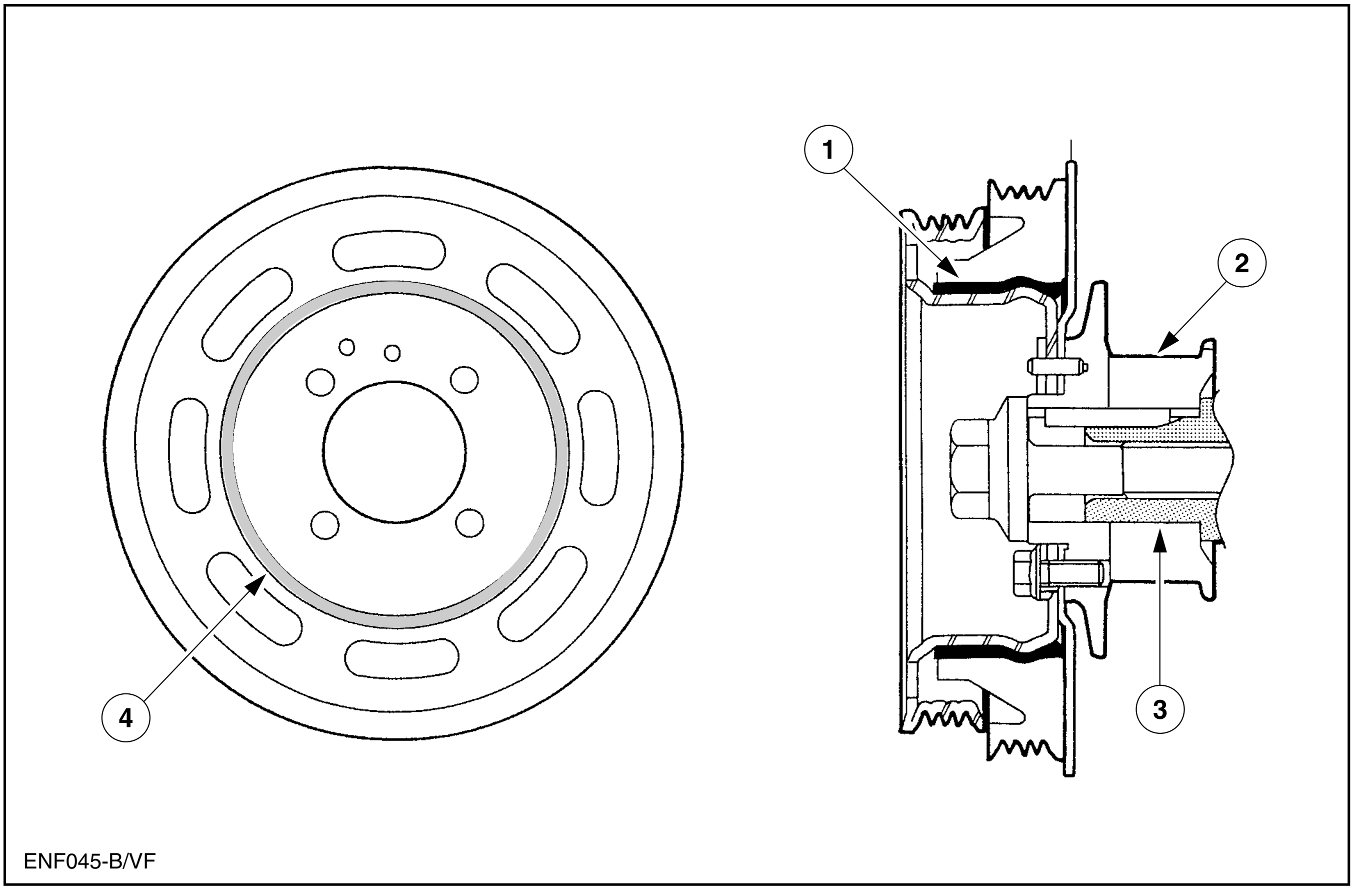
In addition to rotating, the crankshaft tends to move back and forth. Since this type of motion has a negative effect on the crankshaft associated components measures are taken to limit back and forth motion. One of the main journals on the crankshaft is machined to accept a thrust bearing. The thrust bearing keeps the crankshaft from moving back and forth. The upper and lower thrust bearings have oil grooves that allow oil to flow around the journal.



Crankshaft main bearings

1 Upper thrust bearing
2 Crankshaft
3 Lower thrust bearing
4 Crankshaft main bearings (lower)
5 Crankshaft main bearings (upper)

Vibration damper



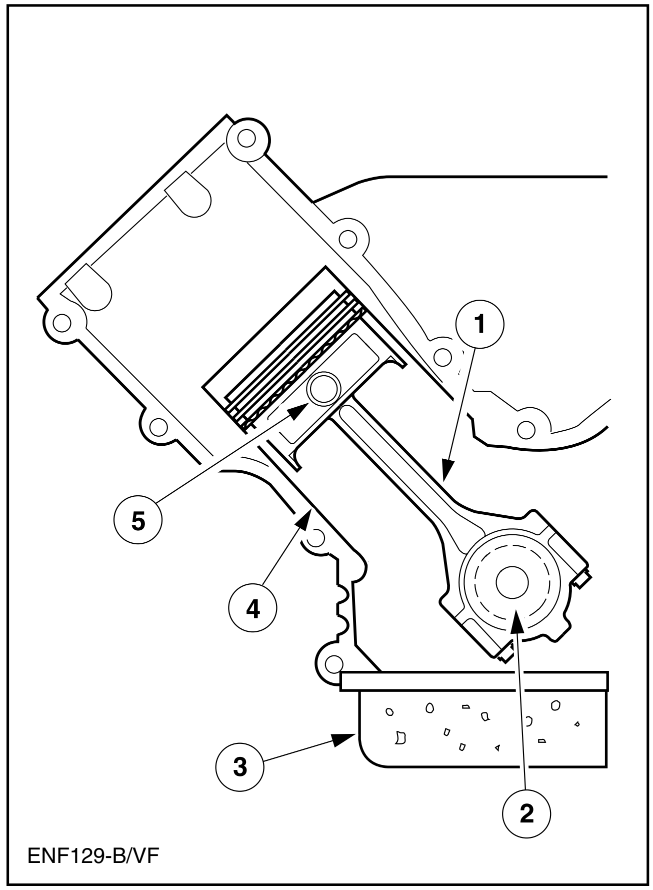
Crankshaft vibration damper

1 Rubber
2 Timing belt pulley
3 Crankshaft
4 Vibration damper

Even though the crankshaft is very strong, it has a certain amount of flexibility. During a power stroke the crankshaft actually twists slightly then springs back. At a normal hot idle, this twisting and untwisting may repeat five times every second. When accelerating under load, the cycle may occur 25 or 30 times per second. The twisting and untwisting causes vibrations. The vibration damper, which is usually mounted on the front end of the crankshaft, works to minimize these crankshaft vibrations.

Connecting rods

The connecting rod transfers the movement of the piston to the crankpin on the crankshaft. A steel piston pin connects the piston to the connecting rod. The piston pin allows the piston to pivot on the small end of the connecting rod. The large end of the connecting rod is connected to the crankshaft with a connecting rod bearing cap. The cap is very similar in design and function to the main bearing caps. The connecting rod bearings are similar to the crankshaft main bearings.

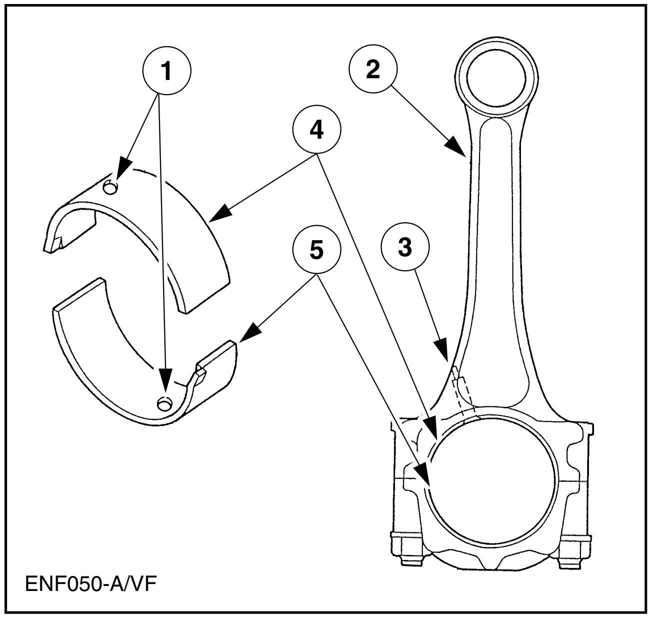


Connecting rod

1 Connecting rod
2 Crankshaft
3 Oil pan
4 Cylinder block
5 Piston pin

Cylinder wall lubrication

An oil jet in the connecting rod lubricates the cylinder walls and cools the piston. Some engine designs use oil splash to lubricate and cool the cylinder walls. Crankshaft oil passages deliver oil to the connecting rod journals. When the bearing holes match up with the oil hole in the connecting rod journal, pressurized oil squirts through the oil jet.



Connecting rod oiling

1 Oil holes
2 Connecting rod
3 Oil jet
4 Upper connecting rod bearing
5 Lower connecting rod bearing

Pistons

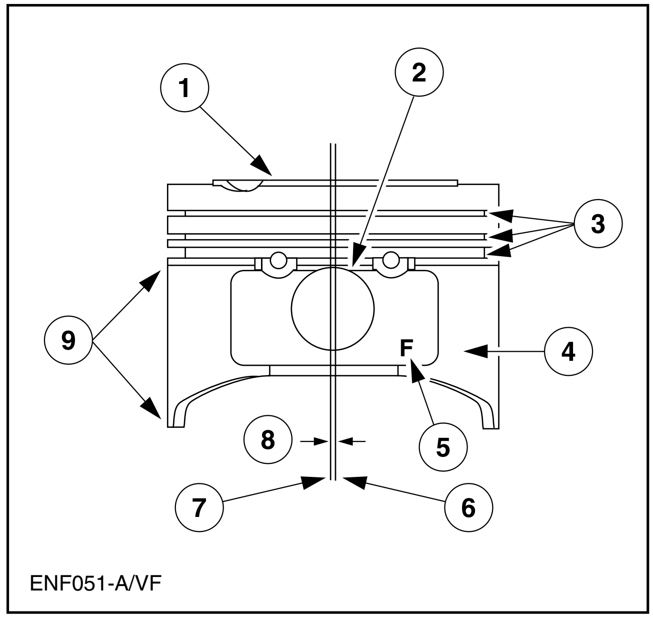
The piston top forms the bottom of the combustion chamber in the cylinder. The piston transfers the power created by the burning air-fuel mixture to the crankshaft.

The top surface of the piston is called the head, or crown. The upper part of the piston contains several grooves where the compression rings and oil ring fit. The lower part of the piston, under the rings, is called the skirt. Thrust surfaces on the skirt guide the piston in the cylinder bore and prevent the piston from rocking back and forth in the cylinder. Most pistons have a mark on one side or the top that identifies the side of the piston that faces the front of the engine.

The piston pin is inserted through the piston pin bore to connect the piston to the connecting rod. In some piston designs, the pin bore is offset slightly from the center of the piston. The offset helps stabilize the piston as it moves up and down in the cylinder.

Piston clearance

Although the piston fits closely in the cylinder bore, it does not completely seal the combustion chamber. The seal is accomplished using the piston rings installed in grooves near the top of the piston. To allow room for the piston rings and lubricating oil, a clearance must be maintained between the outside edge of the piston and the cylinder wall. This clearance lets lubricating oil into the upper part of the cylinder. The clearance also prevents the engine from seizing if one of the pistons expands too much from overheating. Two types of piston design are used to control heat expansion: tapering, and cam grinding.



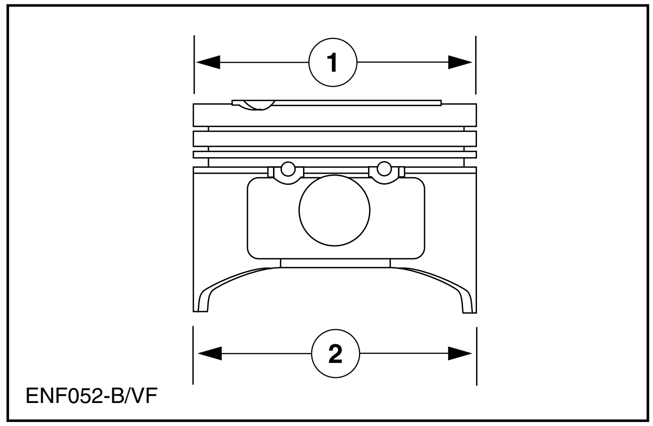
Piston features

1 Head
2 Piston pin bore
3 Piston ring grooves
4 Thrust surface
5 “Front” mark
6 Center of piston
7 Center of piston pin bore
8 Offset
9 Skirt

Pistons (continued)

Tapered pistons

To maintain a consistent clearance from the top to the bottom of the cylinder, the piston usually has a slight tapered shape. The top diameter of the piston is slightly smaller than the bottom diameter when the piston is cold. When the engine operates, the top of the piston gets much hotter than the bottom, and the expansion at the top evens up the diameter.

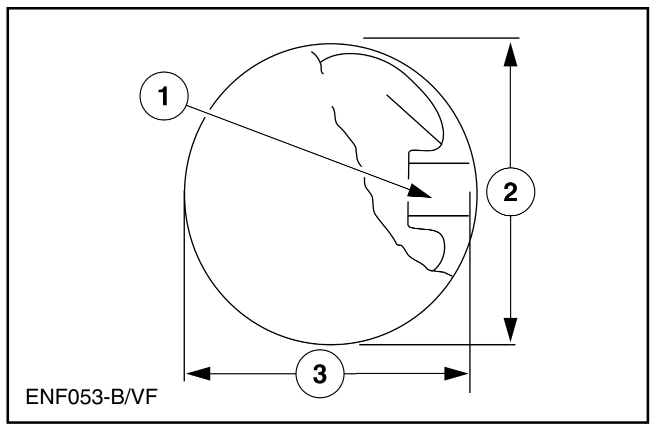


Tapered piston

1 Top diameter (smaller)
2 Bottom diameter (larger)

Cam-ground pistons

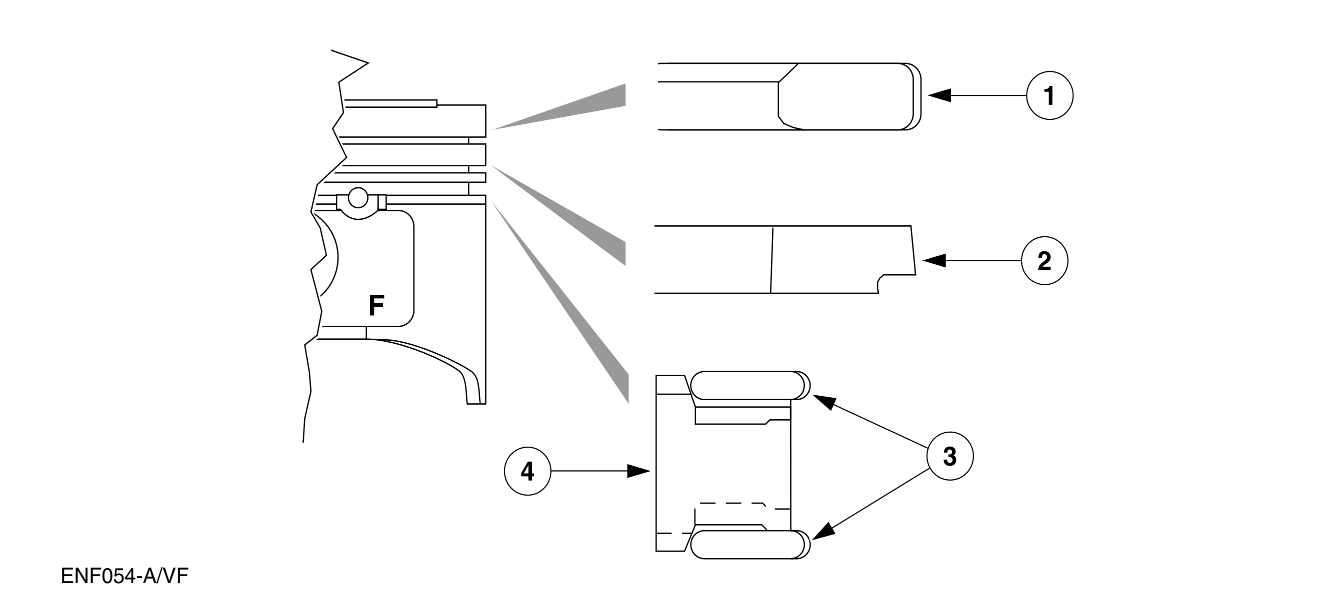
Another technique used to make the piston fit better in the cylinder and control heat expansion is called cam grinding. Cam-ground pistons are manufactured so that they have a slightly oval shape. The piston is designed to expand in the direction of the small diameter when heated, making the piston more round without substantially increasing the overall diameter.



Cam-ground piston

1 Piston pin bore
2 Large diameter
3 Small diameter

Piston rings



Piston rings

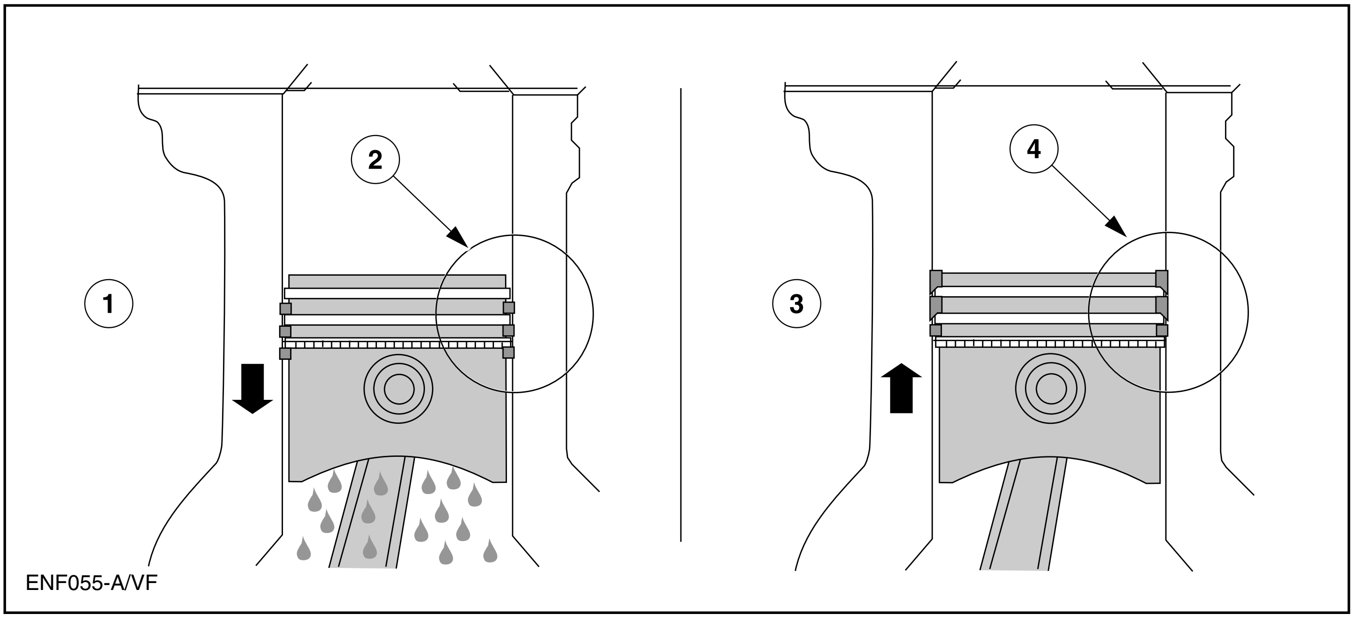
1 Top compression ring
2 Second compression ring
3 Scuff rings on oil ring
4 Expander on oil ring

Piston rings seal the combustion chamber where the air-fuel mixture is ignited. In addition to sealing the combustion chamber, piston rings scrape oil from the cylinder walls and direct it back into the crankcase. Piston rings also help transfer heat from the piston to the cylinder walls.

The top two rings are called compression rings. They are usually made of cast iron with chrome plating on the surface facing the cylinder wall. Compression rings are available with different edge shapes. The bottom ring is called an oil ring. The oil ring is usually made up of several parts assembled in a specific order in the same piston groove. A typical oil ring is made up of two scuff rings separated by an expander.

Piston rings (continued)

Compression rings

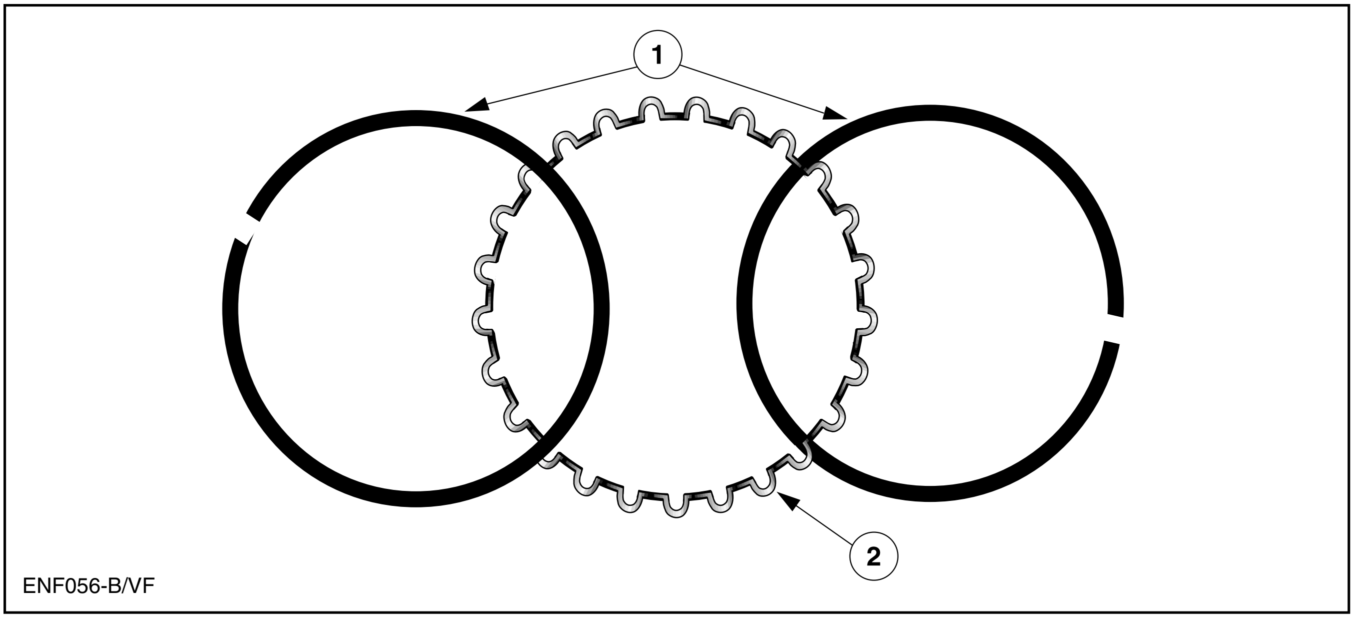


Compression ring oil control

1 Intake or power stroke
2 Compression rings scrape cylinder wall
3 Compression or exhaust stroke
4 Compression rings skim over oil film

Compression rings seal the combustion chamber, scrape the cylinder walls clean, and transfer heat from the piston to the cylinder wall. When the piston is moving down the cylinder during the intake stroke the lower edges of the compression rings scrape off any oil that was not recovered by the oil ring. On the compression and exhaust strokes, the compression rings skim over the oil film so the oil is not pushed into the combustion chamber. During the power stroke, the rings create a tight seal for the combustion chamber. The rings also create a path for heat to flow from the piston to the cylinder wall.

Oil rings



Oil ring assembly

1 Oil rings
2 Expander ring

Oil rings control the lubrication of the cylinder walls and direct oil back to the crankcase. Oil is constantly sprayed or splashed onto the walls of the cylinders to provide lubrication between the piston rings and cylinder wall. The amount of oil on the cylinder wall cannot fit into the space between the piston and cylinder when the piston moves toward BDC and therefore needs some place to go. The oil ring provides a path for the oil to return to the crankcase.

As oil is scraped from the cylinder wall by the compression rings, it flows behind the top expander ring and into holes in the oil ring groove. These holes direct oil to the open space inside the piston skirt. The oil then drains back into the crankcase.

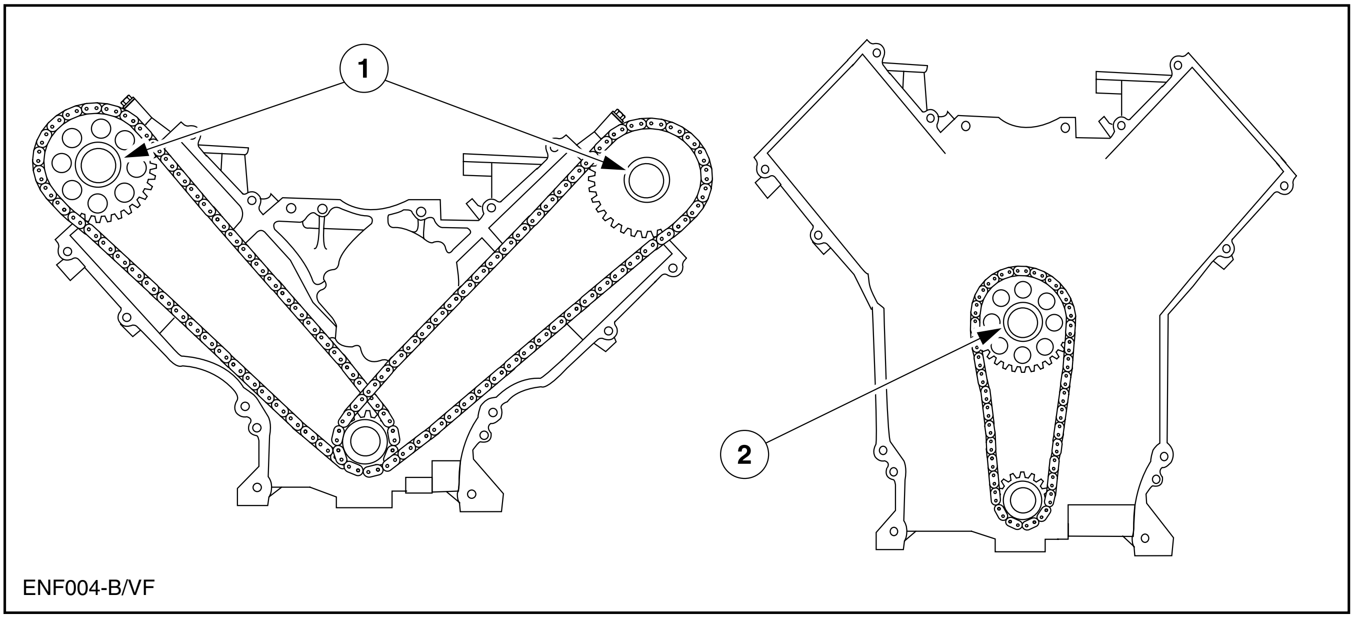
To properly seal the cylinder for compression and to control oil bypass, the ring end-gaps are staggered.

Objectives

Upon completion of this lesson, you will be able to:

- Explain the purpose and function of the valve train.
- Describe valve train types.
- Describe the Overhead Valve (OHV) train configuration.
- Describe the Overhead Camshaft (OHC) configuration.

Valve train types overview



OHC and pushrod-type camshaft drives

1 OHC: the camshaft(s) are located in the cylinder head(s).

2 OHV: the single camshaft is located in the cylinder block.

Air and fuel enter and exit the combustion chamber through valve ports. Valves, located at the combustion chamber side of the port, open and close to either allow flow or tightly seal the combustion chamber. The valves must open and close at the correct times for proper engine function. Valve timing is accomplished by the camshaft acting on the valve train.

There are two main types of valve trains used in automotive engines. The two types are Overhead Valve (OHV), and Overhead Camshaft (OHC). The OHV type valve train uses a single camshaft centrally located in the cylinder block. The camshaft lobes control the opening and closing events of the valves in the cylinder head through a series of linking mechanical components. The OHC type valve train uses one or more camshafts attached directly to the cylinder head above the valves. Valve opening and closing events are controlled by camshaft lobes.

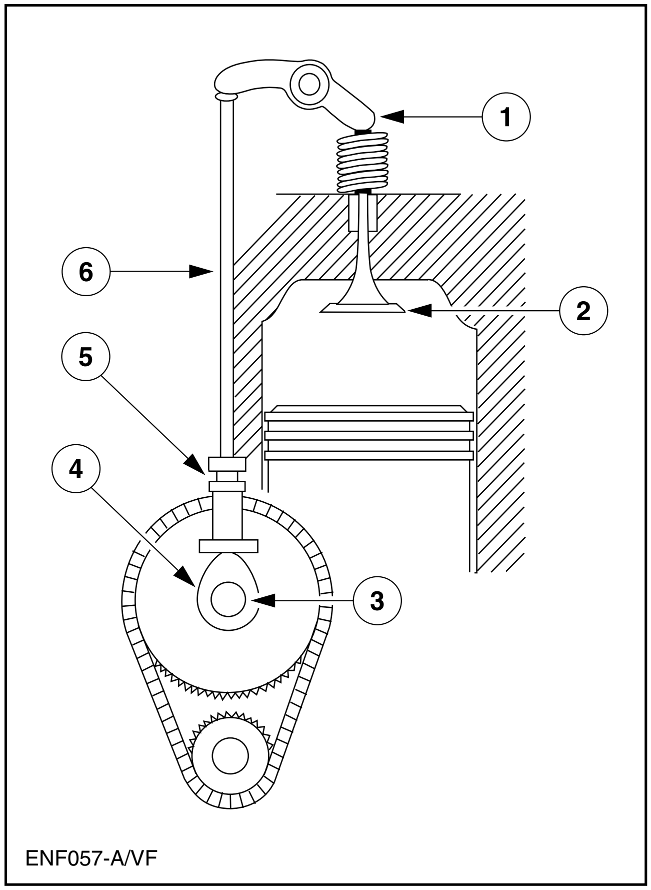
Valve train types overview (continued)

Pushrod-type valve (OHV) configuration

Pushrod-type engines, also known as Overhead Valve (OHV) engines, have a single camshaft located in the cylinder block. The valves are located in the cylinder head above the combustion chamber. Valves are opened and closed by camshaft lobes acting on lifters, pushrods, and rocker arms.

The major components of the OHV valvetrain include:

- Cylinder head
- Valves
- Valve seats
- Valve guides
- Valve springs
- Camshaft
- Pushrods
- Lifters
- Rocker arms
- Camshaft drives
- Overhead valve drive



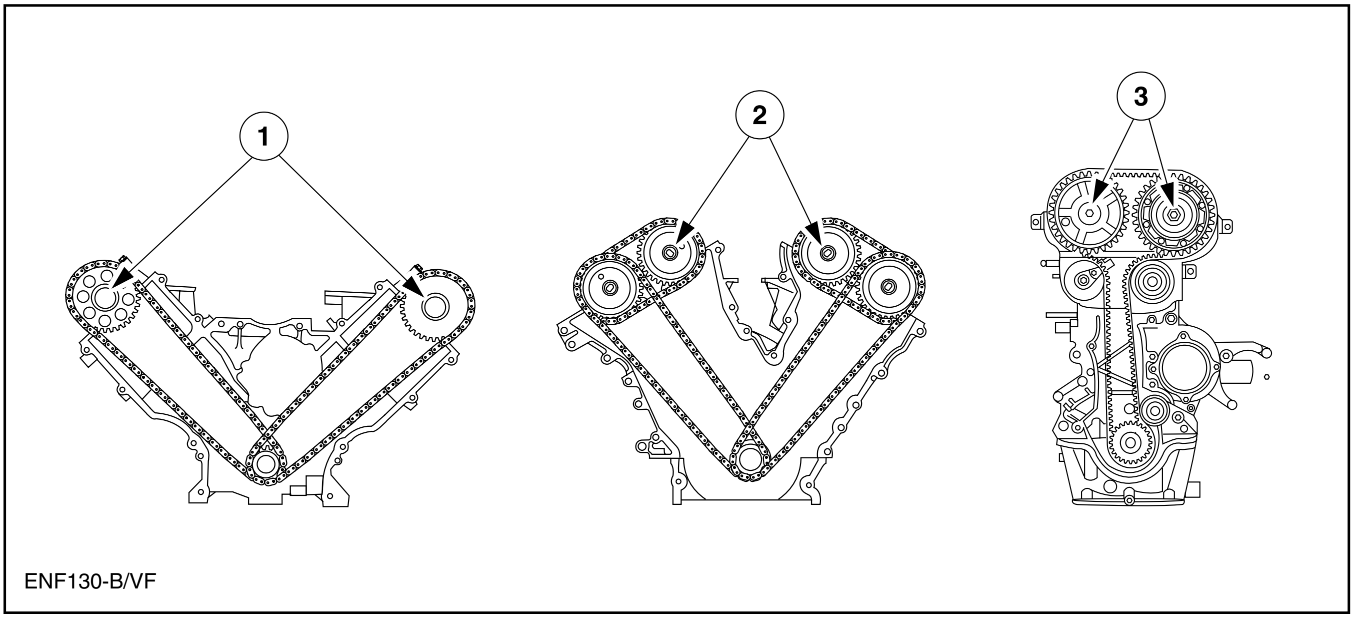
Pushrod-type valve train

1 Rocker arm
2 Valve
3 Camshaft
4 Cam lobe
5 Lifter
6 Pushrod

Engines have passages that let the air-fuel mixture into the cylinders and let exhaust gases out after the mixture has burned. These passages, called valve ports, seal very tightly during parts of the four-stroke cycle. The valves must open and close the ports at precise times.

As the camshaft turns, the cam lobe moves against the lifter. The lifter pushes up on the pushrod, which pushes up on one end of the rocker arm. The other end of the rocker arm pushes down on the valve stem and causes the valve to overcome spring pressure and move to the open position. As the cam lobe moves past the lifter, the valve spring pushes against the valve, pushrod, rocker arm, and lifter. When the cam lobe has rotated far enough, the valve closes tight against the valve seat.

Overhead camshaft (OHC) configuration



Camshaft drives

1 Chain driven SOHC
2 Chain driven DOHC
3 Belt driven DOHC

OHC engines have the camshaft(s) located in the cylinder head.

The benefits of an overhead camshaft include:

- Fewer components in the valve train
- More precise and direct valve actuation
- Reduce frictional losses

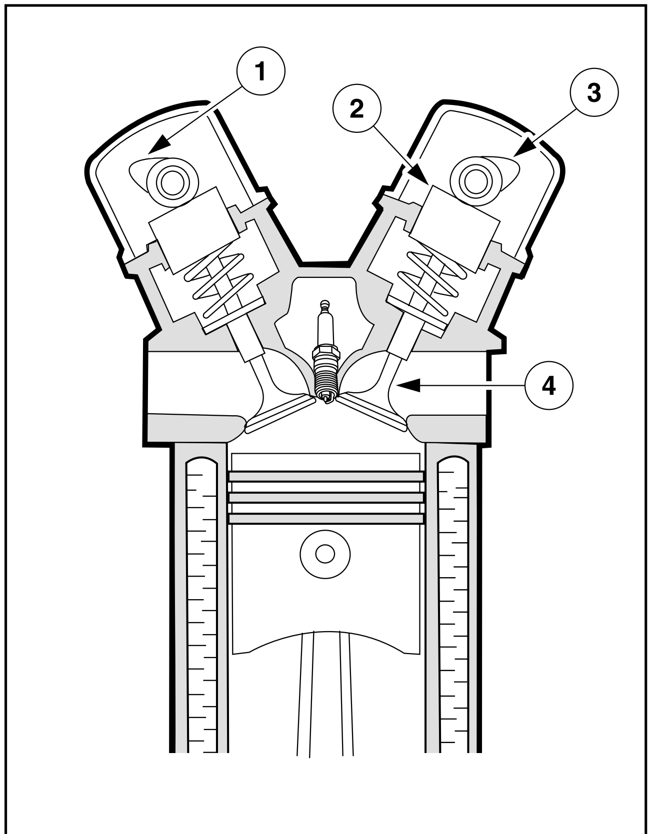
Single overhead cam (SOHC)

SOHC engines normally actuate two valves per cylinder. SOHC engines use roller finger followers which sit below the camshaft, or use rocker arms which sit above the camshaft.

Double overhead cam (DOHC)

DOHC engine design divides the job of valve opening between two camshafts. DOHC engines normally actuate four valves per cylinder. More valves per cylinder allows more efficient intake of the air and fuel mixture during the intake stroke, and removal of exhaust gases during the exhaust stroke.

DOHC engines use either roller finger followers or direct acting mechanical buckets to actuate the valves.



Double overhead camshafts

1 Camshaft
2 Lifter
3 Cam lobe
4 Valve

Camshaft drives

The task of the engine timing system is to coordinate the induction of the air and fuel mixture and the expulsion of the exhaust gases with the up and down motion of the piston. This is accomplished by synchronizing the rotation of the crankshaft with the camshaft(s). Since the crankshaft makes two revolutions for each combustion cycle, and the camshaft makes one revolution, the gear ratio must always be 2:1. Valve opening and closing times are indicated in crankshaft degrees. There are various ways of driving the camshaft. The valve gear can be driven by:

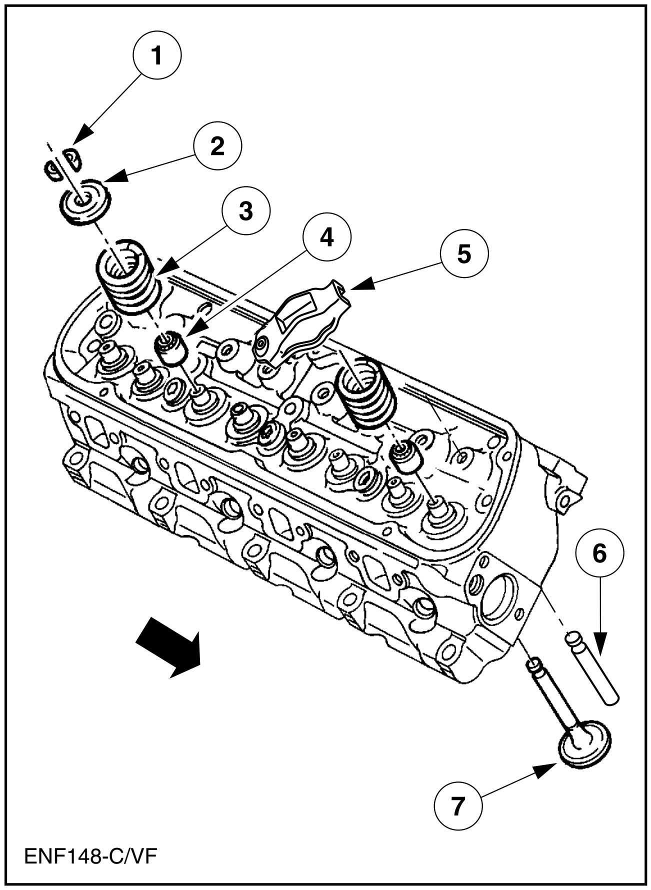
- Timing gears
- Timing chain
- Timing belt

Pushrod type (OHV) Cylinder head

The cylinder head is bolted on top of the cylinder block to form the roof of the combustion chamber. The cylinder head:

- seals the tops of the cylinders.
- holds the spark plugs.
- provides seats, guides, and ports for the intake and exhaust valves.
- holds the valve train.
- provides mountings for the intake and exhaust manifolds.

Like the cylinder block, the cylinder head is made of cast iron or aluminum alloy. The intake and exhaust manifolds are mounted to the cylinder head, against the valve ports. Most V-6 or V-8 engines have two cylinder heads, one for each bank of cylinders. The top part of the cylinder head is manufactured so that the valve rocker arms or other parts of the valve train can be mounted on it.

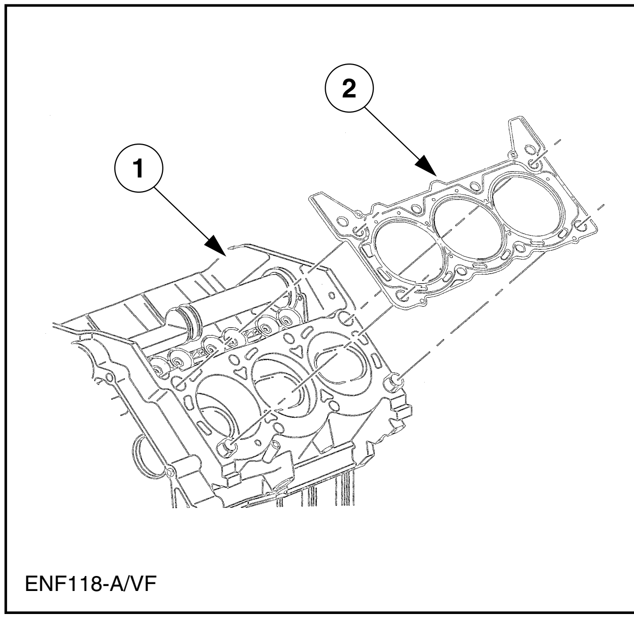


OHV multi-valve cylinder head

1 Valve spring collets
2 Valve spring retainer
3 Valve spring
4 Valve seal
5 Rocker arm
6 Pushrod
7 Valve

Cylinder head gasket

The cylinder head gasket forms the gas and watertight junction between the cylinder head and the cylinder block. In addition, the cylinder head gasket offsets any minor irregularities in the mating surfaces. For this reason the cylinder head gasket must be made of a somewhat flexible material.

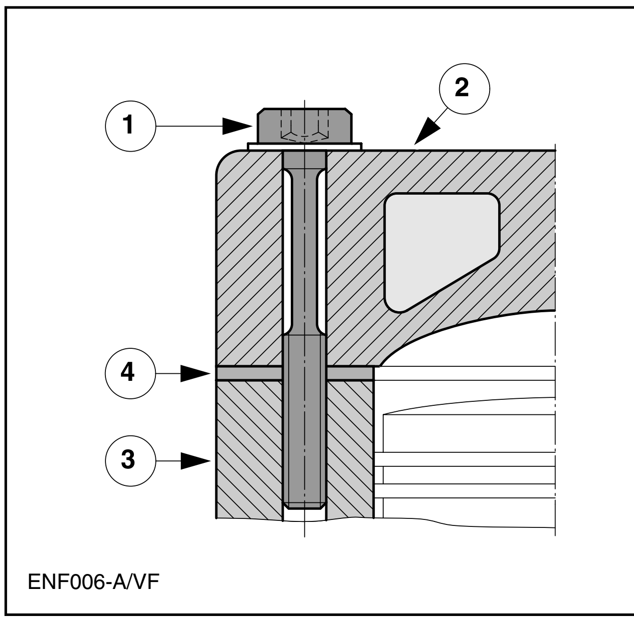


Cylinder head gasket

1 Cylinder block
2 Cylinder head gasket

Head bolts

Cylinder head bolts hold the cylinder head firmly to the cylinder block. There are two types of cylinder head bolts: conventional and torque-to-yield. Conventional bolts are tightened using a torque wrench in steps of progressively higher torques. Torque-to-yield bolts are also tightened in a sequence of progressively higher torques. However, the final step is to tighten the bolts a predetermined angle using an angle torque gauge. This final step distorts the threads slightly resulting in greater holding power. Due to the fact that the cylinder head bolt threads are distorted during the tightening sequence, torque-to-yield bolts may only be reused when specified by the vehicle manufacturer.



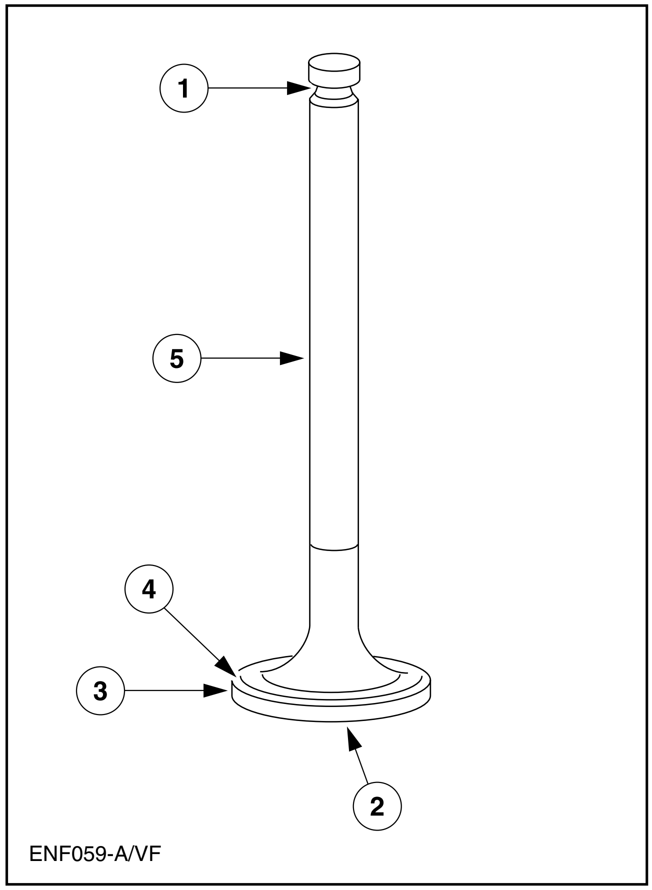
Cylinder head bolt

1 Torque-to-yield bolt
2 Cylinder head
3 Cylinder block
4 Cylinder head gasket

Valves

A valve has a round head with a tapered face that seals against a seat in the cylinder head. Because of its stem-and-head construction, the valve is sometimes called a mushroom valve.

The head of the valve is the larger end that seals the valve port. The surface of the cylinder head that seals the port is called the valve seat. The valve head has a machined surface called the valve face. The valve face is the contact point between the valve and the valve seat. Both the valve face and the valve seat must be machined so that they form a tight seal when closed. Full contact between the valve and valve seat is needed to transfer heat away from the valve face into the cylinder head. The valve margin is the thickness of the valve head.

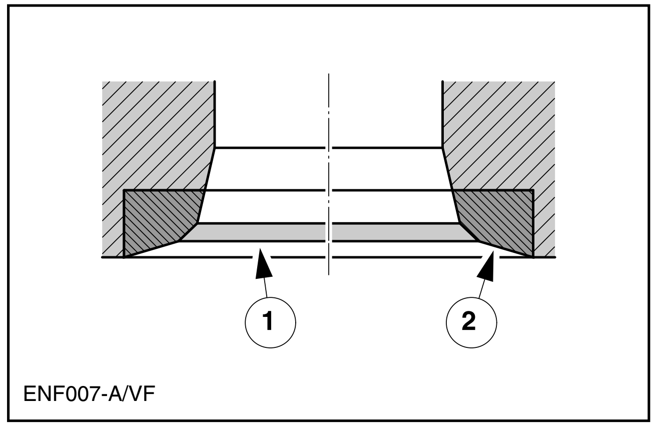


Valve features

1 Collet groove
2 Head
3 Margin
4 Face
5 Stem

Valve seat

The valve seat is the area contacted by the valve face when the valve is in the closed position. Both intake and exhaust valves have seats. The valve seat area must be hard enough to withstand the constant pounding as the valve rapidly opens and closes. The seat must also be able to conduct heat well so that the valve does not overheat and distort. Because exhaust gases are corrosive, the exhaust valve seats must be resistant to corrosion. A valve seat insert is pressed into the cylinder head. This insert is made of a different material from the cylinder head and has the necessary heat, hardness, and anticorrosion properties.

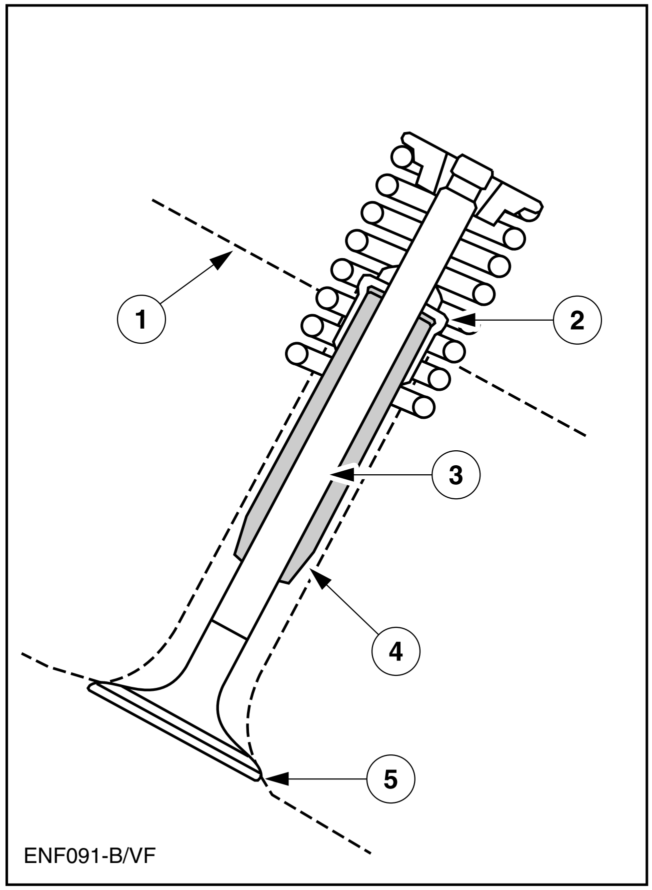


Valve seat features

1 Valve seat
2 Valve seat insert

Valve stem

The valve stem is the long, narrow part above the head. The stem has a groove at the end that is used to secure the valve into the cylinder head with keepers. The valve spring is installed on the stem end of the valve. The spring is compressed into position on the valve stem with the bottom firmly pressed against the spring seat area of the cylinder head, and the top held in place at the top of the valve stem by a retainer and keepers. The retainer and keepers are kept in place by the constant pressure of the spring on them and are locked into the groove of the valve stem, thus providing a constant pulling on the valve into the closed position. The valve stem fits through the valve guide that also holds the valve in alignment in the cylinder head.



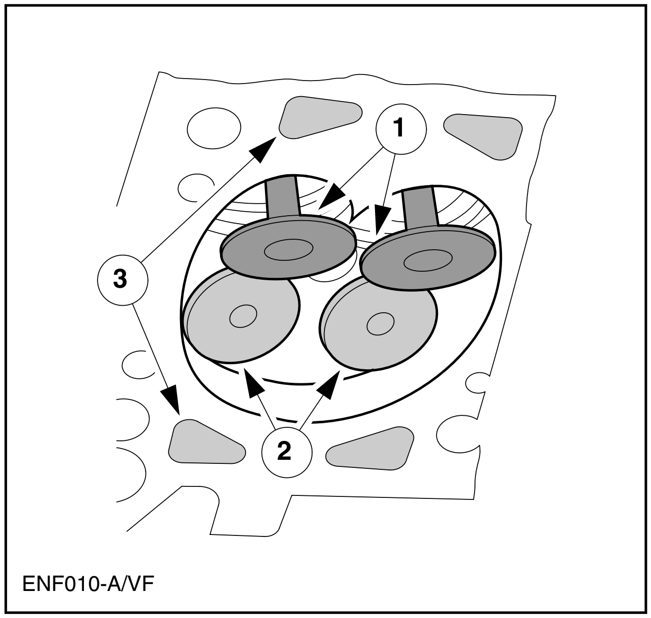
Valve components

1 Cylinder head
2 Valve oil seal
3 Valve stem
4 Valve guide
5 Valve seat

Valve guides

The valve guides keep the valves in precise alignment in the cylinder head. They allow the valve stem to go through the combustion chamber to the upper cylinder head area where the valve springs are mounted. Some valve guides are integral with the cylinder head casting. Other valve guides are soft alloy inserts that are manufactured separately and pressed into the head. The valve guide fits very closely around the valve stem, with just enough room for lubricant and free up-and-down movement of the stem.

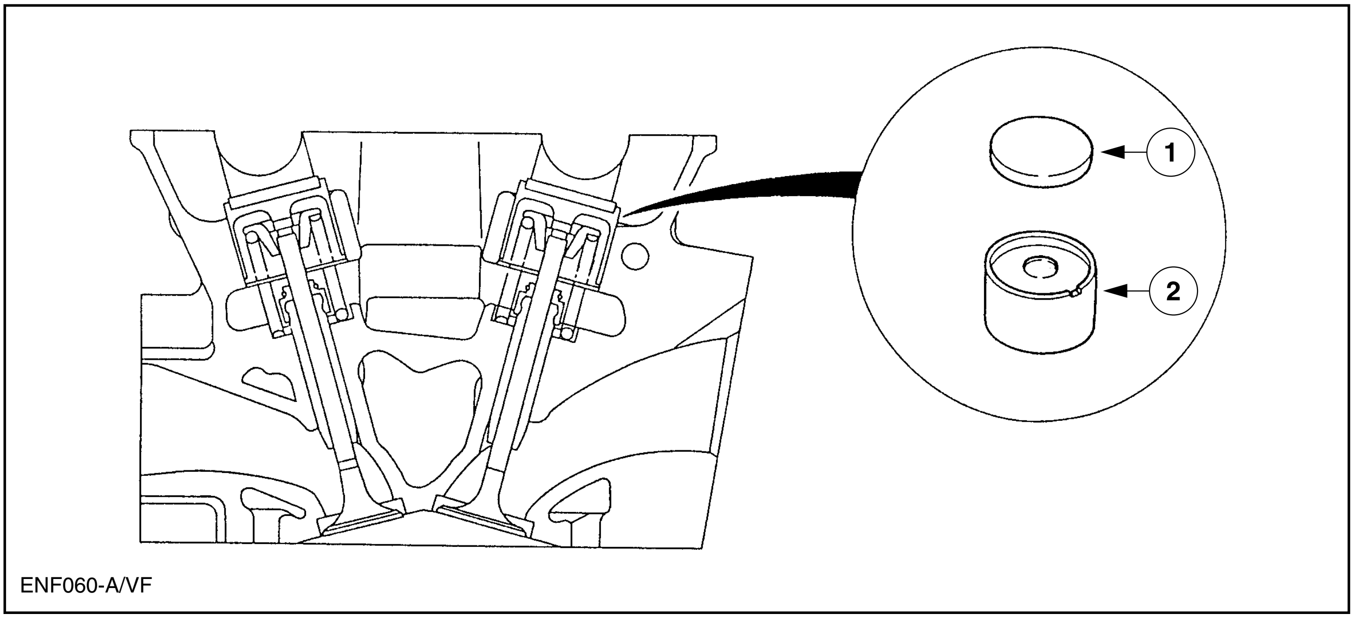
Designs of three or four valves per cylinder are used because multiple valves are more precise and efficient. A three-valve design typically uses two valves for intake and one valve for exhaust. A four-valve design uses two valves each for intake and exhaust.



Multi-valve design valve arrangement

1 Intake valves
2 Exhaust valves
3 Cooling passages

Valve clearance



Valve clearance adjustment components

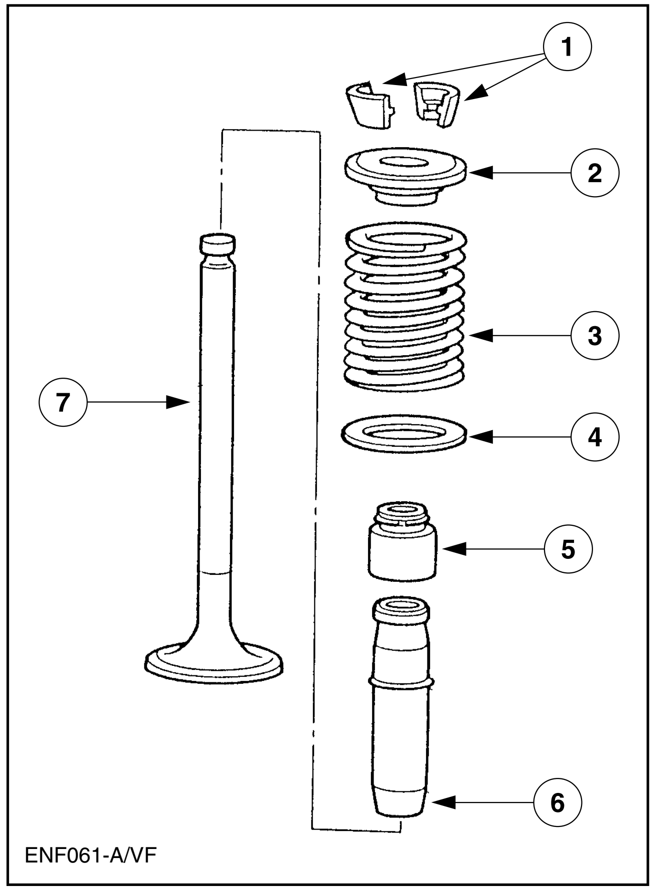
1 Adjustment shim
2 Tappet

When a valve moves to the closed position, it must be seated firmly against the valve seat. To accomplish this, there must not be any pressure on the stem side of the valve. On some engines, a small space is created between the valve stem tip and the actuating device (rocker arm, follower, bucket, tappet). This space is called valve clearance. Valve clearance must be precisely adjusted to avoid excessive noise and proper operation. If valve clearance is too large, the engine is noisy. If valve clearance is not present, the valve may not be able to seat firmly. Combustion gases may leak past the valve seat and eventually burn a hole in the valve at the leak point. Some engines are designed to maintain valve clearance with mechanical adjustments such as a shim.

Mechanical clearance designs may need periodic adjustments. Some engines maintain valve clearance automatically through hydraulic valve actuator devices. A hydraulic device (lifter, tappet, bucket) expands under oil hydraulic pressure to maintain contact with the valve tip at all times. During valve close events, oil pressure is cut off, allowing the valve to close firmly onto the seat.

Valve springs

The valve spring is responsible for closing the valve firmly onto the valve seat. The spring is installed onto the upper cylinder head around the valve stem. Upper and lower spring seats prevent wear and keep the spring in place. Collets installed into the upper spring seat (sometime called a retainer) lock into grooves in the valve stem and keep all components locked into place.



Valve spring and components

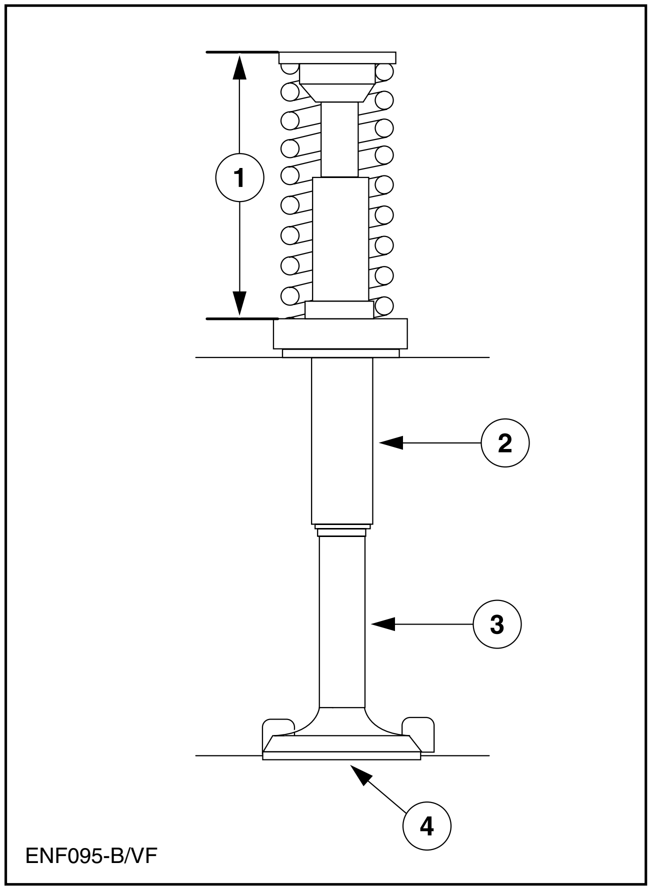
1 Collets
2 Upper spring seat
3 Spring
4 Lower spring seat
5 Valve seal
6 Valve guide
7 Valve

Spring tension

The valve spring must be able to generate enough pressure to keep the valve closed firmly against the valve seat. The valve springs must also keep all valve train components in contact with one another as the engine operates at high speed. At the same time, the valve spring cannot press so much that components wear out prematurely. As a result, valve springs are designed to generate just the right amount of pressure for the engine design.

Working height

Working height is the length of the spring when it is installed in on the cylinder head and the valve is fully closed.

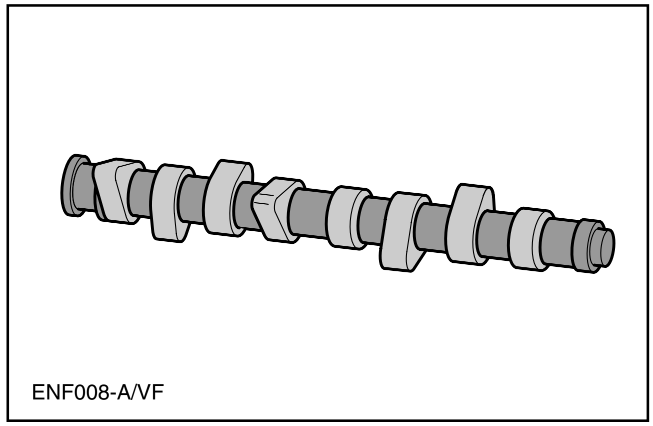


Valve working height dimensions

1 Working height measurement
2 Valve guide
3 Valve
4 Valve closed

Camshaft

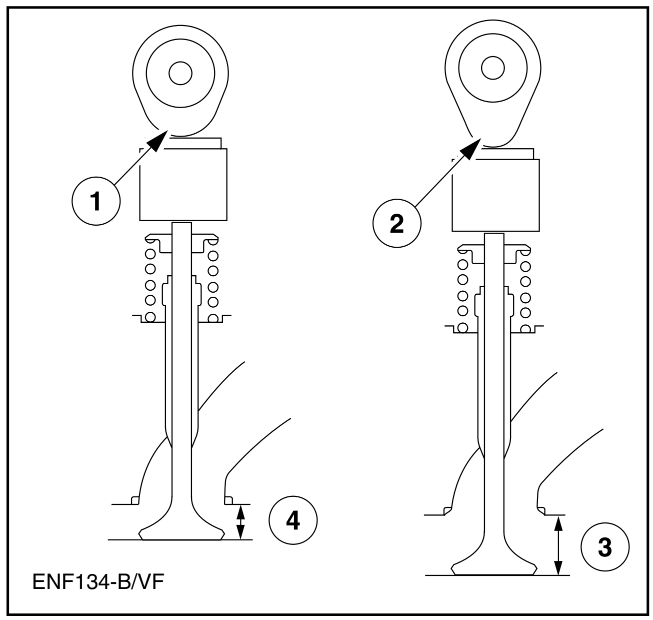
The camshaft controls the valve opening and closing events. The camshaft is driven by the crankshaft through a gear, chain, or belt connection. The camshaft rotates at half the speed of the crankshaft to maintain proper timing of the four cycles of combustion. Valve opening and closing events are accomplished by lobes on the camshaft. Each valve in the engine, no matter the design, has its own corresponding camshaft lobe. Depending upon engine design, there may be only one, or multiple camshafts in an engine.



Camshaft (typical)

Lift

Valve lift is the distance the valve is lifted off the valve seat when fully opened. The height of the cam lobe and the design of the valve train determine the amount of valve lift. A valve needs enough lift to allow the air and fuel mixture to flow freely into the cylinder, and for exhaust gasses to flow out of the cylinder, without interfering with the piston or binding the spring.

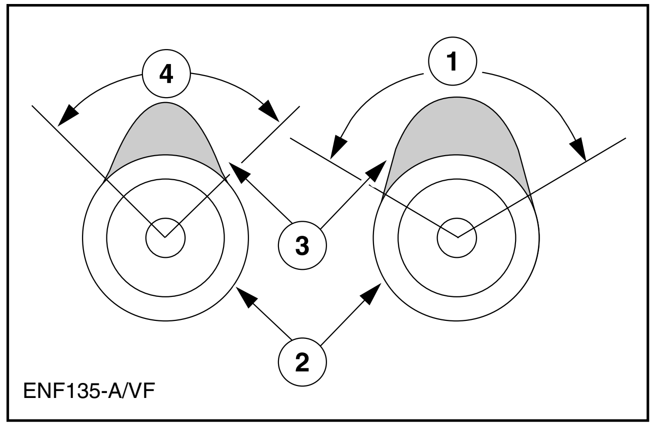


Low-lift versus high-lift camshaft

1 Low-lift camshaft lobe
2 High-lift camshaft lobe
3 High valve lift
4 Low valve lift

Duration

Duration is the length of time the cam lobe keeps the valve open. Duration is measured in degrees of camshaft rotation. The shape of the cam lobe determines the amount of duration. Changing the duration affects the operating characteristics of the engine regarding how much torque and power are produced at a given engine speed.



Short duration versus long duration

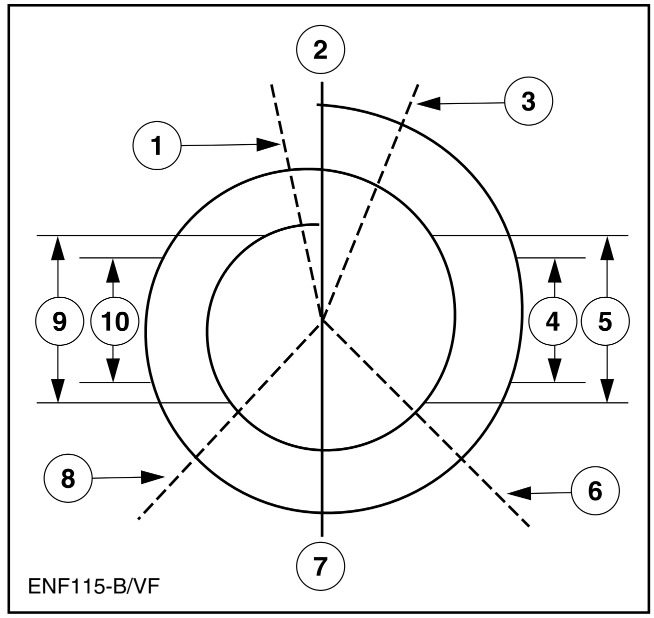
1 Long duration camshaft lobe
2 Camshaft
3 Camshaft lobes
4 Short duration camshaft lobe

Overlap

Overlap is the condition where both the intake and exhaust valves are open simultaneously.

Overlap normally occurs in the four-stoke cycle in the last part of the exhaust stroke. In order to ensure good airflow into the cylinder during the intake stroke, the intake valve must begin opening before the exhaust stroke is completed.

Overlap is controlled through camshaft lobe position. Overlap is measured in degrees of camshaft rotation. Changing overlap has an effect on engine performance characteristics.

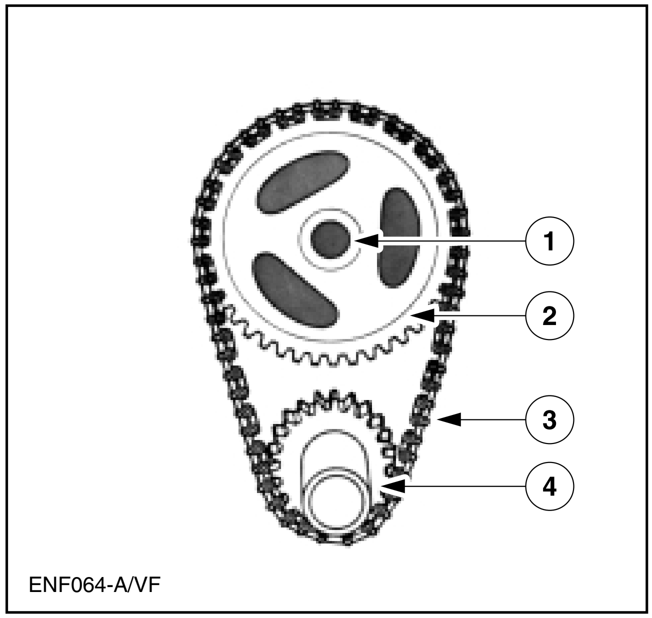


Valve overlap

1 Intake valve opens
2 Top dead center
3 Exhaust valve closes
4 Power stroke
5 Intake stroke
6 Exhaust valve opens
7 Bottom dead center
8 Intake valve closes
9 Compression stroke
10 Exhaust stroke

Overhead valve drive

In an OHV engine, where the camshaft is mounted below the valves in the block, a crankshaft gear is used to drive a timing chain, which drives the camshaft gear.

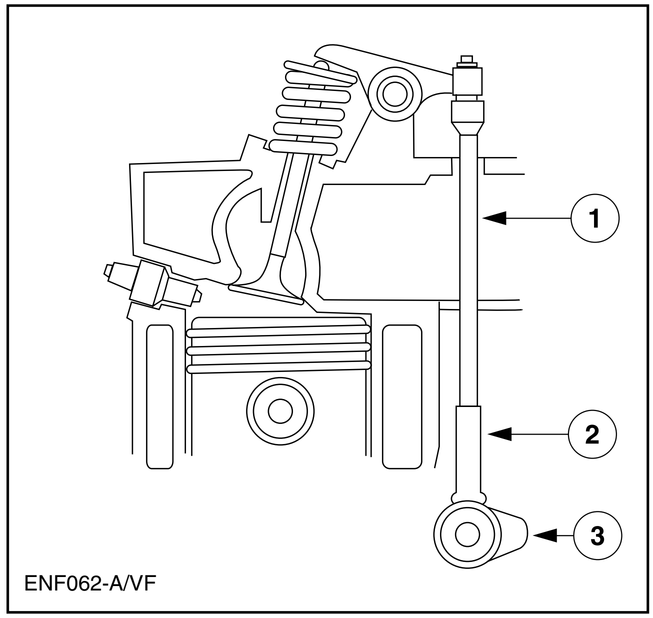


Pushrod-type (OHV) camshaft drive

1 Camshaft
2 Camshaft gear
3 Timing chain
4 Crankshaft gear

Pushrods

In an OHV engine, pushrods transfer the lifting motion from the camshaft and lifters to the valves. Pushrods are made of stiff steel tubing, with cups or balls on the ends. On some engines, pushrods come in varying lengths to provide an initial clearance adjustment with hydraulic lifters.

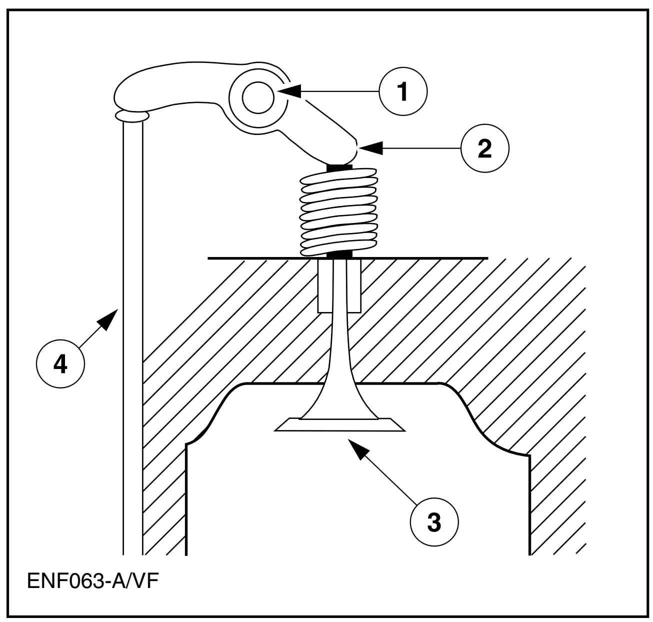


Pushrod and associated components

1 Pushrod
2 Lifter
3 Camshaft

Rocker arms

The rocker arm reverses the direction of lift from the pushrod or camshaft to the valve.
A pivot is drilled out in the rocker arm, so the rocker arm can run on a hollow rocker arm shaft.

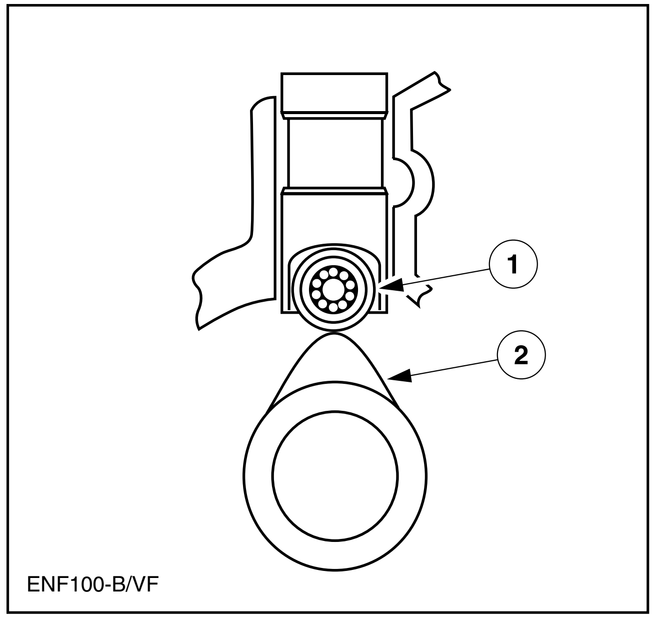


Rocker arm and associated components

1 Shaft-pivot on rocker arm.
2 Rocker arm
3 Valve
4 Pushrod

Valve lifters

Valve lifters transmit the lifting motion of the cams to the valve stems. The lifter protects the valve stem against side thrust. Lifters can be solid or have hydraulic actuation. Lifters may also have either a flat contact surface, or a roller mechanism to reduce friction.



Lifter

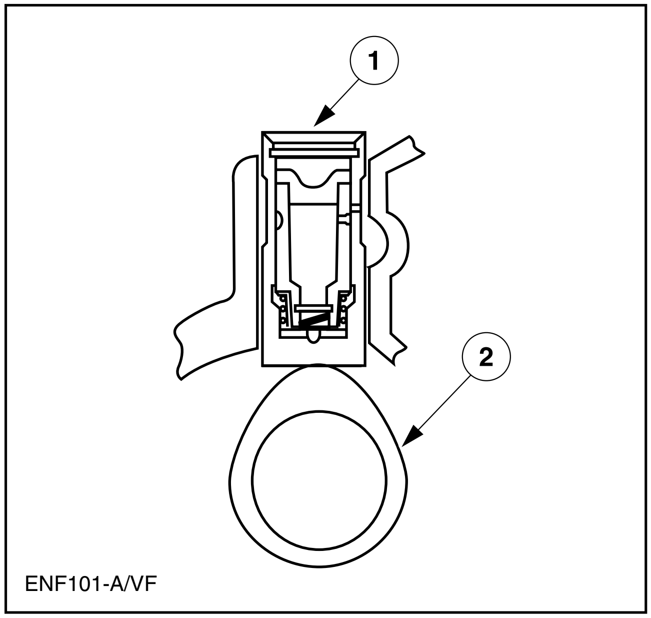
1 Solid lifter
2 Camshaft lobe

Solid lifter

A solid lifter transmits the movement between the cam and the valve. The solid lifter is one piece and has no moving parts. Solid lifter equipped engines require periodic adjustments to correct for valve train wear and eliminate noise.

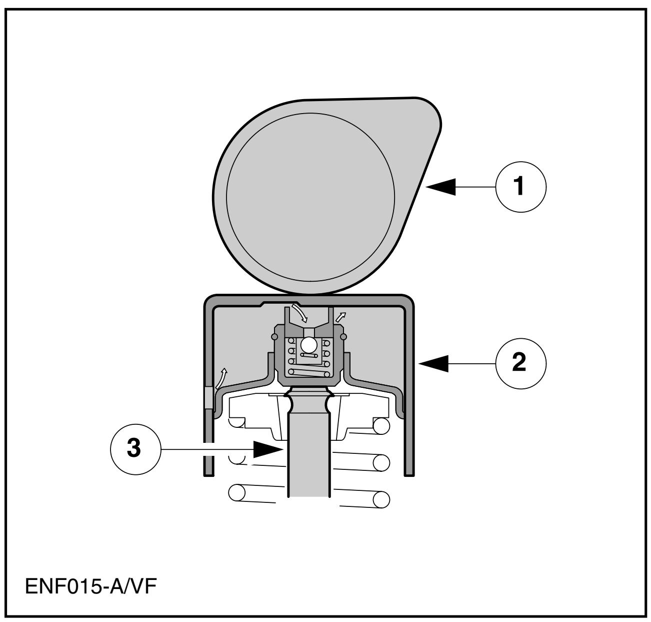
Hydraulic lifters and buckets

Hydraulic lifters not only transmit movement, they can also offset changes in valve clearance.
The hydraulic lifter is a hydraulic cylinder which corrects valve clearance using engine oil pressure and internal spring pressure.



Hydraulic lifter

1 Hydraulic lifter
2 Camshaft lobe

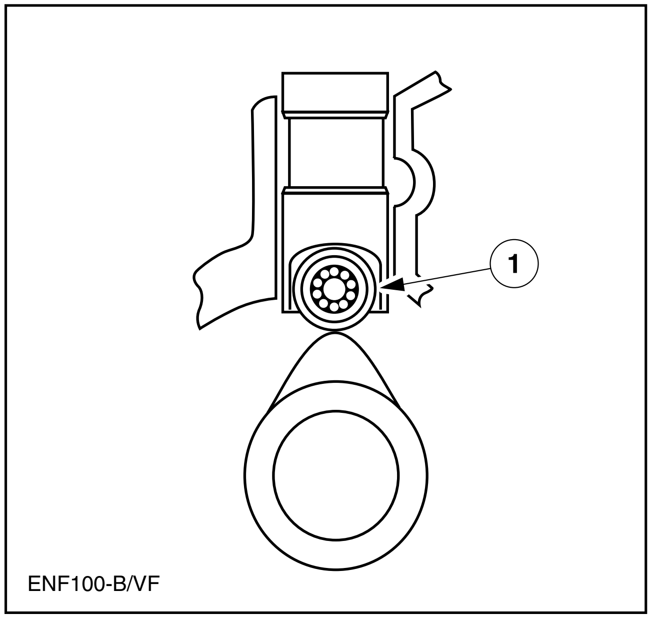


Hydraulic cam bucket

1 Camshaft
2 Hydraulic lifter
3 Valve stem

Roller versus flat lifters

The camshaft acting on a flat lifter creates friction. To reduce friction, some lifters have a roller wheel built into the lifter contact surface. The camshaft contacts the roller wheel instead of a friction surface. The roller finger follower is similar to a rocker arm and has the same advantage as a roller lifter. One end of the roller finger follower is supported by a lifter that controls lash adjustment. The other end of the roller finger follower actuates the valve as a camshaft rides the roller wheel.



Roller

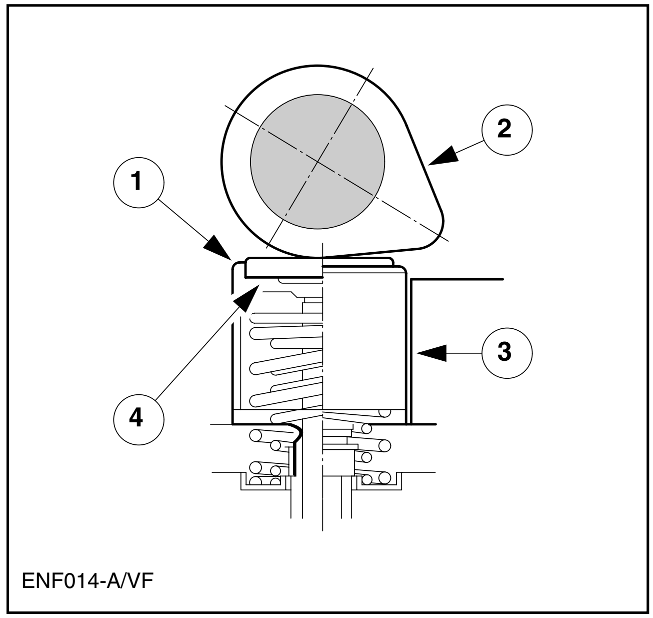
1 Roller

Overhead camshaft (OHC) cam followers

Cam followers are another term describing mechanical lifters. Refer to Valve lifters.

Bucket-type solid lifters

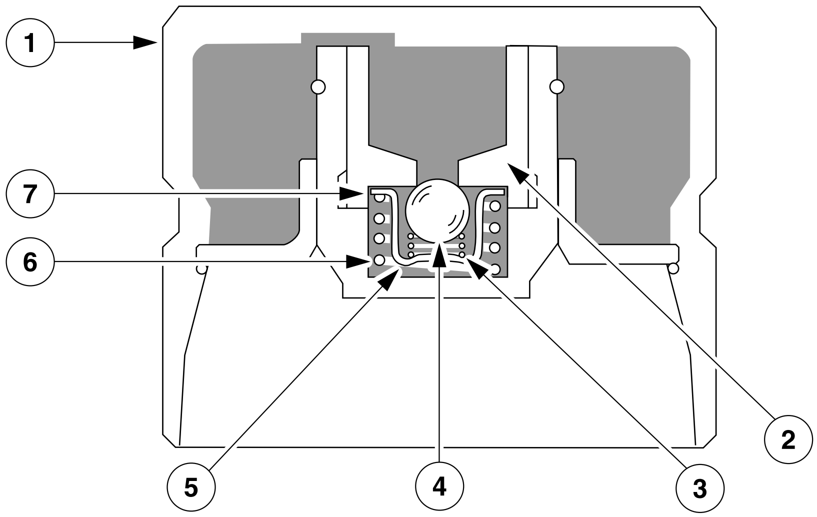
Bucket-type solid lifters, as used in OHC and DOHC engines, offer a way of adjusting the valve clearance. Fitting shims of different thickness can alter the clearance between the camshaft and lifter.



Solid bucket

1 Lifter
2 Camshaft
3 Lifter guide
4 Shim

Overhead camshaft (OHC) hydraulic lash adjusters



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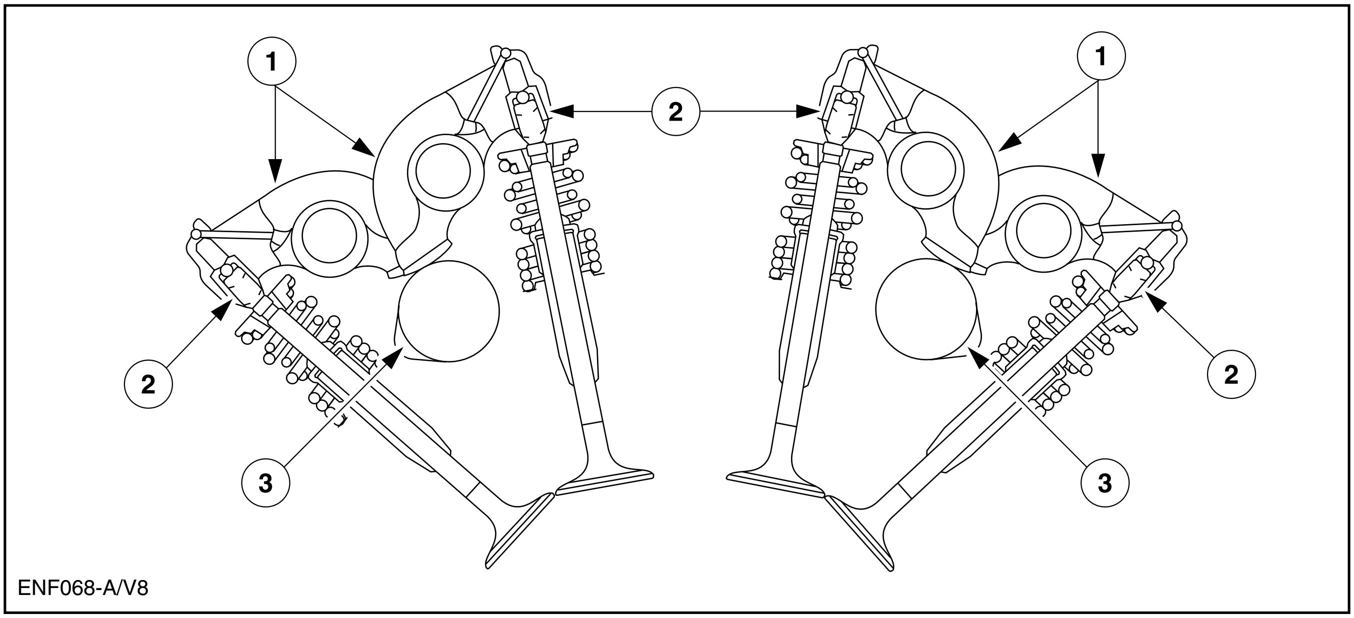
Hydraulic bucket assembly

1 Bucket body
2 Plunger
3 Check ball spring
4 Check ball
5 Check ball cage
6 Plunger spring
7 Body

The hydraulic lash adjuster is the OHC version of the hydraulic lifter. On many OHC engines, the valve clearance is adjusted automatically by hydraulic lash adjusters. Hydraulic lash adjusters eliminate the need for manual valve adjustments. A bucket-type hydraulic lash adjuster is positioned between the top of the valve stem and the camshaft. In this design, the camshaft directly contacts the top of the lash adjuster.

In some engines, a rocker arm-mounted hydraulic lash adjuster fits between the valve stem and the rocker arm. The bucket-type hydraulic lifter has a bucket body that contains two oil chambers. A check ball and spring control the movement of oil between these two chambers. As the oil moves from one chamber to the other, a spring-controlled plunger moves up and down and contacts the top of the valve stem.

Rocker arm-mounted hydraulic lash adjuster



Rocker arm-mounted hydraulic lash adjusters

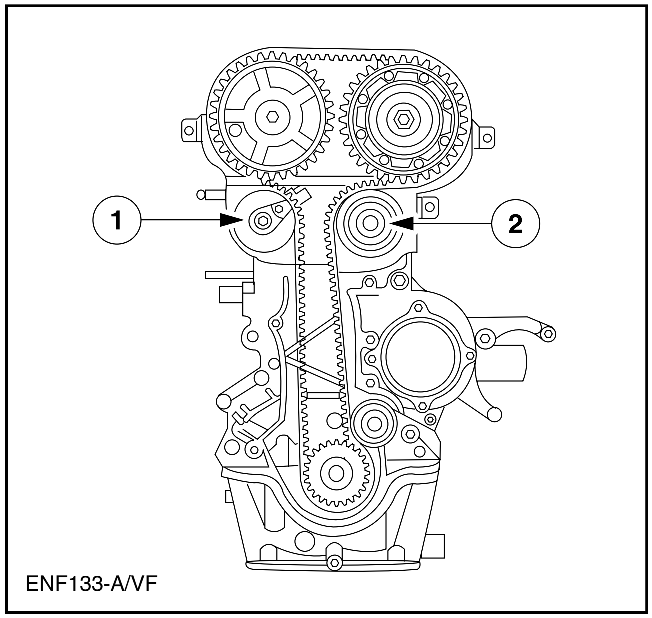
1 Rocker arms
2 Hydraulic lifters
3 Camshafts

A rocker arm-mounted hydraulic lash adjuster operates much like bucket-type hydraulic lash adjuster, except that it is in contact with a rocker arm rather than the camshaft.

A hydraulic lash adjuster mounted on a rocker arm does not have a bucket body, but the check ball, plunger, and body work the same way as a bucket-type hydraulic lash adjuster to maintain zero valve clearance.

Overhead cam drive

To drive the camshaft(s), a pulley on the end of the crankshaft drives a timing belt or timing chain that turns the camshaft pulley(s). The camshaft pulleys connected to the chain or belt then turn each camshaft. The timing belt pulley has half as many teeth as the camshaft pulleys, so the camshafts turn once for every two turns of the crankshaft. OHC drives also include a tensioner pulley and tensioner spring or hydraulic auto tensioner, which maintain timing chain or belt tension and valve timing.

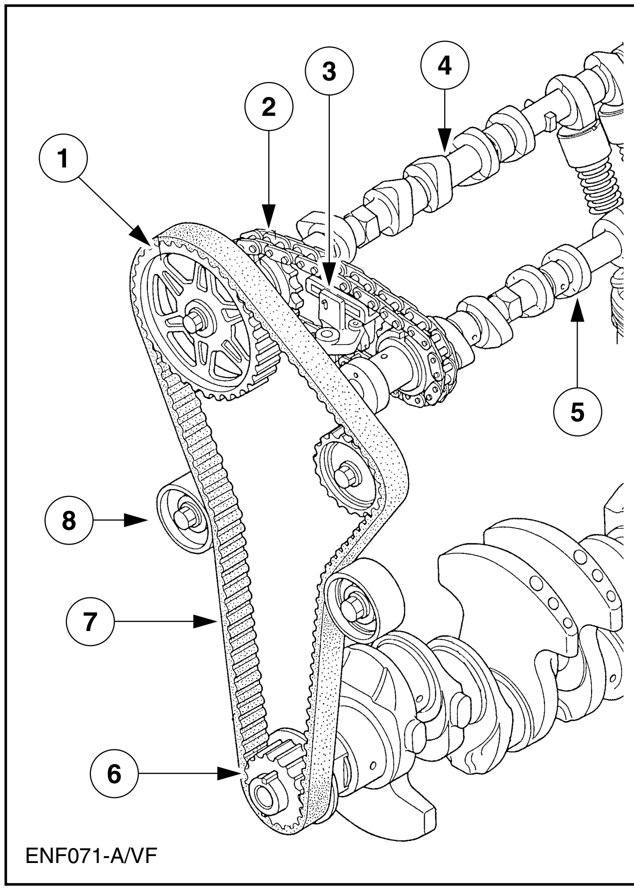


Overhead camshaft drive (belt)

1 Tensioner
2 Idler pulley

Belt and chain drive

Another type of DOHC drive is the combination belt and chain drive. In this design, a timing belt drives the intake camshaft, and a timing chain drives the exhaust camshaft. The major advantage of this design is that it allows the valves to be placed at a more vertical angle. This angle produces enhanced combustion efficiency, better fuel economy, and lower emissions.

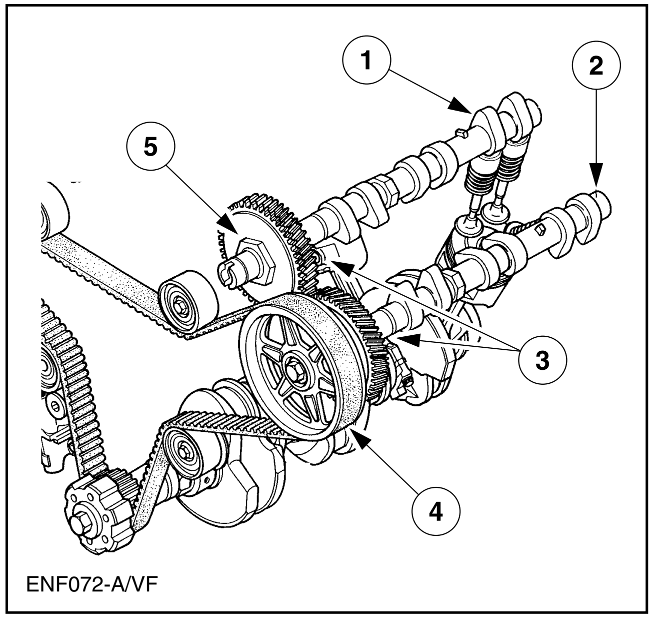


Belt and chain camshaft drive

1 Camshaft pulley
2 Camshaft chain
3 Chain tensioner
4 Intake camshaft
5 Exhaust camshaft
6 Timing belt pulley
7 Timing belt
8 Tensioner pulley

Belt and gear drive

This dual overhead camshaft (DOHC) arrangement uses a belt and pulley attached to one camshaft and the crankshaft. The second camshaft is connected to the first using helical-cut gears. One of the helical gears has one more tooth than the other. The gear with the extra tooth is called a friction gear because it causes a slight binding condition between the gears. This binding action helps reduce noise in the gears and valve train during operation.

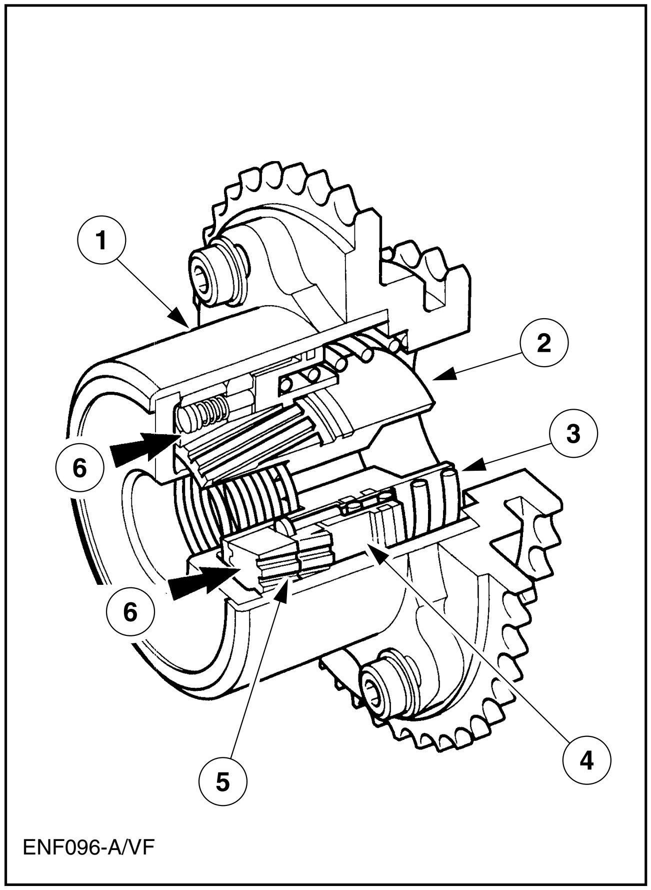


Belt and gear camshaft drive

1 Driven camshaft
2 Drive camshaft
3 Helical gears
4 Timing belt
5 Friction gear

Variable cam timing

Some DOHC engines utilize variable cam timing (VCT). A similar system is known as variable valve timing (VVT). In either system, a hydraulic actuator changes the valve timing of the camshafts. The camshaft timing is changed dependent upon engine load and speed to improve engine performance.



Variable camshaft timing gear assembly

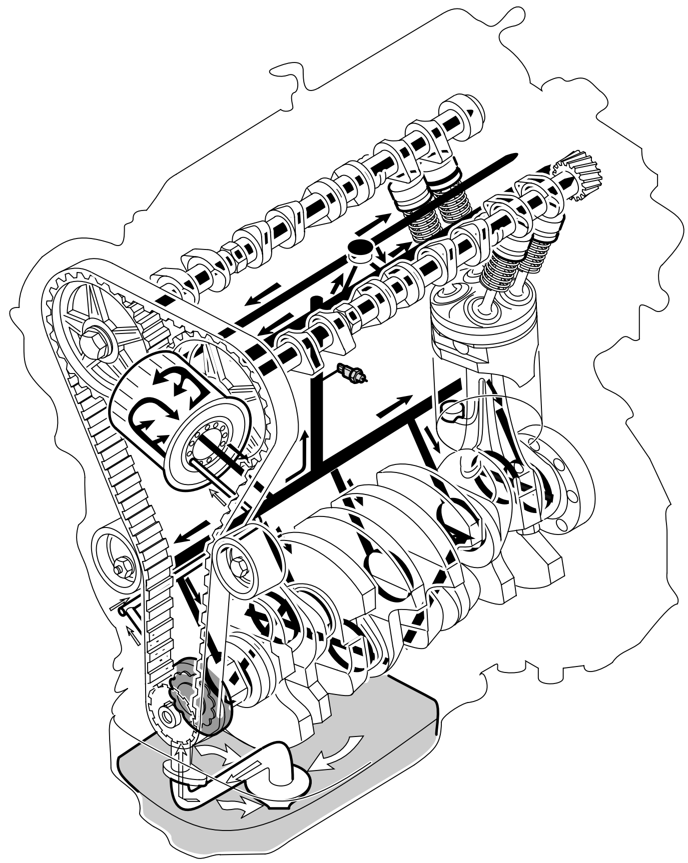
1 Body and sprocket assembly
2 Inner sleeve
3 Return spring
4 Piston
5 Ring gears
6 Oil pressure

Objectives

Upon completion of this lesson, you will be able to:

- Explain the purpose and function of the lubrication system.
- Describe the lubrication system of a modern internal combustion engine.
- Identify the main components of the lubrication system.
- Describe the theory and operation of the lubrication system.

Description



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Engine lubrication system

A large amount of heat is created during engine operation. The heat created between some moving parts is so great that an internal combustion engine cannot operate for long before damage will occur. The lubrication system provides a steady supply of pressurized oil to the moving parts of the engine. Lubrication reduces friction heat and keeps parts from wearing against each other. Oil also helps cool the engine, wash away dirt and debris, and reduce noise.

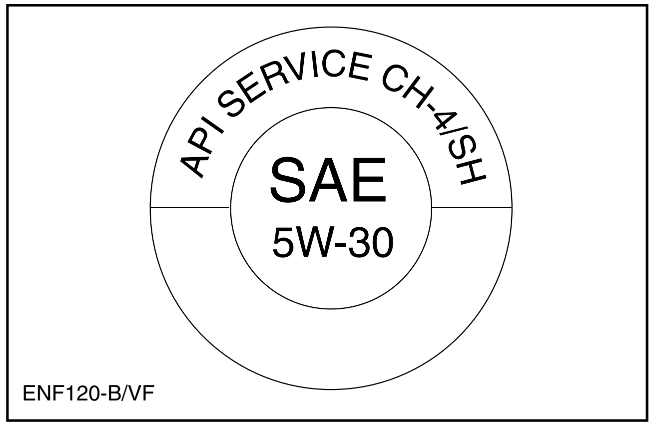
The major components of the lubrication system include:

- Oil pan
- Oil strainer
- Oil pump
- Oil filter
- Oil seals
- Dipstick
- Oil pressure indicator
- Sealing materials

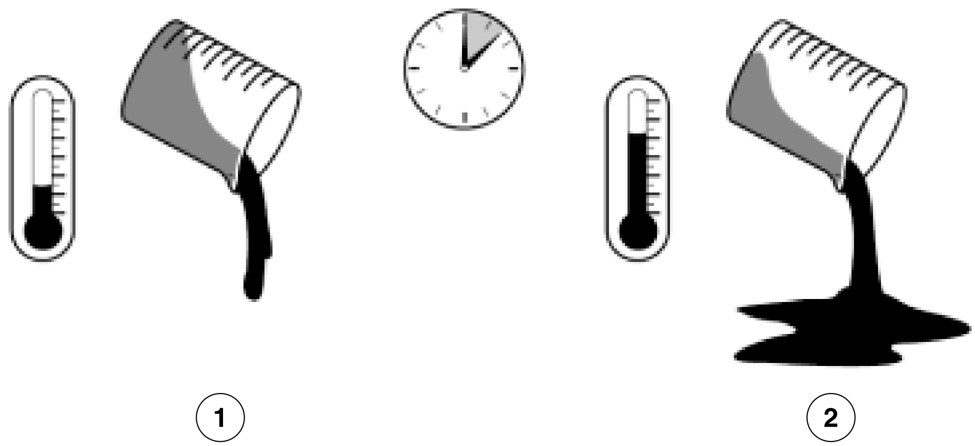
Motor oil

Today's motor oils are made from either naturally occurring crude oil (petroleum) or from man-made chemical compounds (synthetics). Some motor oils are made from both and are called partial synthetics.

Motor oils are categorized according to SAE viscosity classes as defined by the Society of Automotive Engineers (SAE). Viscosity is an expression of the ability of a fluid to flow or move. A thick oil at a given temperature does not flow as quickly as a thinner oil at the same temperature, therefore the thicker oil will have a higher viscosity number. Oils are graded according to their viscosity in relation to ambient temperature. Viscosity is an indication of the characteristics of an oil at a given temperature. The viscosity information says nothing about the quality of the oil.



Motor oil viscosity grade



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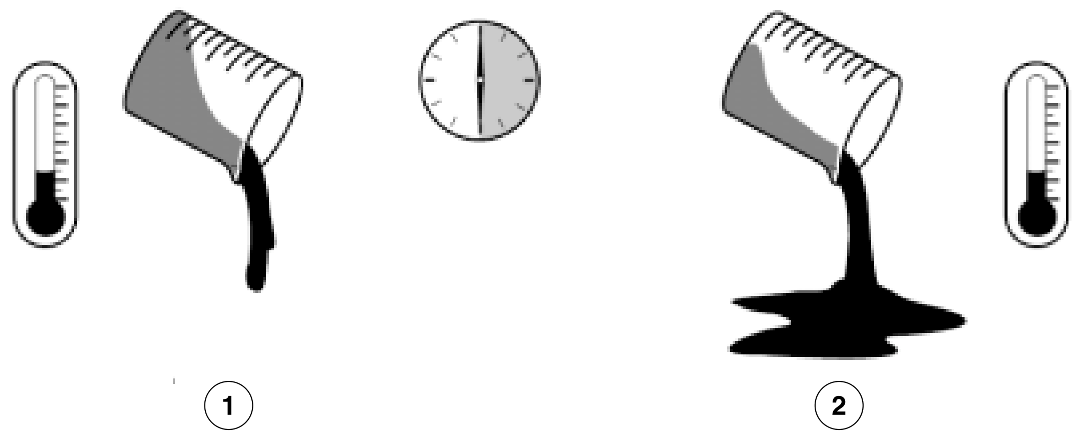
Single viscosity oil at low and high temperature

1 Oil flow at low temperature
2 Oil flow at high temperature

There are single grade oils and multigrade oils in use today in internal combustion engines. A single grade oil is an oil which performs to its grade through the entire range of temperature. A multigrade oil is an oil which performs differently cold than when it is hot. A multigrade oil can be made to act like a thin oil when cold temperatures tend to thicken liquids and act like a thick oil when hot temperatures tend to thin liquids. Multigrade oils are also called multi-viscosity oils.

Motor oil (continued)



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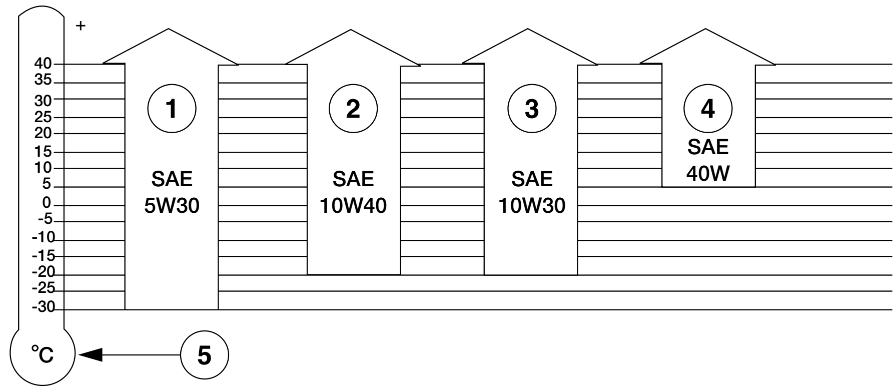
High viscosity oil and low viscosity oil at low temperature

1 High viscosity oil at low temperature
2 Low viscosity oil at low temperature



Viscosity temperature application

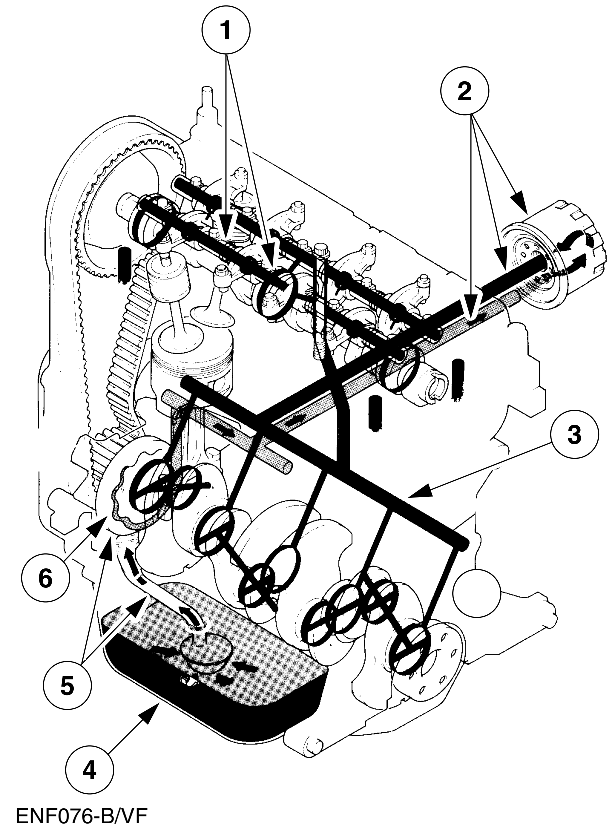
1 Synthetic motor oil
2 High-performance high lubricity motor oil
3 Super multigrade motor oil
4 Super multigrade motor oil
5 Ambient temperature

SAE numbers tell the temperature range that the oil will lubricate best. An SAE 10 classified oil lubricates well at low temperatures but becomes thin at high temperatures. An SAE 30 classified oil lubricates well at mid-range temperatures but becomes thick at low temperatures. Multigrade oils cover more than one SAE viscosity number. Their designations include the two viscosity numbers that the oil has met. For example, SAE 10W30 oil meets the requirements of a 10 weight oil for cold start and cold lubrication, and the requirements of a 30 weight oil for mid temperature lubrication.

Oil circulation

Oil circulates through the engine as follows:

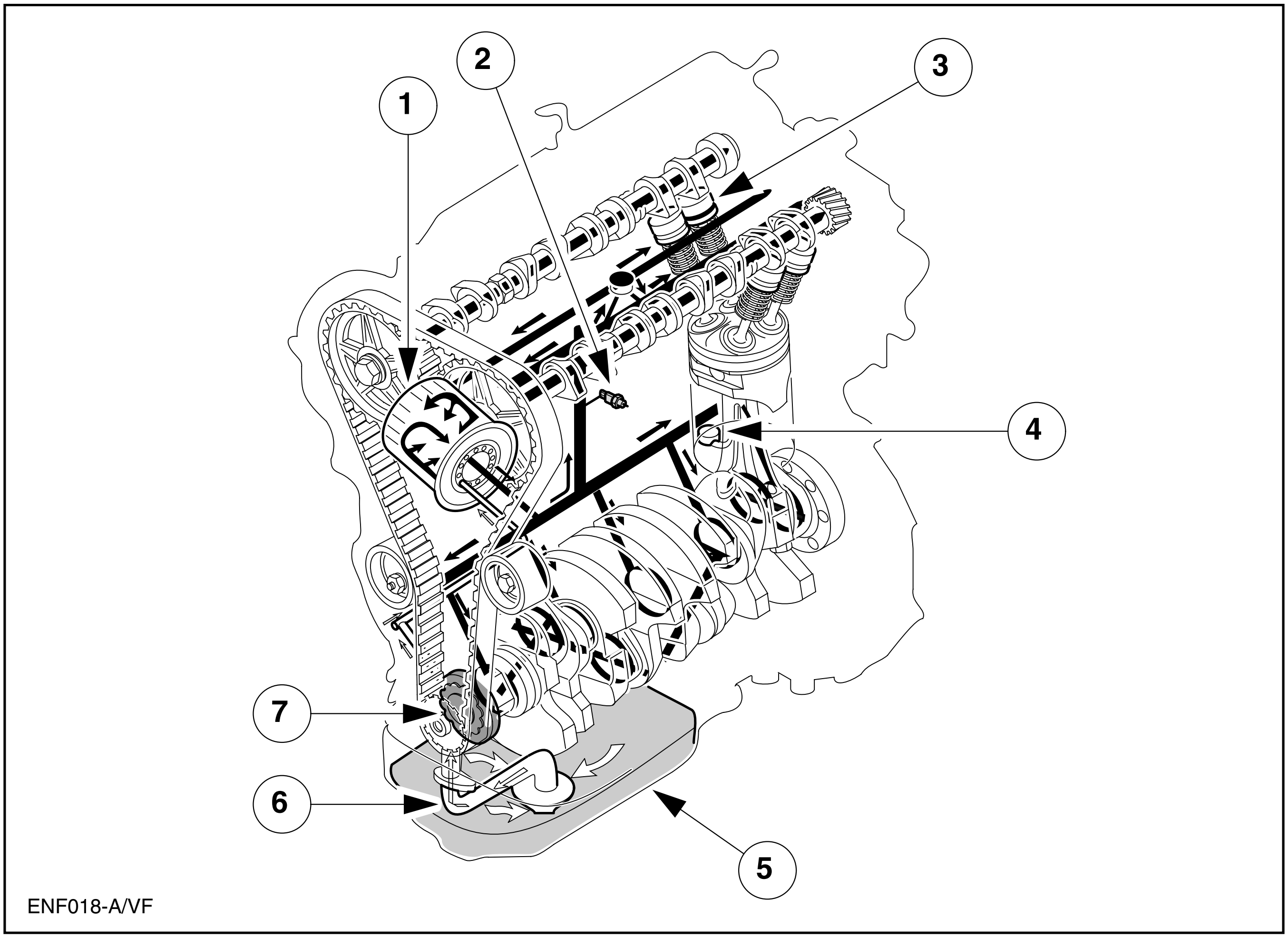
- The oil in the oil pan is drawn up through the oil strainer by the oil pump. The strainer filters out large particles.
- Oil flows through the oil filter, which filters smaller particles of dirt and debris.
- From the oil filter, the oil flows into the main oil passage (or gallery) in the cylinder block.
- From the main gallery, oil flows through smaller passages to the camshaft, pistons, crankshaft, and other moving parts. Oil holes and jets direct the flow of oil to critical parts, such as bearings and pistons.
- As the oil lubricates the surfaces of moving parts, it is constantly pushed off by new oil. The oil drips from the lubricated surfaces back into the oil pan. In many engines, an oil cooler is used to cool the oil before the oil is drawn back through the oil strainer to repeat the cycle.



Oil circulation

1 Upper oil gallery oil flow
2 Filter oil flow
3 Main gallery oil flow
4 Oil pan oil source
5 Oil strainer to oil pump oil flow
6 Oil pump

Pressure lubrication



Oil circulation

1 Oil filter
2 Oil pressure switch or sending unit
3 Hydraulic bucket lifter
4 Oil splash nozzles
5 Oil pan
6 Oil intake pipe and strainer
7 Oil pump

Oil drips off the moving parts into the oil pan. A pump draws the oil from the pan, through a strainer, and forces it under pressure through a filter. After filtering, the oil passes to the lubricating points in the cylinder head and the cylinder block. A pressure relief valve in the oil pump ensures that oil pressure does not exceed engine oil pressure specifications.

Full pressure is used to pump oil through the main oil gallery. Oil from the main gallery lubricates the crankshaft main bearings, connecting rod bearings, camshaft, and hydraulic valve lifters (if equipped). In other parts of the engine, the volume is reduced as oil flows through smaller passages. Pushrod ends and rocker arms receive reduced pressure lubrication.

Stresses on the oil

The lubricating oil in the engine is subjected to great stresses from temperature and contamination. The oil must retain its lubricating ability at temperatures of up to 150° C (300º F). Oil coolers are sometimes used to keep engine oil from getting too hot. Oil coolers transfer heat from oil to the outside air or to engine coolant. The oil is also subjected to chemical stresses from combustion gases, dust, metal particles from wear, and combustion residues. The high temperature and contaminants reduce the ability of the oil to perform well and lead to the formation of sludge.

Oil changes

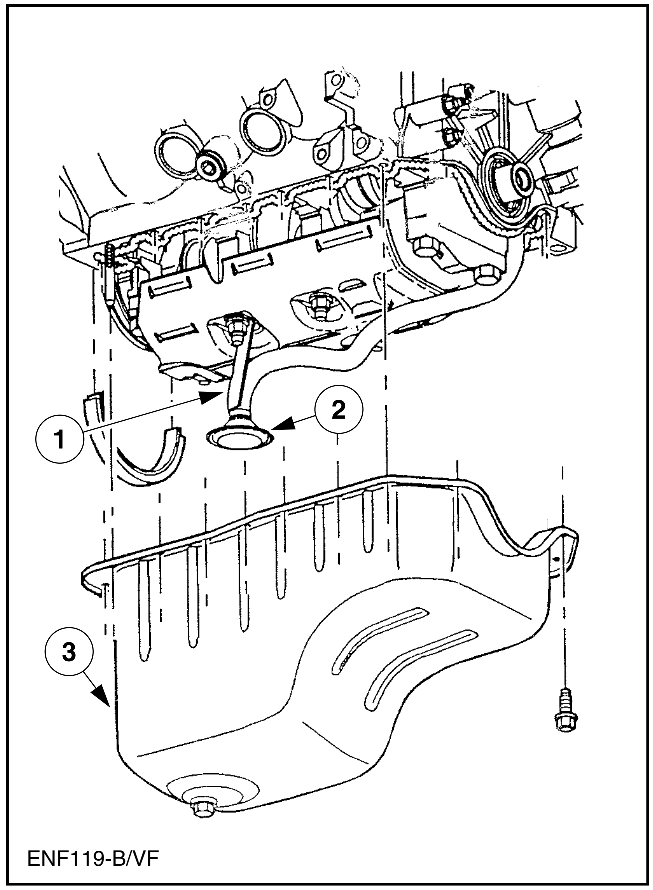
It is important to change the engine oil at the specified service intervals. The oil filter should always be changed when changing engine oil. When adding new oil, it is important to use the correct type, quantity, and quality specified by the manufacturer. Overfilling or underfilling of the engine oil can lead to internal engine damage and high exhaust emissions.

Oil pan components

The oil pan is attached to the bottom of the engine block. The oil pan provides a reservoir for engine oil and seals the crankcase. The oil pan helps dissipate some heat from the oil into the surrounding air. Some oil pans have a baffle that helps reduce oil sloshing in the pan during engine operation.

Oil strainer

The oil strainer is a screen that blocks dirt and debris from entering the oil pump inlet. The oil strainer is located in the bottom of the oil pan attached to the inlet side of the oil pump. The strainer is kept completely covered by the engine oil so that air is not sucked into the oil pump. Oil enters through the strainer into the oil pump inlet, then is pushed throughout the engine.



Oil pan and strainer

1 Pick-up tube
2 Strainer
3 Oil pan

Oil pump

The oil pump provides the “push” that circulates pressurized oil throughout the engine. The oil pump pulls oil from the oil pan and pushes the oil through the lubrication system. The oil pump is usually mounted on the cylinder block or the front engine cover. The oil pump is normally driven by the crankshaft or camshaft using a gear, belt, or drive shaft. Engine oil pumps are classified as positive displacement pumps. All oil entering the pump inlet comes out the pump outlet. Oil is not allowed to circulate inside the pump.

Pressure relief valve

Excessive oil pressure damages seals and gaskets, causing oil leaks. The faster an oil pump is driven, the more oil it pumps. Lubrication systems include a pressure relief valve that limits the maximum pressure that the pump can develop. If all the oil from the pump is forced into the oil passages, the oil would quickly heat up and break down. To limit the oil pressure, the pressure relief valve opens at a preset limit and sends some of the oil from the pump outlet back into the inlet or back into the oil pan.

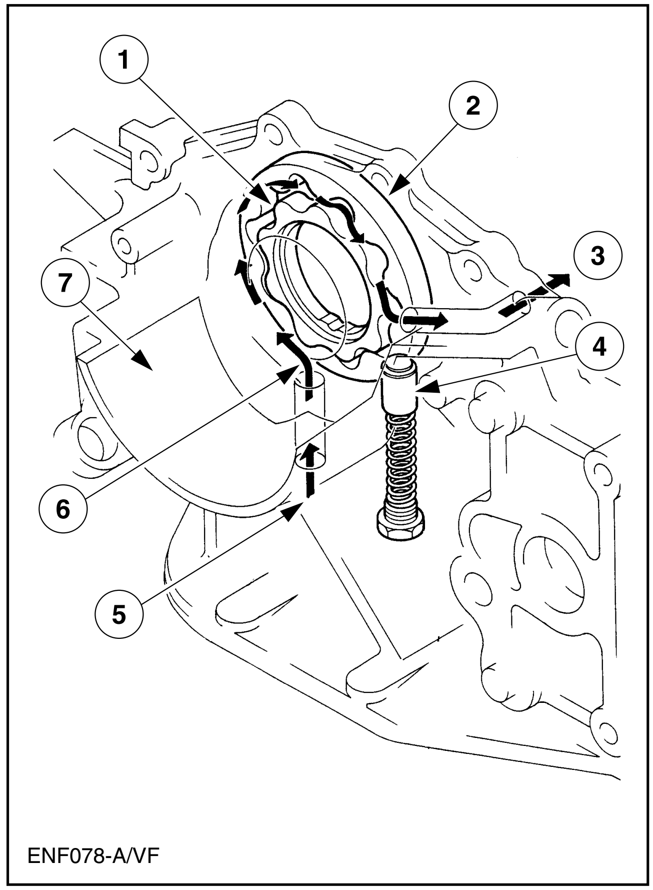
Oil pump types

Rotor-type pump

A rotor-type pump uses two rotors, one turning inside the other, to pressurize the oil. The two rotors turn at slightly different speeds. The rotors have smooth, rounded lobes. These types of rotors are called trochoid gears.

In this design, the crankshaft drives the inner rotor. The inner rotor drives the outer rotor. As the two rotors turn, pumping cavities are formed between the lobes on the two rotors. The pumping cavities become smaller and larger as the lobes on the two rotors go into and out of mesh. An opening in the pump housing at the meshing (pump outlet) and de-mesh (pump inlet) points allows oil into and out of the pump as the rotors spin.

Rotor-type pumps are very reliable and can withstand high speed operation. Rotor-type pumps produce a smooth flow of oil, rather than a pulsing action. The rotor-type pump used on many engines has a small hole at the outlet side to allow air to escape. If there is no oil in the pump because the vehicle has not been driven for a long time, the air hole vents the air quickly when the engine is started, allowing oil to flow almost immediately to critical engine parts.



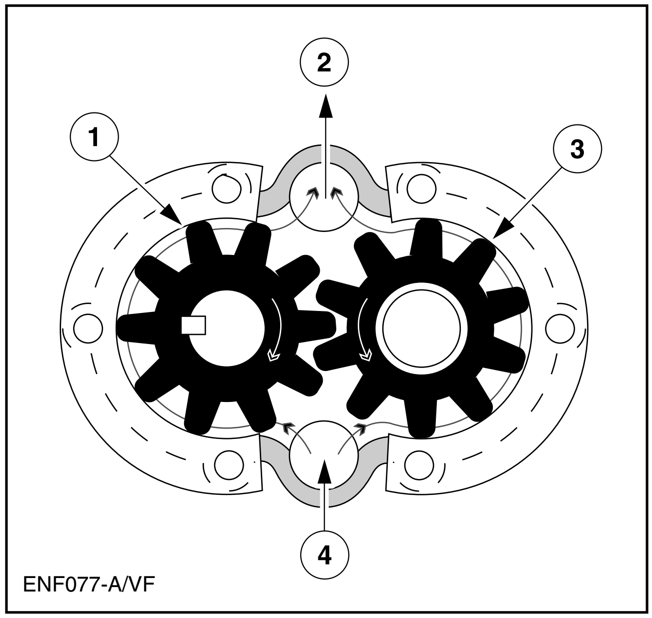
Rotor-type oil pump

1 Inner rotor
2 Outer rotor
3 Outlet port
4 Pressure relief valve
5 Inlet port
6 Engine oil
7 Pump body

Oil pump types (continued)

Gear pump

In a gear-type oil pump, two gears are used to push the oil through the pump. The camshaft or crankshaft drives the drive gear. As the drive gear turns, it meshes with the driven gear, which turns in the opposite direction. As the gears turn within the pump body, they create a suction at the inlet port. The oil is pulled between the gears and the pump body to the outlet port.



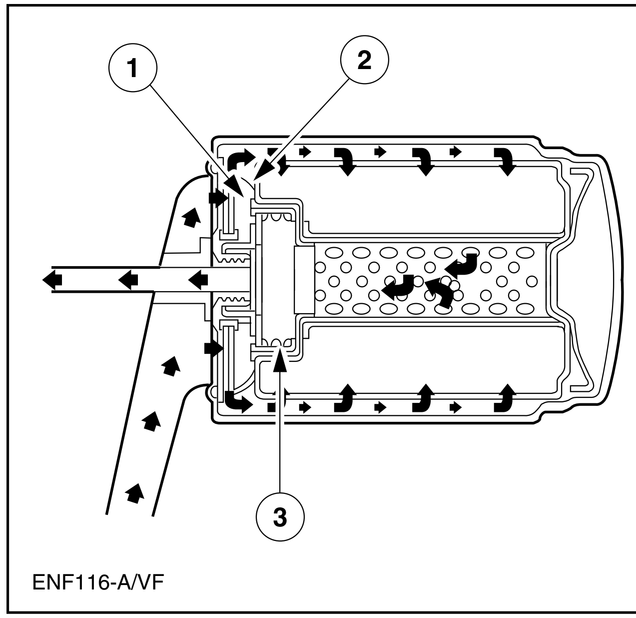
Gear-type oil pump

1 Drive gear
2 Outlet port
3 Driven gear
4 Inlet port

Oil filter

The oil filter traps smaller particles of metal, dirt, and debris carried by the oil so they do not recirculate through the engine. The filter keeps the oil clean to reduce engine wear. The oil filter traps very small particles that may get through the oil strainer. Most oil filters are the full-flow type. All the oil pumped by the oil pump passes through the oil filter. The filter contains a paper element that screens out particles in the oil. Oil flows from the oil pump and enters the oil filter through several holes. The oil first flows around the outer part of the filter element. Then the oil passes through the filter material into the center of the element. Finally, the oil flows out to the main gallery through a tube in the center of the filter.

The filter screws onto the main oil gallery tube. A seal prevents oil from leaking at the connection between the filter and the cylinder block.



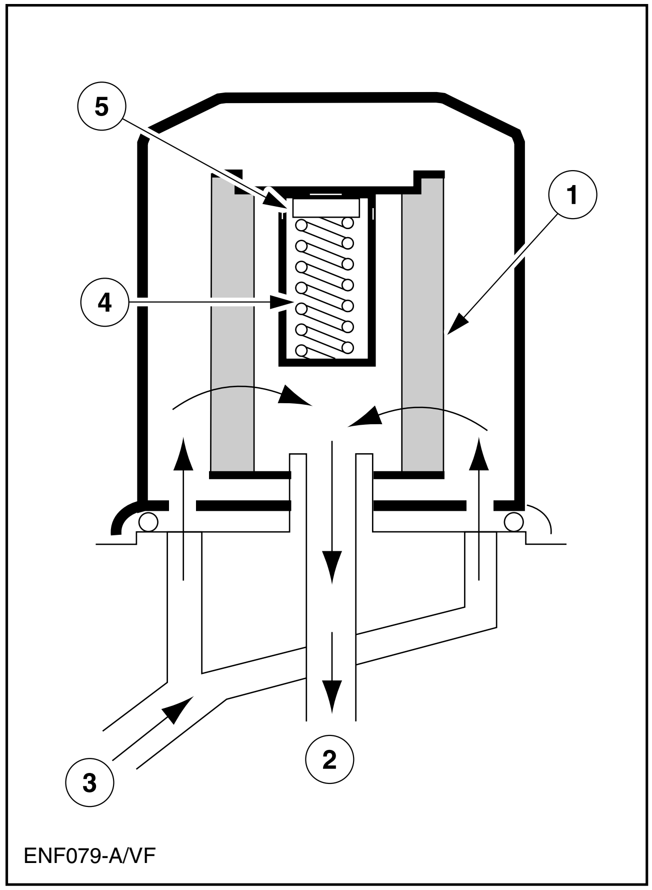
Oil filter and flow

1 Bypass valve (closed)
2 Anti-drainback diaphragm
3 Bypass valve spring

Oil filter (continued)

Bypass valve

As the element in the oil filter becomes dirty, the oil pump works harder to push oil through the filter. If the filter becomes clogged, and no way is provided to bypass the filter, engine damage could result. To prevent this type of damage, most original equipment manufacturer (OEM) oil filters also include a spring-loaded bypass valve. This valve is designed to allow oil to bypass the filter if the filter becomes clogged. When back-pressure becomes great enough to overcome the spring on the bypass valve, the valve opens, allowing some of the oil to bypass the filter and go directly to the oil gallery tube.

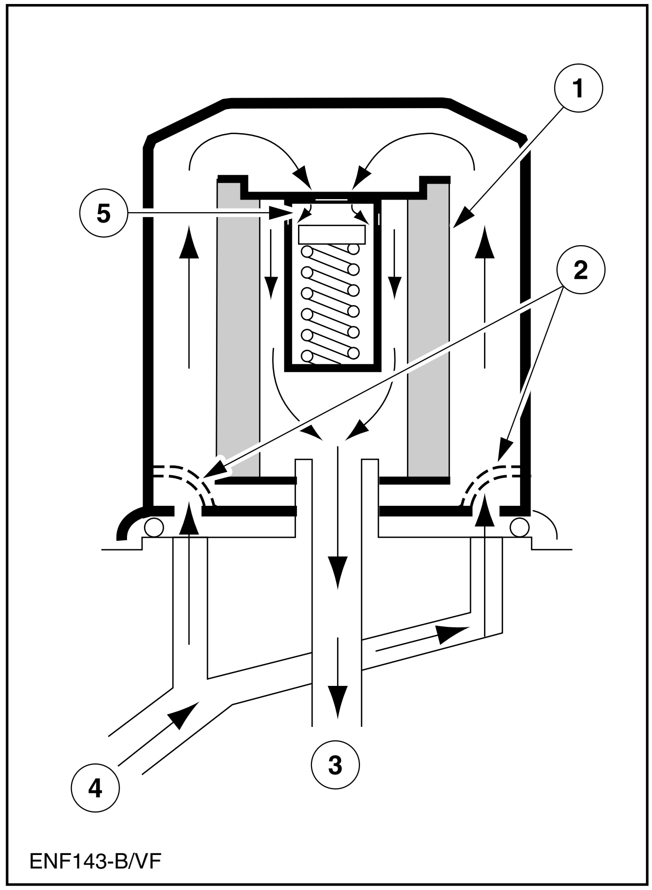


Oil filter normal filtered flow

1 Filter element
2 Filtered oil out
3 Unfiltered oil in
4 Bypass valve spring
5 Bypass valve (closed)

Anti-drainback diaphragm

Many OEM oil filters also contain an anti-drainback diaphragm, which keeps oil inside the filter when the engine is shut off. The diaphragm covers all the filter inlet holes when the oil pump stops. When the engine is shut off, the pressure of the oil in the filter forces the diaphragm down on the holes, sealing oil in the filter. When the engine starts again, oil flows immediately from the filter allowing critical engine parts to receive lubrication immediately. As the pressure from the oil pump grows, the diaphragm is pushed away from the holes and normal oil flow begins again.



Oil filter bypass flow (unfiltered)

1 Filter element
2 Anti-drainback valve
3 Unfiltered bypass oil out
4 Unfiltered oil in
5 Oil flow past open bypass valve

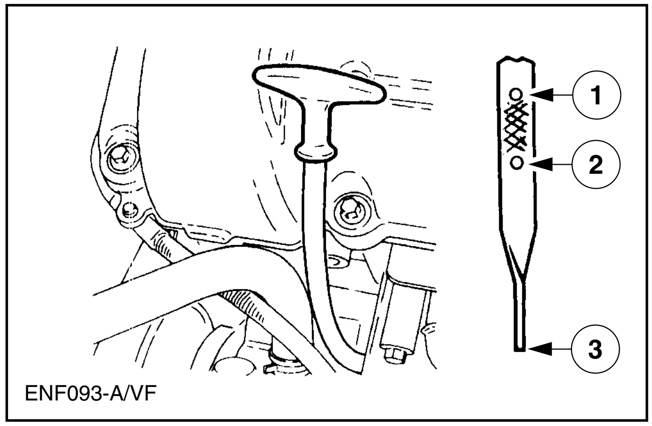
Oil seals

At various locations in the engine, seals and gaskets keep oil from leaking out of the engine or into places in the engine where oil should not be present.

Dipstick

The engine oil dipstick is used to measure the level of oil in the oil pan. One end of the dipstick dips into the top of the oil reservoir, and the other end has a handle so it can be pulled out easily. The end that dips into the oil pan has a gauge on it that shows whether oil should be added to the engine.

It is important to keep the oil level above the "MIN" line at all times. The crankcase should never be overfilled or allowed to drop too low. Too much oil may permit the crankshaft to contact the oil and churn it until it turns to foam. The oil pump cannot pump foam, and foam will not lubricate. Low oil levels can result in excessively high oil temperatures, which may lead to bearing failure. An oil level that is too high or too low can also increase oil consumption. Consult the Workshop Manual or Owner's Manual for the correct oil capacity and recommended oil.

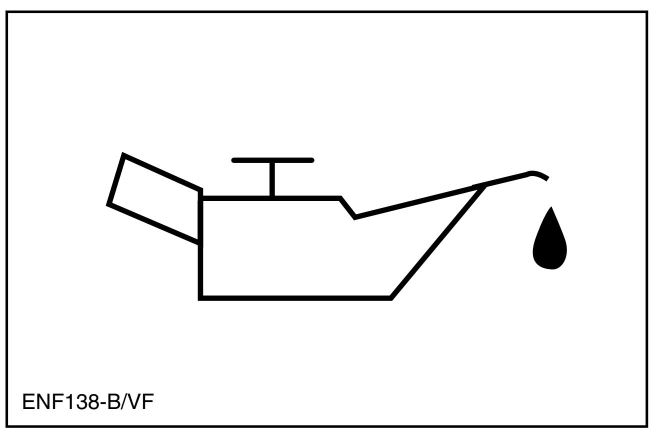


Oil dipstick and markings

1 Maximum oil level
2 Minimum oil level
3 Bottom tip of dipstick

Oil pressure warning indicator

The instrument panel usually has some type of oil pressure indicator that warns the driver when the lubrication system cannot maintain the oil pressure needed by the engine. This indicator may be a gauge or a warning light.



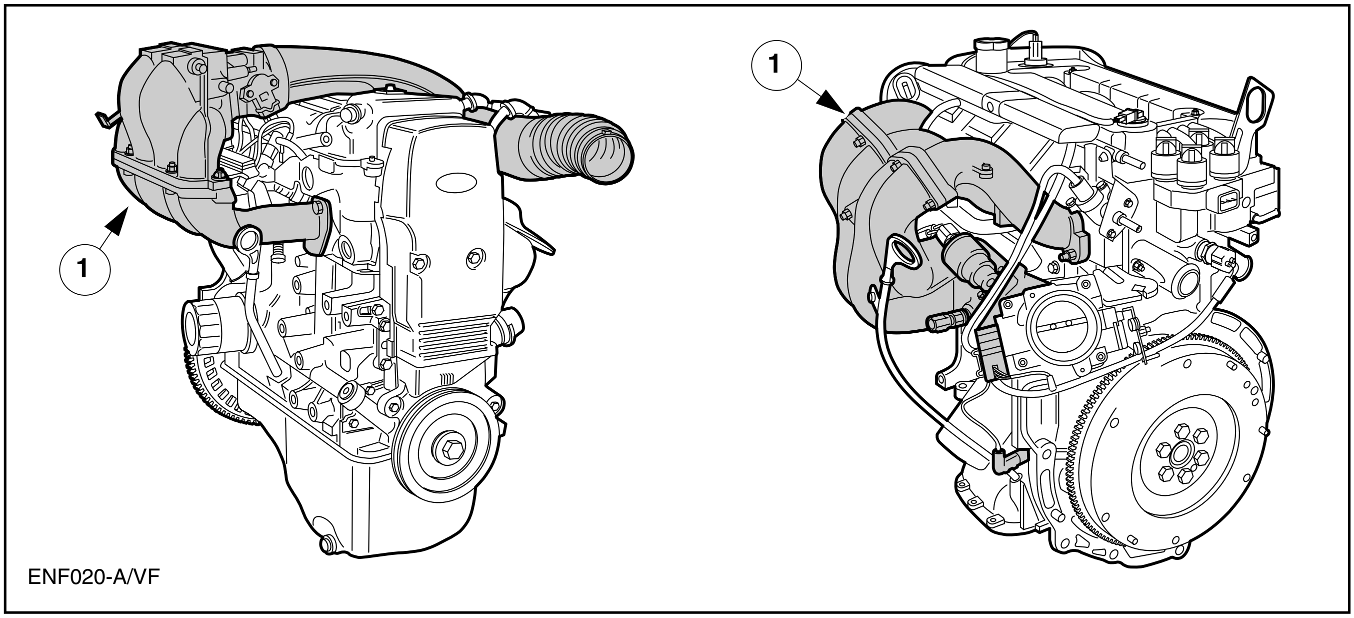
Instrument cluster oil pressure warning indicator

Objectives

Upon completion of this lesson, you will be able to:

- Explain the purpose and function of the intake air system.
- Identify components of the intake air system.
- Describe the intake air system of the internal combustion engine.
- Explain the theory and operation of the intake air system.

Air intake system



Air intake manifold

1 Intake manifold

The air intake system is designed to clean the intake air and feed the air and fuel mixture to the cylinders. The major components of the air intake system includes:

- Air intake ducting
- Air induction resonator
- Air cleaner assembly
- Intake manifold

Resonator assemblies may be included to reduce air intake noise. Air induction resonators can be separate components or part of the air intake housing (i.e., conical air cleaner). Additionally, a mass air flow sensor and a throttle body which are both part of the fuel injection system are located between the air cleaner assembly and the intake manifold. Refer to Engine Performance for information about the fuel injection system.

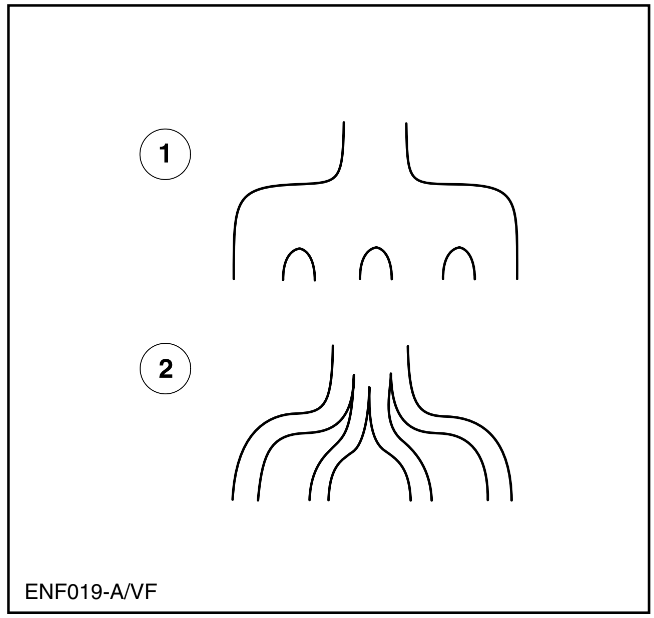
Air cleaner and intake components

The air cleaner assembly houses the air filter element. The filter element removes any particles of dirt, dust, or debris entering the air intake system. The intake manifold directs intake air into the cylinders. Intake manifolds are made of aluminum alloy or plastic composites. To ensure good cylinder charging, intake manifolds must have a very smooth internal surface offering minimal resistance to the inflowing gases. The shape of the intake manifold can cause the air flow to swirl all the way into the combustion chamber for more efficient combustion. If the ports to the individual cylinders are the same length and diameter, the same conditions apply at all the cylinders during induction, resulting in uniform cylinder charging.

During the warm-up phase, some of the fuel condenses on the internal walls of the intake manifold. To minimize these condensation losses, intake manifolds are often fitted with a pre-heater. Intake systems must be perfectly sealed from the outside. Unmetered air induced through leaks disturbs engine management and results in uneven engine operation, especially at idle. Refer to the Engine Performance Fundamentals book for information regarding the engine management system. The vacuum in the intake manifold can be used for various purposes. Brake servos and automatic choke systems can be operated by means of vacuum diaphragm units. Appropriate connectors are provided on the intake manifold for these different functions.

Inlet runners

The length and diameter of the intake manifold inlet runners also have an effect on volumetric efficiency. During low engine speeds, longer and thinner inlet runners produce higher volumetric efficiency. During high engine speeds, shorter and wider inlet runners are more efficient. More modern engine designs utilize such innovations as multi-valve engines and variable intake systems to increase volumetric efficiency.



Inlet runners

1 Shorter, thicker inlet runners
2 Longer, thinner inlet runners

Variable induction systems

Because the length and diameter of the intake runners affect performance, efficiency and exhaust emissions, some engines utilize variable length induction systems. These systems use both long and short intake runners. At lower engine speeds, the air flows through the long runners for best performance. At a certain engine speed, a valve opens to allow air also to flow through the short runners for maximum output at high engine speeds. These intake subsystems are used to provide increased air flow when required to improve torque and performance. There are basic two types of variable length intake manifold designs:

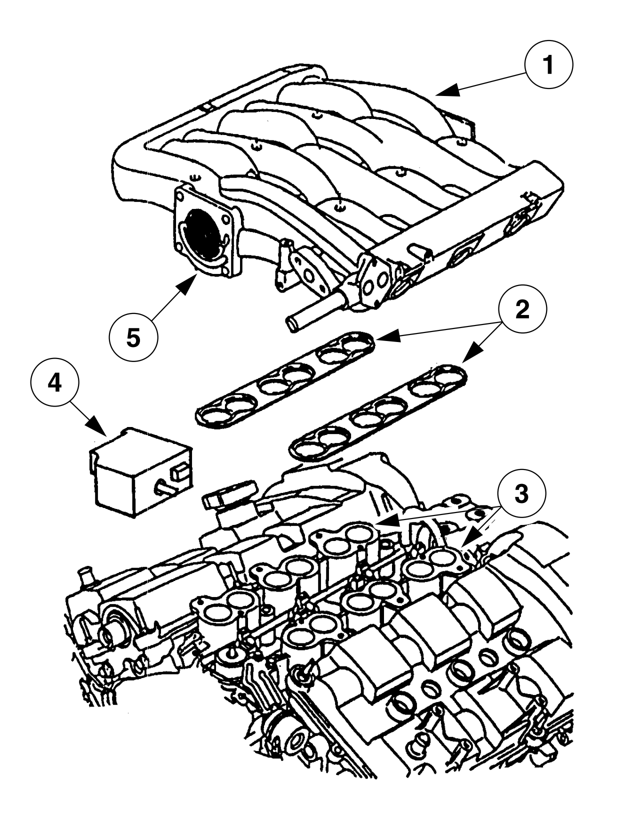
- Intake manifold runner control (IMRC) actuated system and
- Intake manifold tuning (IMT) valve

Intake manifold runner control (IMRC) system

The intake manifold has two runners per cylinder, feeding each of the intake ports in the cylinder heads.

The IMRC assemblies are located between the intake manifold and cylinder heads, providing two air passages for each cylinder. The IMRC assemblies are actually the lower manifold, in what becomes a two piece intake manifold assembly. One air passage is always open and the other passage switches from closed to open by means of a valve plate.

Below a certain rpm, generally 3,000 rpm, the valve plate is closed to improve low speed and cold engine performance. Above this rpm, the valve plate opens to improve high speed engine performance. The valve plates are opened and closed by the IMRC actuator. Most actuator designs are electric in operation. Some actuators are vacuum operated. The engine control system controls the IMRC actuator. Refer to the Engine Performance book for information about the engine control system.

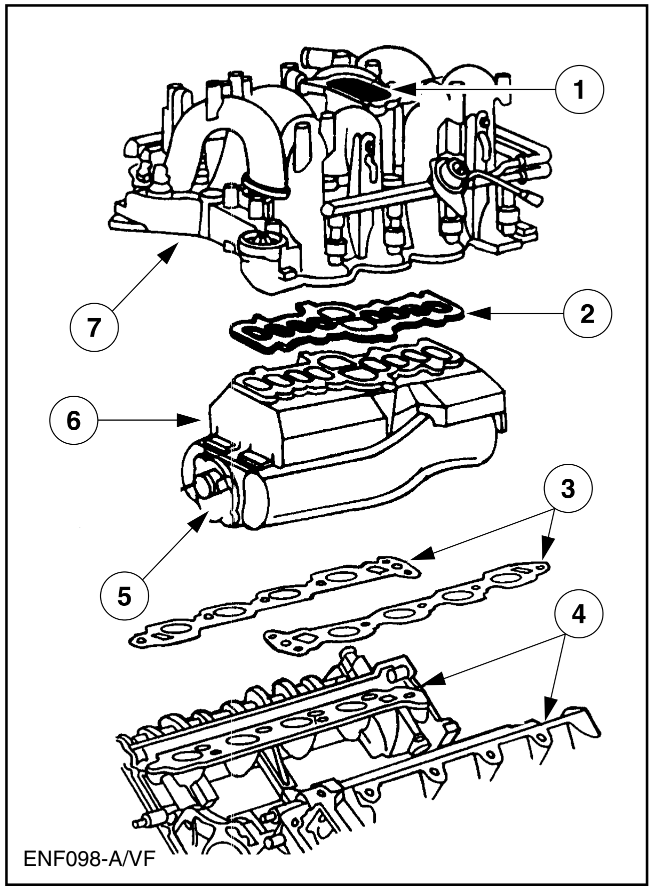


IMRC components

1 Upper intake manifold
2 Upper manifold gaskets
3 IMRC assemblies (lower intake manifold)
4 IMRC actuator
5 Air inlet

Intake manifold tuning (IMT) valve

The IMT valve is an electric actuator controlling a valve plate or shutter device mounted directly to the intake manifold. Below a certain rpm the IMT valve is closed. Above a certain rpm, the IMT valve opens allowing more into the cylinders to improve high speed engine performance. The engine control system controls the IMT valve. Refer to the Engine Performance book for information about the engine control system.



IMTV components

1 Intake airflow
2 Manifold gasket
3 Manifold to cylinder head gaskets
4 Cylinder heads
5 IMT valve
6 Lower intake manifold
7 Upper intake manifold

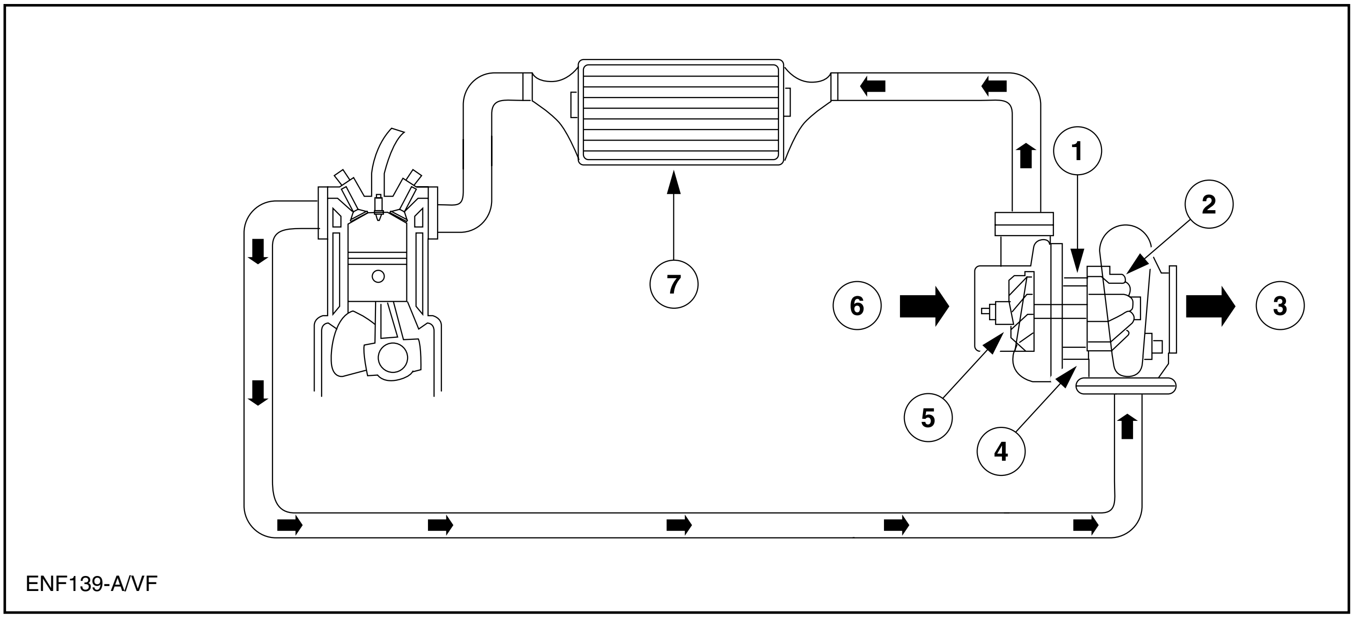
Forced induction

Most vehicle engines draw in the air-fuel mixture from vacuum created by the downward travel of the piston, and for this reason are called naturally aspirated engines. Naturally aspirated engines rely on atmospheric air pressure to supply air to the cylinder.

The power output of an engine is directly linked to its volumetric efficiency. A naturally aspirated engine usually has about an 80% volumetric efficiency. This means that the engine draws in about 80% of its displacement. Streamlining passages and increasing port sizes improves volumetric efficiency. The air still has difficulty reaching the cylinder. As long as the engine relies on atmospheric pressure to push the air through the intake system, the engine does not produce as much power as it is capable of producing.

Without external help, an engine receives only a partial air-fuel charge. Pumping air into the cylinders can increase the air-fuel charge. This forcing of more air into the cylinders allows the engine to fill its cylinders with a charge, which meets or exceeds 100% volumetric efficiency. This process of pumping more air into the engine cylinders is called forced induction. There are two different methods used to pump air into an engine: turbocharging and supercharging.

Turbocharging



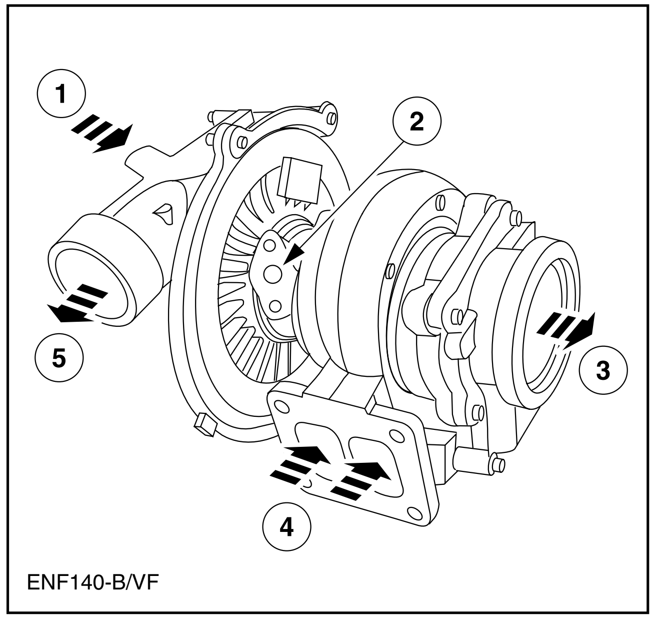
Turbocharger system

1 Compressor shaft oil feed
2 Turbine
3 Turbine exhaust out
4 Compressor shaft oil drain
5 Compressor
6 Compressor air intake
7 Air intercooler

The most common type of air pump or compressor is a turbocharger. The turbocharger uses exhaust gas to drive a turbine wheel attached to a shaft and connected to a compressor wheel. The exhaust gas flow sets the turbine wheel in motion, which in turn powers the compressor wheel located in the intake pipe. The compressor wheel compresses the air and forces it into the engine at pressures up to about 9 psi. To ensure that the pressure in the turbocharger unit does not become too high and damage the engine, a pressure-regulating valve called a wastegate is used. The wastegate opens at a certain pre-set pressure.

A large turbocharger unit generates more torque, but responds more slowly at low engine speeds. A smaller turbocharger unit has a smaller turbine wheel, which is easier to set in motion. Some vehicle manufacturers have begun using smaller turbocharger units, which begin charging at low engine speeds and provide full effect during “normal driving”. These smaller turbocharger units are often called light pressure turbochargers.

Because a turbocharger is driven by exhaust gas flow, it does not consume engine power. Some turbocharged engines experience a short interval of time before the turbocharger begins to pump a large amount of air into the engine. This short interval of time is called turbo lag. During this period of turbo lag, the engine does not deliver the extra power that the turbocharger provides at higher rpm. Some turbochargers use a variable inlet design. This design helps the turbocharger reach optimal speed at a lower rpm which increases low-speed engine performance and reduces turbo lag.

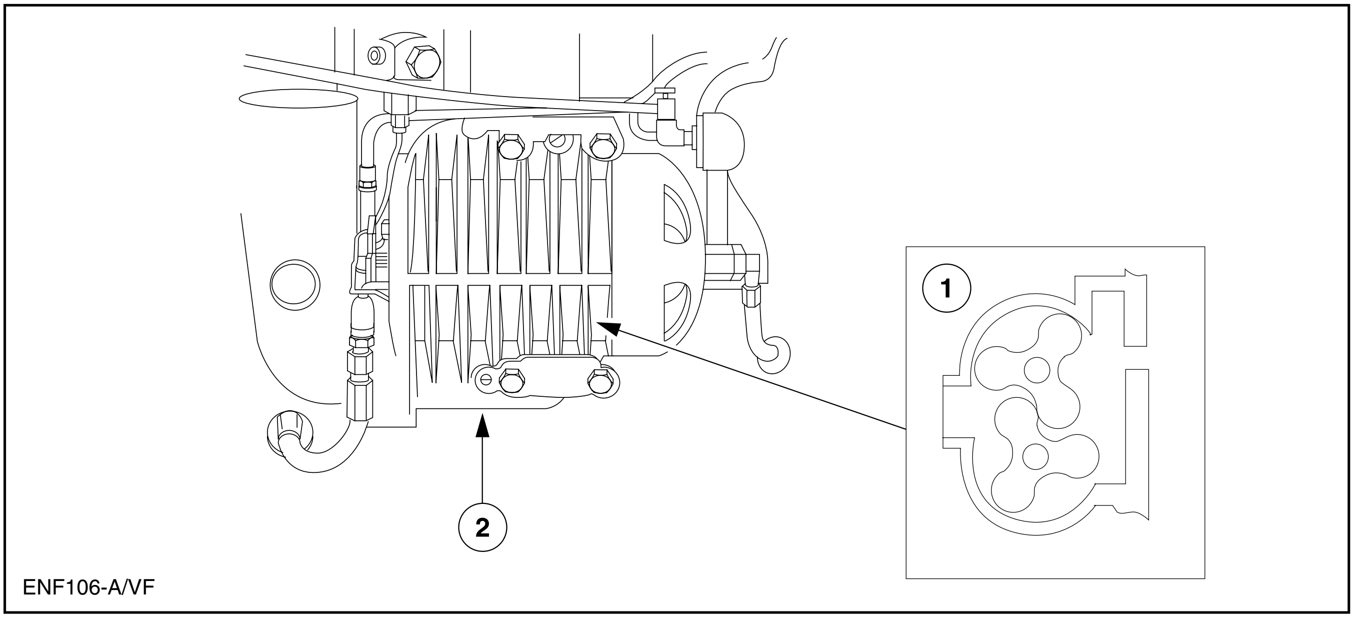


Compressor and turbine housing

1 Fresh air intake
2 Oil feed
3 Exhaust out
4 Exhaust in
5 Compressed air to engine

Turbocharging (continued)

Supercharging



Lobe-type supercharger

1 Lobe-type compressor rotors
2 Supercharger assembly

A supercharger is a type of air pump or compressor. Exhaust gases do not drive a supercharger. The power source of a supercharger is the engine itself. The crankshaft drives the supercharger through a belt, gear or chain. Intake manifold pressures of up to 13 psi are typical for supercharged engines.

As with a turbocharger, the amount of power available to drive the supercharger depends upon engine speed. Unlike some turbocharged engines, when accelerating a supercharger immediately delivers extra engine power. Although it takes engine power to drive a supercharger, a supercharger helps produce much more power in return. There are different types of superchargers. No matter how a supercharger is designed, its main purpose is to force more air into the cylinders and help the engine produce more power.

Objectives

Upon completion of this lesson, you will be able to:

- Explain the purpose and function of the exhaust system.
- Describe the exhaust system and identify types.
- Identify the components of the exhaust system.
- Explain the theory and operation of the exhaust system.

Description and purpose

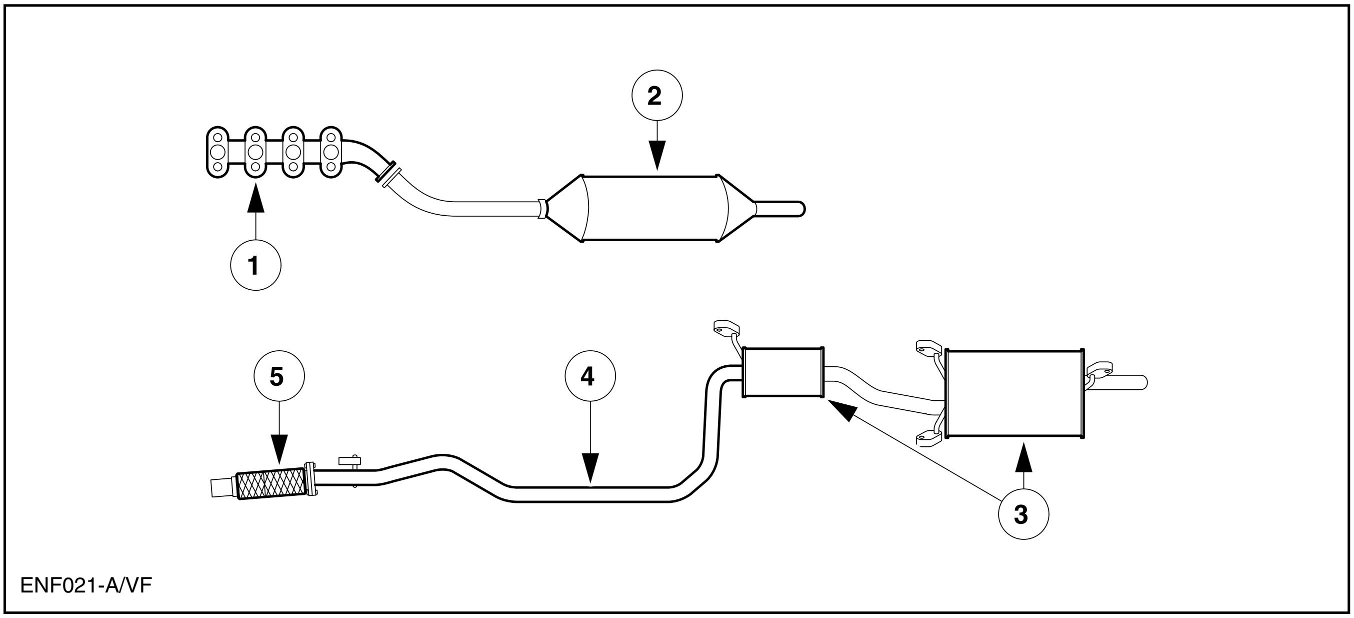
The exhaust system carries the engine exhaust gases to the rear of the vehicle, dampens the noise produced by combustion and cleans the exhaust gases (when applicable).

The major components of the exhaust system include:

- Exhaust manifold
- Exhaust pipes
- Mufflers
- Catalytic converter

Exhaust systems are specifically tuned to particular engines and vehicles. This tuning allows the optimum combination of engine performance and noise reduction. Because the exhaust manifold is the part of the exhaust system exposed to the highest temperatures, it is made of a durable metal such as cast iron or steel. The exhaust pipes and mufflers can be made of sheet metal or stainless steel. The exhaust system is subjected to corrosion from water and road salt. High temperatures and vibration also reduce exhaust system life.

If the exhaust system is damaged or leaking, it must be repaired or renewed. Otherwise, toxic exhaust gases can get into the passenger compartment of the vehicle. In addition, the engine management system is affected adversely by air getting into the exhaust system. Refer to the Engine Performance Fundamentals book for information about the engine management system.



Exhaust system (typical)

1 Exhaust manifold
2 Catalytic converter
3 Muffler
4 Exhaust pipe
5 Flexible pipe

Flexible lengths of pipe give the exhaust system limited scope for movement. Flexible pipe ensures that thermal expansion and vibration cannot cause stresses in the material. Flexible pipe helps reduce noise and failures from stress.

Mufflers

The muffler reduces the level of noise produced by the engine, and it also reduces the noise produced by exhaust gases as they travel from the catalytic converter to the atmosphere.

Mufflers are usually treated during manufacturing with an anti-corrosive coating agent to increase the life of the muffler.

Catalytic converter

The concentration of exhaust gas products released to the atmosphere must be controlled. The catalytic converter assists in this task. A catalyst is a material that remains unchanged when it initiates and increases the speed of a chemical reaction. A catalyst will also enable a chemical reaction to occur at a lower temperature.

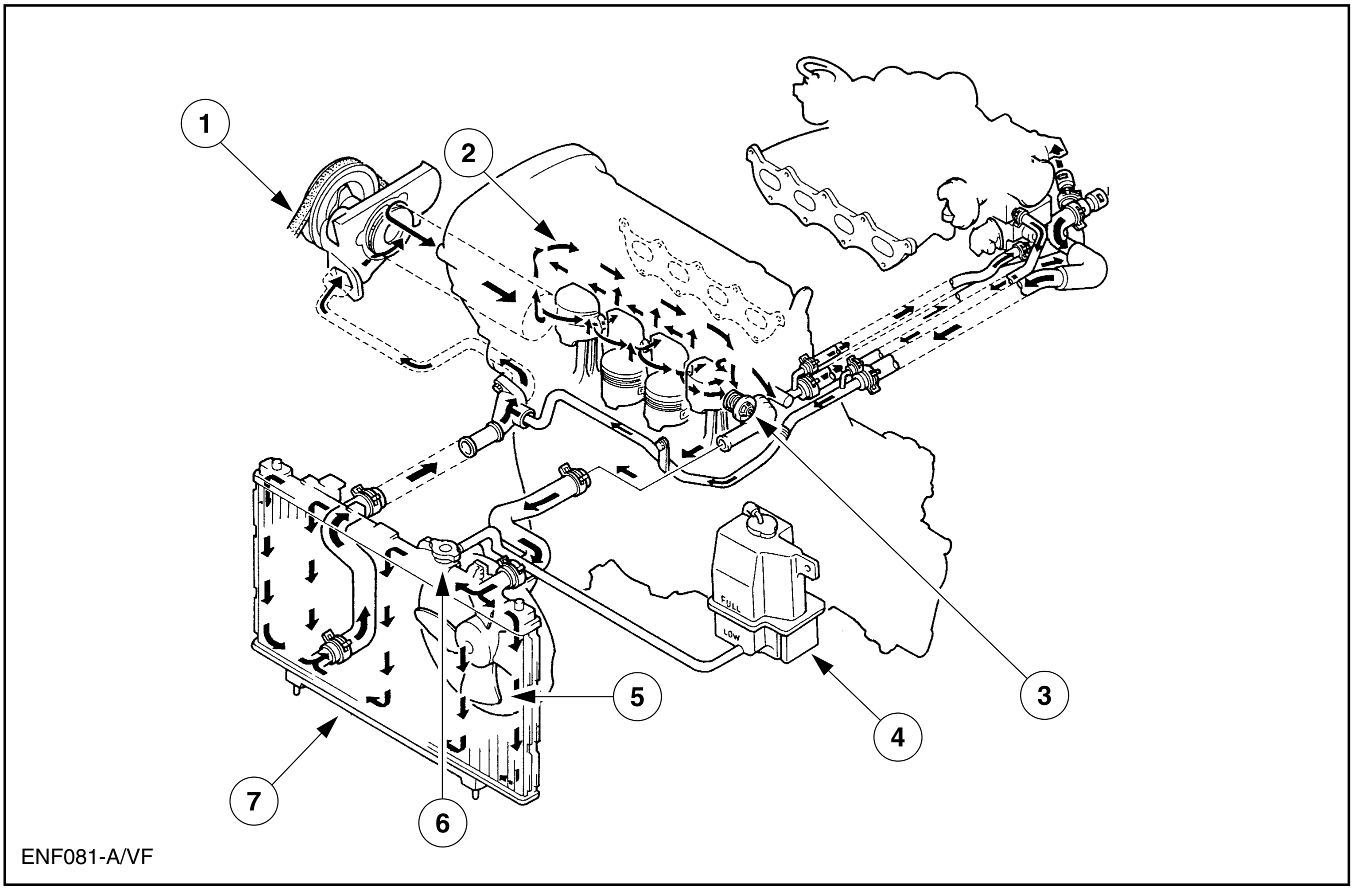
The catalytic converter contains a catalyst in the form of a specially treated honeycomb structure. As the exhaust gases come in contact with the catalyst, they are chemically changed into less harmful gases. Refer to Engine Performance (TF1010008S) for further details.

Objectives

Upon completion of this lesson, you will be able to:

- Describe the cooling system and identify types.
- Identify the components of a typical automotive cooling system.
- Explain the theory and operation of the cooling system.

Description



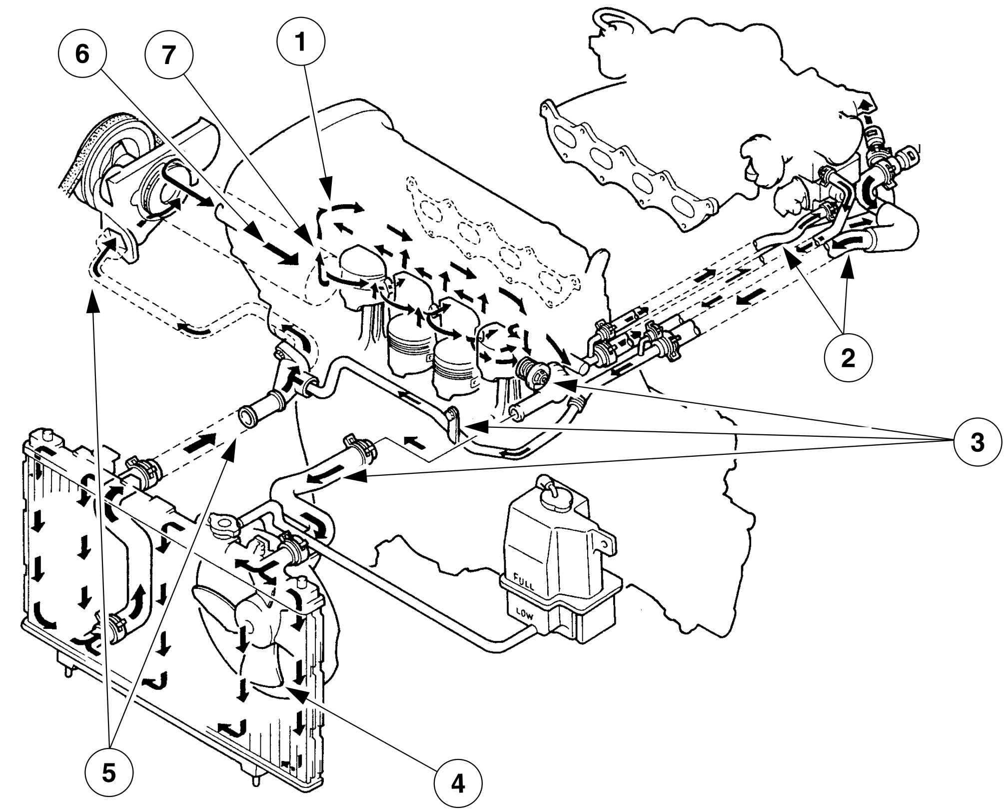
Cooling system

1 Coolant pump
2 Coolant passages
3 Thermostat
4 Radiator reservoir and degas bottle
5 Fan
6 Pressure cap
7 Radiator

The cooling system maintains an efficient engine operating temperature. About one third of the heat created by combustion is removed by the cooling system. The method used to cool automotive engines in the vast majority of applications is liquid cooling.

Most engines are cooled by a steady flow of liquid coolant through the cylinder block and heads. The cooling system removes excess heat produced during combustion and keeps the engine operating at its most efficient temperature. If the cooling system fails, the engine can overheat and may be damaged. An operating temperature that is too cool results in incomplete combustion and poor gas mileage.

Coolant



Cooling system flow

1 Flow into cylinder head
2 Flow to throttle body
3 Flow to thermostat and bypass
4 Flow into radiator
5 Flow out of radiator
6 Flow into cylinder block
7 Flow from cylinder block into cylinder head

Coolant passages are cast into the cylinder block and cylinder head. These passages carry coolant around the cylinders and combustion chambers. The coolant picks up heat and carries it away from these parts.

In early engines, water alone was used as coolant. Today, most engines use an ethylene-glycol based coolant mixed with water. Ethylene-glycol coolant lowers the freezing point of water, raises the boiling point of water, adds water pump lubrication, and prevents engine corrosion.

Some vehicles use Organic Acid Technology (OAT) coolant. OAT coolant is designed to be an extended life coolant, reducing cooling system maintenance. OAT coolant is orange in color to distinguish it from other coolants and has special additives to lubricate and protect the cooling system from corrosion. OAT coolant is not compatible with other coolants.

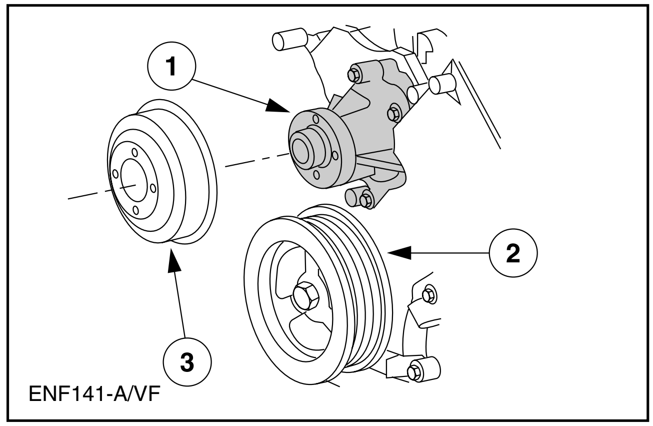
Operation

When a cold engine is started, the coolant pump only circulates coolant through the cylinder head and engine block coolant passages, quickly raising the engine temperature. Some of the coolant may be diverted to the heating system, which heats the passenger compartment of the vehicle.

When enough heat is created to open the thermostat, the water pump circulates coolant throughout the engine and into the radiator. The hot coolant flows from the upper tank of the radiator to the lower radiator tank. Cool air passing over the radiator fins removes heat from the coolant. From the lower tank, coolant flows through the lower radiator hose to the coolant pump inlet. The coolant pump circulates the coolant through the pump outlet into the cylinder block coolant passage. Coolant flows from the cylinder block passage into the cylinder head coolant passage to complete the circuit.

Coolant pump

The coolant pump circulates coolant throughout the cooling system. Most coolant pumps are impeller or non-positive displacement pumps. All the coolant that enters the pump does not necessarily have to come out of the pump. This design is different from the oil pump (a positive displacement type), in which all the oil that enters the pump is pumped out.



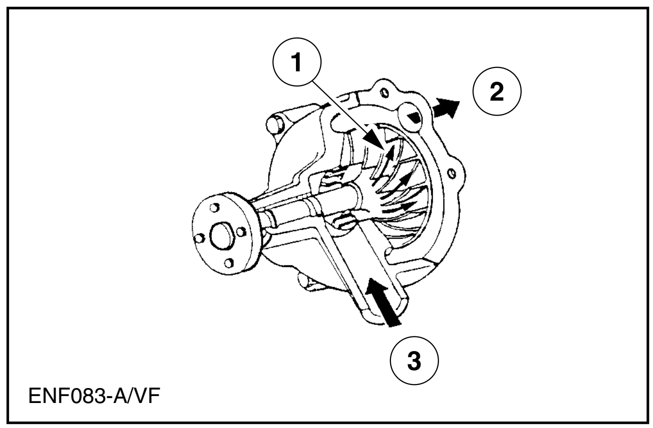
Coolant pump (typical)

1 Coolant pump
2 Crankshaft pulley
3 Coolant pump drive pulley

Impeller-type pump

Coolant pumps are usually designed as simple impeller-type pumps. The coolant pump has a pump body, which holds the impeller. The impeller turns on a shaft that is connected to a drive pulley.

The impeller-type pump operates on centrifugal action. Centrifugal action is the tendency of a rotating weight to be pushed outward. Coolant flows through the pump inlet and enters the center of the impeller. As the impeller rotates, it “slings” the coolant to the outside edges of the impeller. The coolant is trapped by the pump body and forced into the pump outlet.

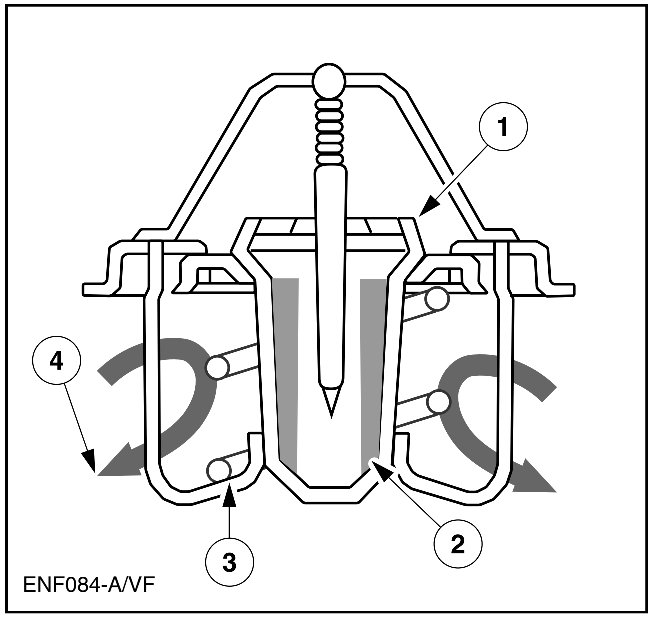


Impeller-type pump

1 Impeller
2 Pump outlet
3 Pump inlet

Thermostat

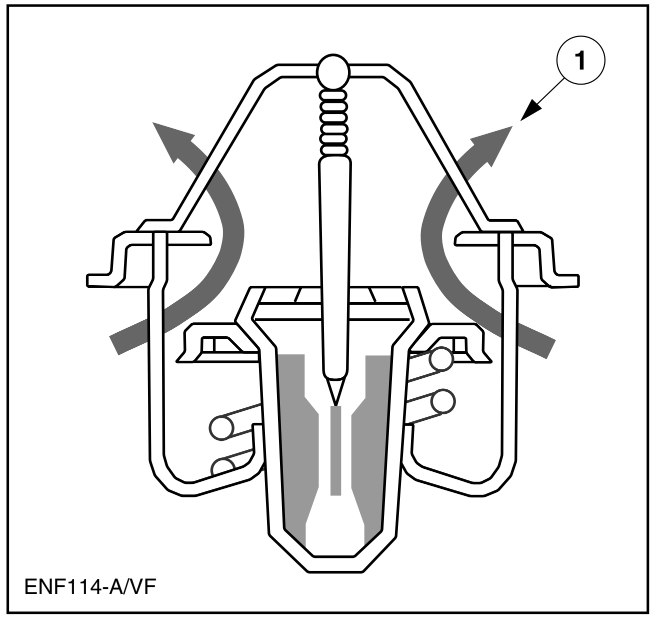
The thermostat restricts the flow of coolant through the system until the engine reaches its operating temperature. The engine warms up quickly, improving fuel economy and emissions. A quick warm-up also reduces combustion chamber gases blowing by the pistons and entering the crankcase.



Wax pellet-type thermostat

1 Valve
2 Wax
3 Spring
4 Coolant flow

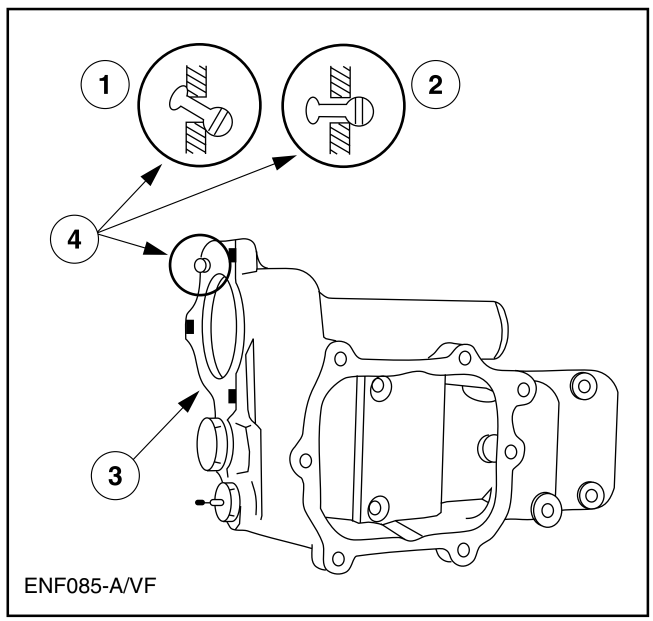
The thermostat contains a heat-sensitive wax pellet. When the engine is cold, the wax remains solid, and the spring holds the valve closed. When the coolant heats up, the wax turns to liquid and expands. The expansion pushes the body of the valve down, which opens the flow of coolant to the radiator.



Thermostat coolant flow

1 Coolant flow

To provide an outlet for air in the cooling system, many thermostats include a jiggle pin, near the top of the engine either in the thermostat itself or in the thermostat housing. When there is air in the cooling system, the weighted end of the jiggle pin drops down, allowing air to escape. When the engine is operating, pressure from the water pump pushes the jiggle pin against its seat. The closed jiggle pin prevents coolant from flowing to the radiator until the thermostat opens.



Jiggle pin

1 Jiggle pin open
2 Jiggle pin closed
3 Thermostat housing
4 Jiggle pin

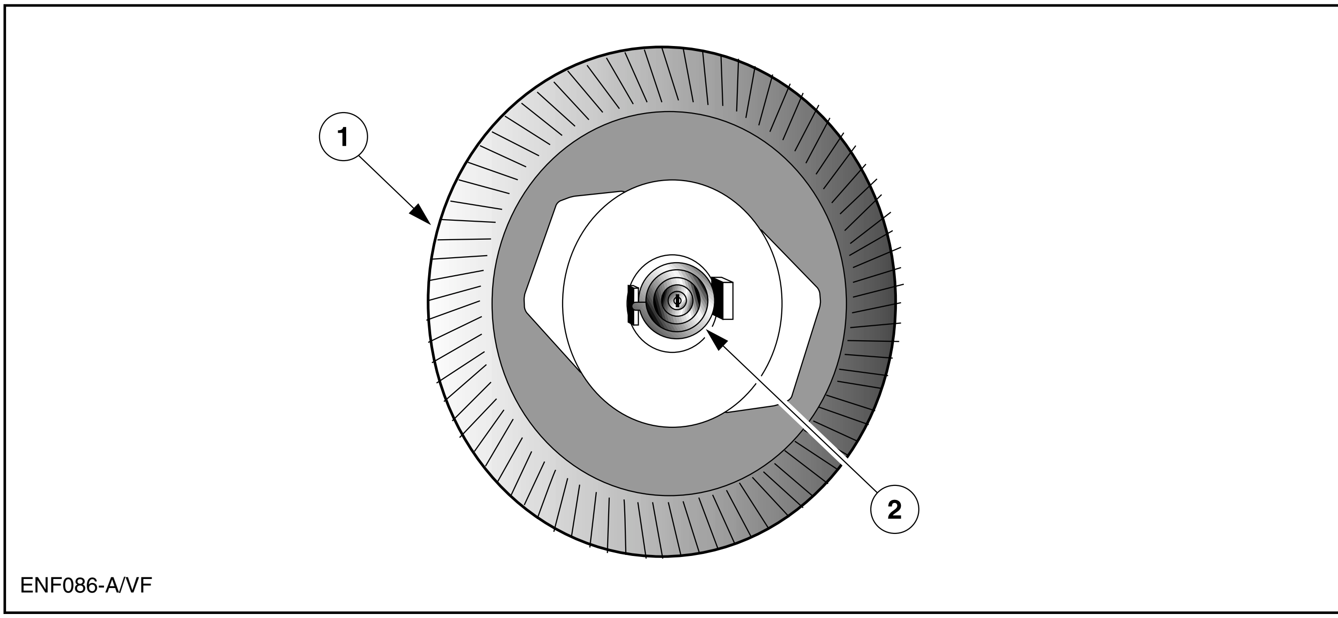
Cooling fan

The radiator fan pulls cool outside air over the radiator surface to pick up heat from the coolant for faster heat transfer, especially during idling. Most vehicles equipped with air conditioning usually have an additional fan for increased cooling. Most fans have four or more blades to increase their cooling capacity. A fan shroud may surround the fan to concentrate the flow of air.

Cooling fan drives

There are several different types of fan drive including electric, viscous, hydraulic and mechanical. Some vehicles may use a combination of two different types of fan drives. Some fans are driven by an electric motor which turns the fan on and off depending upon engine coolant temperature. When the coolant reaches a preset temperature, the thermoswitch (engine coolant temperature sensor) activates an electrical relay, which turns on the fan motor. When the coolant temperature drops, the thermoswitch turns off the fan motor. Other fans are controlled by a microprocessor-based control module. Sensors send engine coolant temperature data to the module which uses the data to determine if the engine coolant fan should be switched on or off.

A hydraulic fan drive uses hydraulic oil pressure to drive the fan.



Viscous fan clutch and bi-metal spring

1 Clutch plate
2 Bi-metal thermostat

A mechanical fan drive uses a pulley and belt to drive the fan. Most mechanical drive fans use a clutch drive, which allows the fan to turn at lower speeds when the temperature is lower. If the fan were constantly turned at the speed of the engine, the fan would become very noisy at high speeds and would also sap engine power.

One of the most common types of fan clutches is the viscous type. A viscous drive is a fluid coupling.

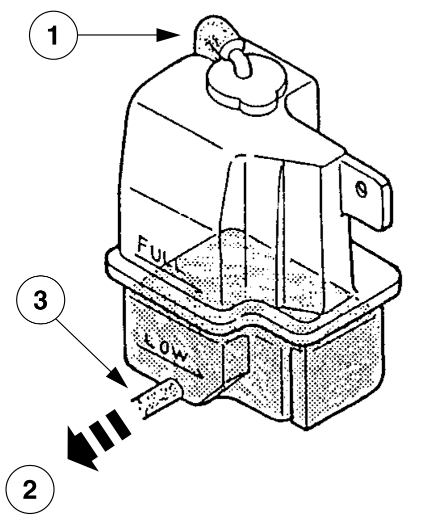
A bi-metal thermostat controls the amount of coupling. The bi-metal thermostat is a spring made of two types of metal. The spring expands at higher temperatures and contracts at lower temperatures. The thermostat is connected to a valve that controls the amount of fluid available to couple the clutch. The thermostat responds to the temperature of the air passing through the radiator. If the air temperature is cold, the flow of fluid in the clutch is restricted. Little or no coupling occurs, and the fan turns very slowly or not at all. At higher temperatures, the fluid operating on the clutch increases, causing a tighter coupling and faster fan speed.

Coolant overflow reservoir and degas bottle

Two types of coolant overflow reservoirs are commonly used: a non-pressurized coolant overflow reservoir, and a pressurized type of reservoir known as a degas bottle.

As coolant becomes hot, it expands. The non-pressurized coolant recovery reservoir stores the excess coolant released from the radiator. When the engine cools, the coolant in the reservoir is drawn back into the cooling system. This keeps the cooling system constantly full, increasing cooling system efficiency.

Coolant level is checked and coolant is added at the radiator. A hose connects the reservoir to the radiator filler neck. As engine temperature rises, a pressure cap permits the expanding coolant to flow from the radiator into the reservoir as required. When the engine is stopped, the coolant temperature drops and the coolant contracts. A partial vacuum develops in the cooling system, drawing coolant from the reservoir back into the cooling system. The reservoir has an overflow tube that allows coolant to escape if the cooling system is overfilled or if the engine overheats.



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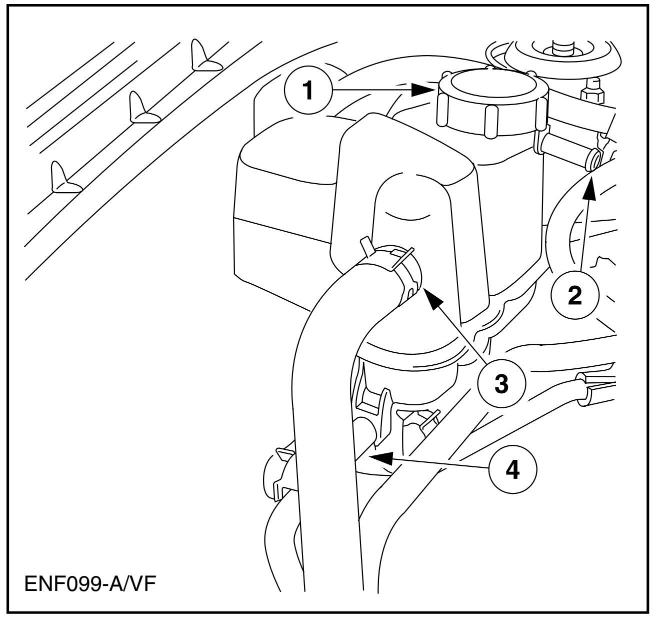
Coolant reservoir

1 Overflow tube
2 Coolant flow to or from radiator
3 Radiator reservoir hose

Degas bottle

The degas bottle is similar in operation and appearance to the coolant overflow reservoir. However, the bottle is pressurized like the radiator, and the pressure cap is located on the degas bottle itself instead of on the radiator. The cooling system is filled through the pressure cap located on the degas bottle. The degas bottle provides for coolant expansion during normal operation. An overflow tube provides an outlet for excess coolant to escape if the cooling system is overfilled or the engine overheats. The degas bottle provides air separation during engine operation. The degas bottle replenishes engine coolant to the system.



Coolant degas bottle

1 Pressure cap
2 Overflow outlet
3 Coolant inlet
4 Coolant outlet

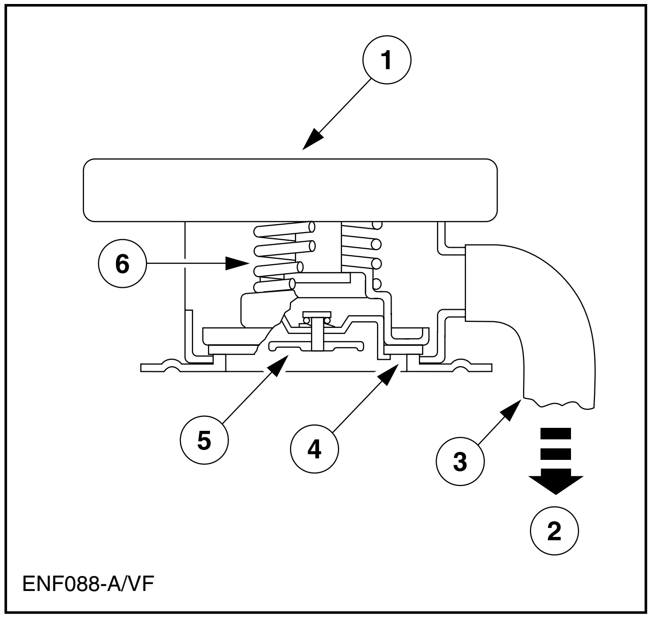
Degas bottle (continued)

Pressure cap

The pressure cap maintains pressure in the system, which raises the boiling temperature of the coolant. The pressure cap also allows excess pressure to escape from the system.

The boiling point of a liquid rises with the amount of pressure it is under. For example, water at sea level boils at about 100º C (212º F). Water in a typical pressurized cooling system boils at more than 121º C (250º F). Pressurizing the cooling system effectively raises the operating temperature of the engine. The cooling system's increased pressure raises the coolant's boiling point to add a comfortable margin between the engine operating temperature and the boiling point of the coolant.

The pressure cap fits on either the filler neck of the radiator or on a degas bottle. The pressure cap includes a pressure valve and a vacuum valve. Both are spring-loaded to remain closed when the system is within operating ranges.



Radiator pressure cap (typical)

1 Pressure cap
2 Coolant flow to or from overflow reservoir
3 Overflow reservoir hose
4 Pressure valve
5 Vacuum valve
6 Spring

If the pressure in the cooling system exceeds a specified limit, the pressure valve opens to avoid bursting the radiator or hoses. Steam and coolant can then escape through the reservoir hose (attached to the filler neck) into the radiator reservoir or out the overflow tube if the vehicle is equipped with a degas bottle.

When the engine is shut off, steam in the system condenses back into liquid, creating a vacuum in the system. The vacuum valve on the pressure cap opens, allowing coolant from the reservoir back into the radiator through the radiator reservoir hose. Without a vacuum valve, the radiator tanks and hoses could collapse.

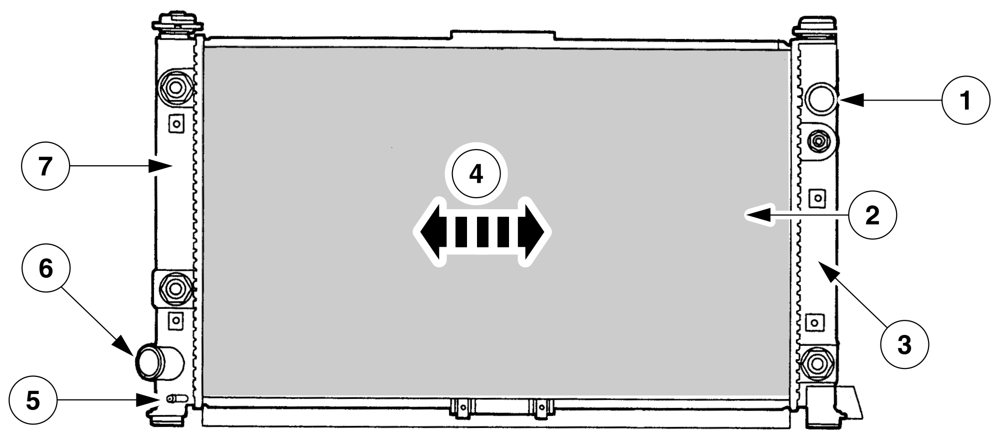
The pressure cap protects the cooling system from springing leaks due to excess pressure or vacuum. For the cap to work correctly, the entire cooling system must be airtight.

Removing the radiator cap while the engine is running, or when the engine and radiator are hot is dangerous. Coolant and steam may escape and cause serious injury. Turn off the engine and wait until it is cool before removing the cap.

Radiator

The radiator transfers heat from the coolant to the outside air. The radiator core contains tubes and fins. Coolant flows through the tubes, and the fins increase the radiator's surface area exposed to the air. The increased surface area allows the air to carry away more heat, reducing the coolant temperature. Radiators are either crossflow or downflow in design.

Crossflow



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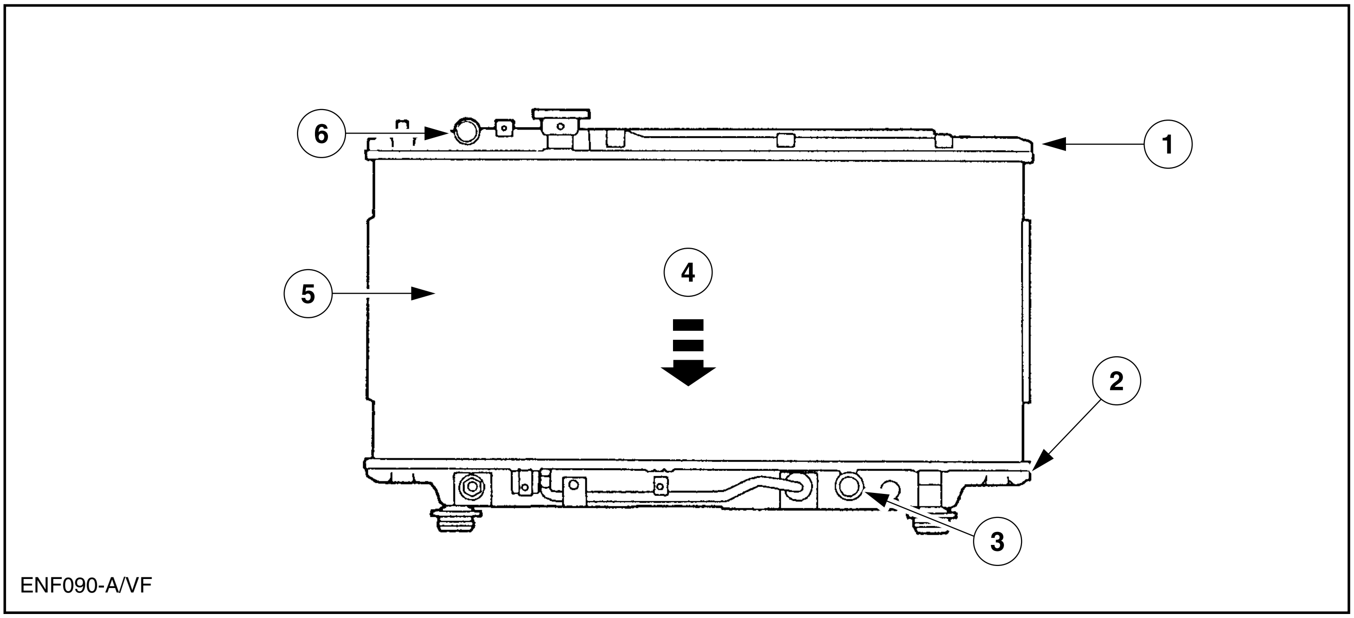
Crossflow radiator

1 Coolant outlet
2 Core
3 Right tank
4 Coolant flows from side to side
5 Outlet tube to or from coolant reservoir
6 Coolant inlet
7 Left tank

The crossflow-type radiator is commonly used. The crossflow radiator has tanks on the side of the core, so coolant flows through tubes from one side to the other.

Downflow

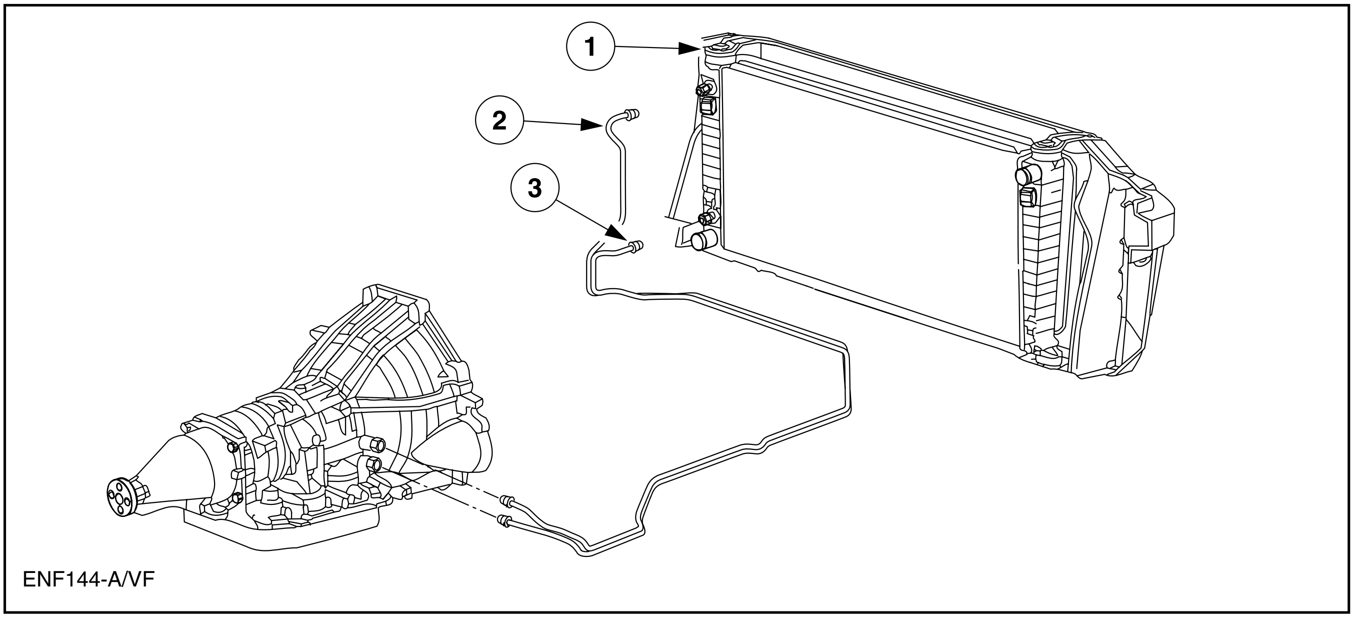


Downflow radiator

1 Upper tank
2 Lower tank
3 Coolant outlet
4 Coolant flows downward
5 Core
6 Coolant inlet

The downflow radiator has an upper and lower tank. Tubes connect the tanks. Coolant flows down from the upper tank through the core and into the lower tank. Cooling takes place as the liquid passes through the radiator core.

Radiator (continued)



In-tank transmission fluid cooler

1 Radiator tank with internal transmission fluid cooler
2 Transmission fluid in
3 Transmission fluid out

If the vehicle has an automatic transmission, the radiator may have a separate cooler in one of the tanks for the automatic transmission fluid.

Objectives

Upon completion of this lesson, you will be able to:

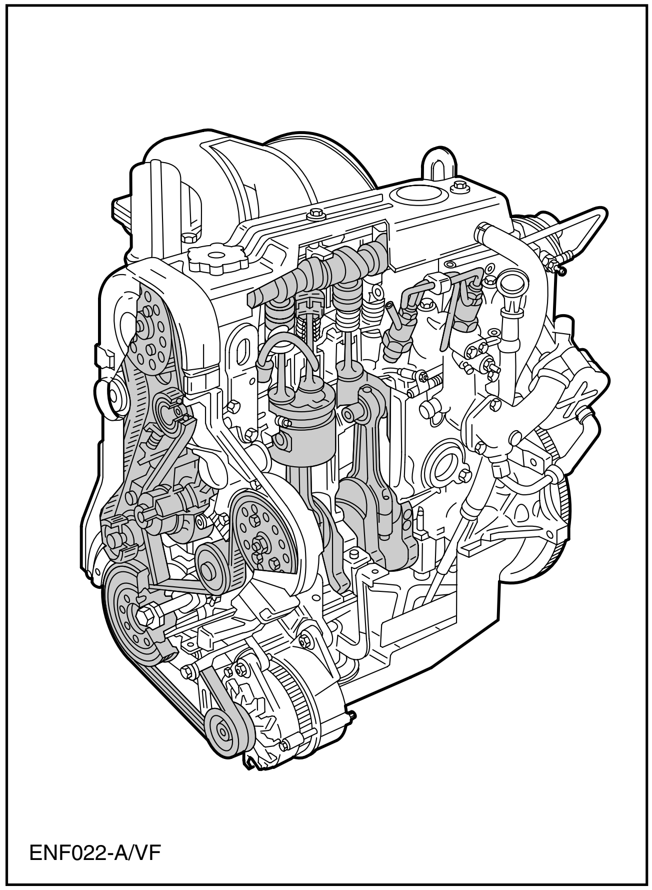
- Explain the purpose and function of the diesel engine.
- Describe a diesel engine.
- Identify similarities and differences of diesel and gasoline engines.
- Explain the theory and operation of a diesel engine.

Description

The diesel engine is a reciprocating piston engine having the same basic structure and cycle as the gasoline engine. The main difference between a diesel engine and gasoline engine is the fuel used, and the method of ignition for fuel combustion.

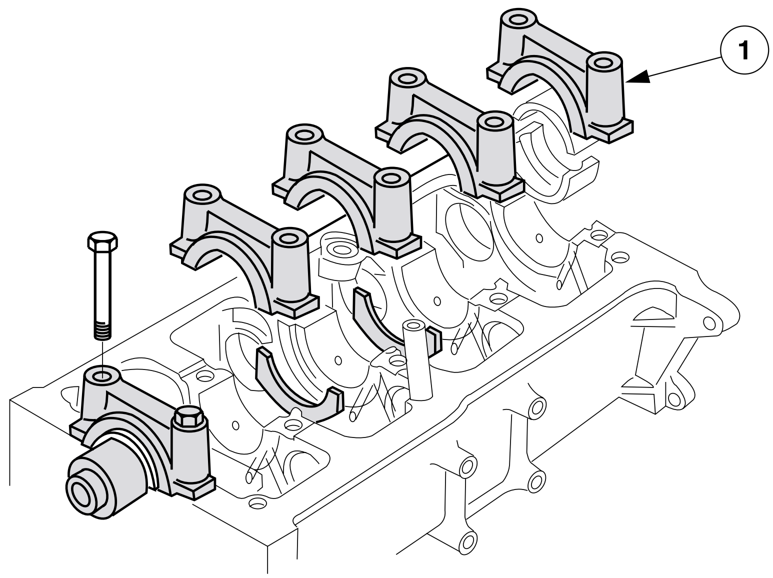
Operation

Diesel engines use the heat of compression to ignite the air and fuel mixture in the combustion chamber. This type of ignition is accomplished using a high compression pressure and diesel fuel injected into the combustion chamber under very high pressure. The combination of diesel fuel and high compression pressure produces spontaneous ignition to begin the combustion cycle.



Diesel engine

Cylinder block



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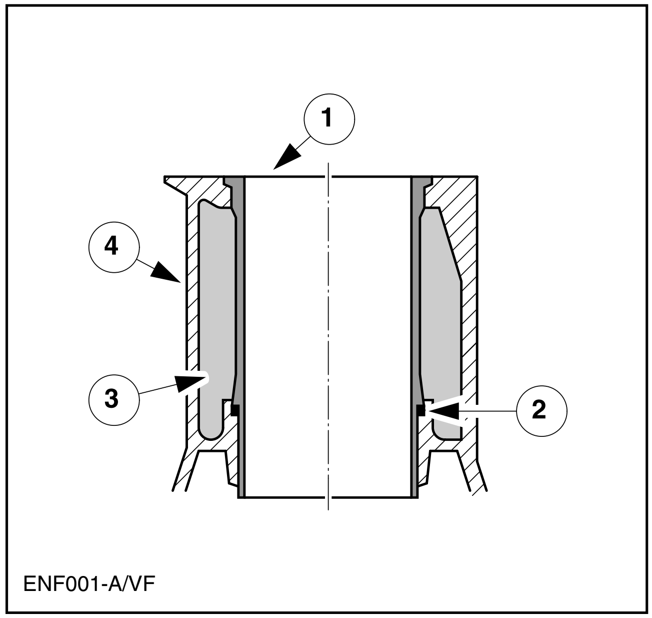
Diesel engine main bearing caps

1 Main bearing cap

Diesel and gasoline engine blocks look similar to each other, but there are some construction differences. Most diesel engines use cylinder liners instead of having the cylinder bores cast as part of the block. By using cylinder liners, repairs can be made to keep the engine in service a long time. On those diesel engines that do not use liners, the cylinder walls are thicker than those of a similar sized gasoline engine. Diesel engines have heavier and thicker main webs for increased crankshaft support.

Wet liners

Wet-type cylinder liners in diesel engines are the same as those used in gasoline engines. The physical dimensions of the liner may be different in order to tolerate the operating conditions of a diesel engine.



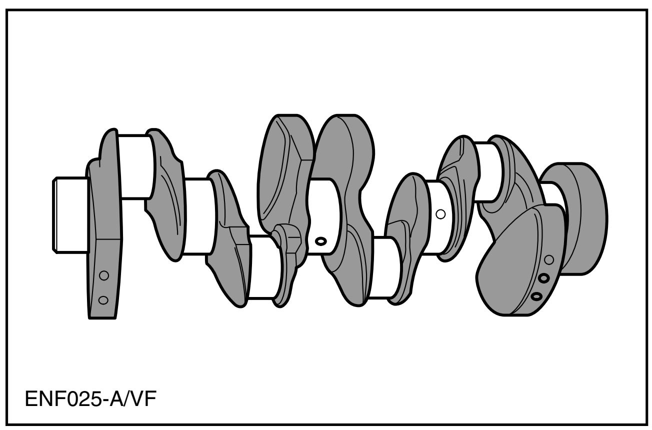
Wet liner

1 Liner
2 Seal
3 Coolant
4 Cylinder block

Crankshaft

The crankshaft used on diesel engines is of similar construction to that of gasoline engines with two differences:

- Diesel crankshafts are usually manufactured by forging rather than casting. Forging makes the crankshaft stronger.
- Diesel crankshaft journals are usually larger than gasoline-type crankshaft journals. Larger journals allow the crankshaft to handle greater force.



Crankshaft

Connecting rods

Connecting rods used in diesel engines are usually made of forged steel. Connecting rods used in diesel engines differ from connecting rods used in gasoline engines in that the end cap is offset and serrated at the mating surface with the rod. Offset and serrated end cap design helps keep the cap in place and reduces the load on the connecting rod bolts.

Pistons and rings

Pistons used in light-duty diesel applications appear similar to those used in gasoline engines. Diesel pistons are heavier than gasoline pistons because diesel pistons are generally made of forged steel rather than aluminum, and the internal thickness of the material is greater.

The compression rings used in diesel engines are usually made of cast iron and are often coated with chrome and molybdenum to reduce friction.

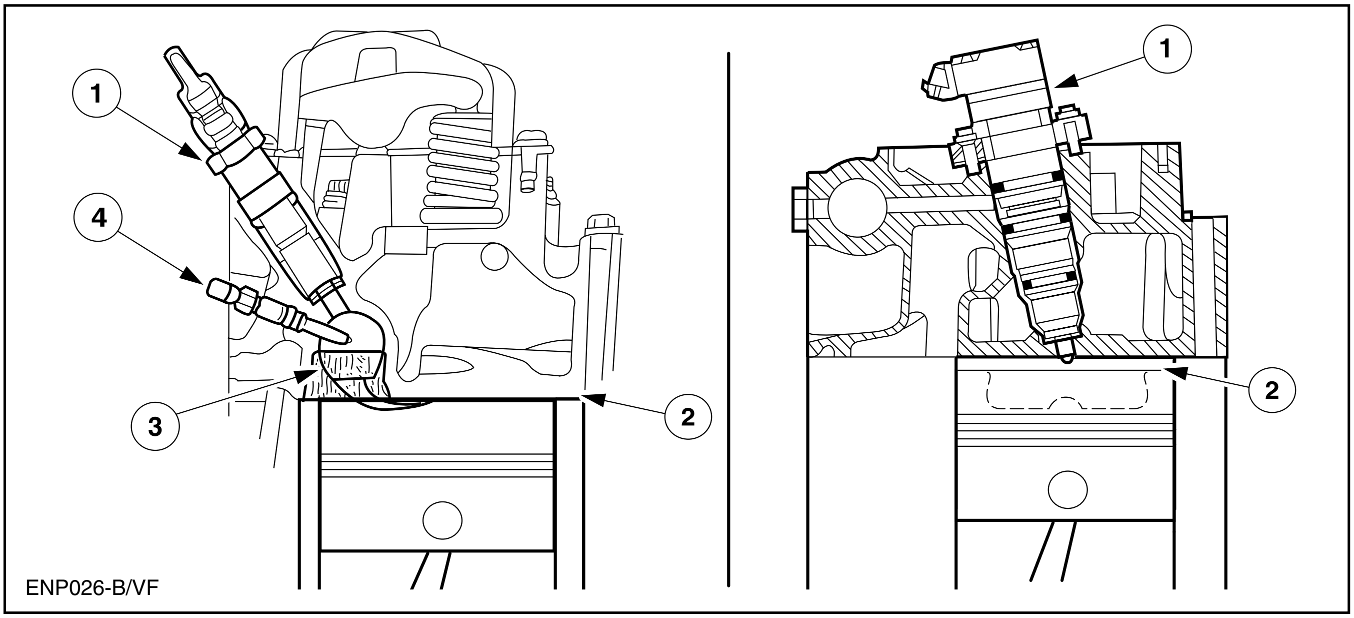
Cylinder head

Externally, the cylinder head of the diesel engine looks much like the cylinder head on a gasoline engine. There are many internal design differences that make diesel engines unique.

The cylinder head itself must be much stronger and heavier on a diesel engine in order to withstand the greater stresses of heat and pressure. Combustion chamber design and air passages on diesel engines can be more complex than on a gasoline engine.

There are several designs of diesel combustion chambers in use, but two designs are most common: open combustion chamber and pre-combustion chamber.

Open combustion chamber design



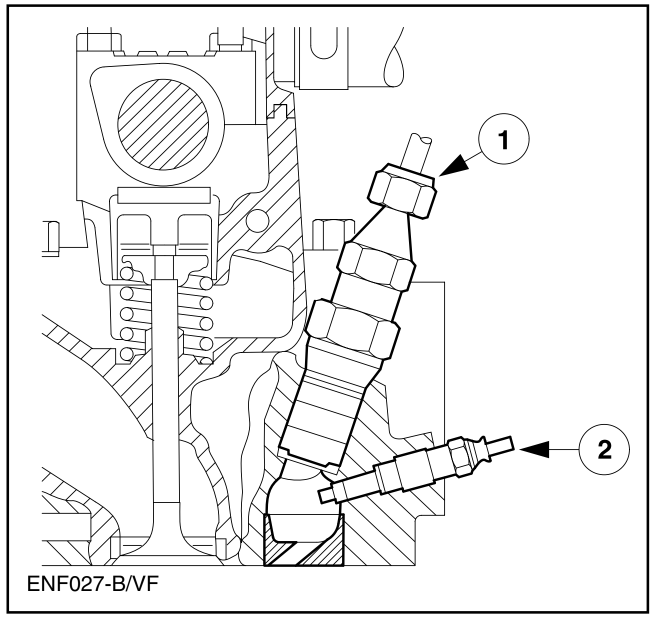
Diesel fuel injection

1 Fuel injector
2 Combustion chamber
3 Inlet air passage
4 Glow plug

The most common type of diesel combustion chamber is the open chamber, also known as the direct injection combustion chamber. The open design relies on the shape of the inlet air passage to cause the intake air charge to become turbulent. Fuel is injected directly into the combustion chamber.

Pre-combustion chamber design

The pre-combustion chamber design uses two combustion chambers for each cylinder. A main chamber connects by a narrow passageway to a smaller pre-combustion chamber. The pre-combustion chamber contains the fuel injector and is designed to begin the combustion process. Intake air is compressed through the narrow passageway into the pre-combustion chamber. Fuel is sprayed into the pre-combustion chamber where it ignites. The burning mixture then forces its way out into the main combustion chamber where it completes its burning and forces the piston down.



Pre-combustion chamber

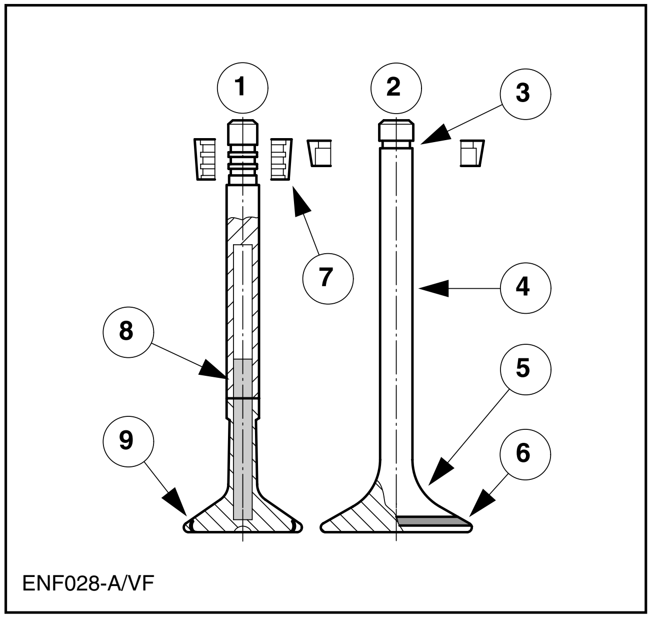
1 Fuel injector
2 Glow plug

Valves and valve seats

Diesel engine valves are constructed of special alloys that are able to perform well in the high heat and pressure of the diesel engine. Some valves are partially filled with sodium which helps them dissipate heat. A large percentage of heat is transferred from the valve head to the valve seat. Particular attention must be paid to valve seat width so that adequate heat transfer takes place.

A wide valve seat has the advantage of being able to conduct a greater amount of heat. However, a wide valve seat has a greater possibility of trapping carbon deposits which may cause a valve leak. A narrow valve seat provides better sealing than a wide valve seat, but does not transfer the same amount of heat. A compromise between wide and narrow seats is necessary in the diesel engine.

Diesel engines frequently use valve seat inserts. The inserts have the advantage of being replaceable. Valve seat inserts are made of special metal alloys that withstand the heat and pressure of the diesel engine.



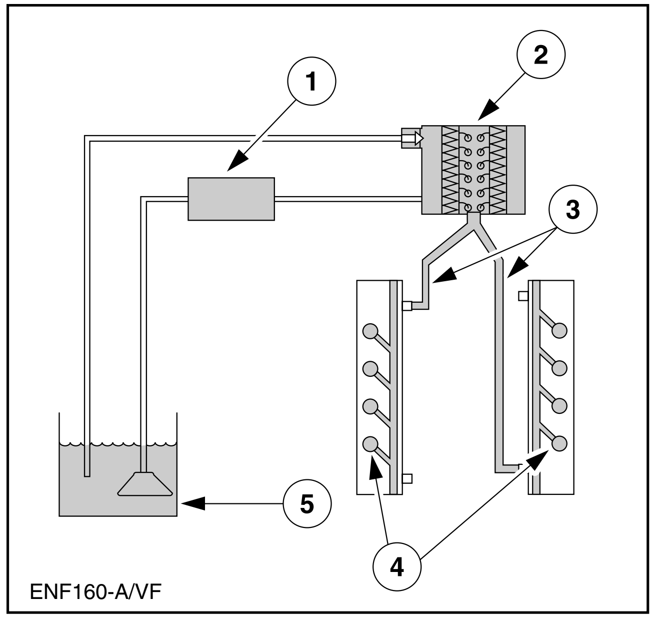
Sodium-filled valve

1 Bimetallic (sodium) valve
2 Single metal valve
3 Collet groove
4 Valve stem
5 Valve head
6 Valve face
7 Valve collet
8 Sodium filling
9 Armoring

Fuel delivery system

Conventional Design

In a conventional diesel fuel delivery system, fuel is pulled from the fuel tank, filtered and delivered to a high-pressure pump. High-pressure fuel is regulated and delivered to a fuel rail that feeds the fuel injectors. An injection control energizes each injector at the appropriate moment to provide fuel in the compression stroke for combustion.

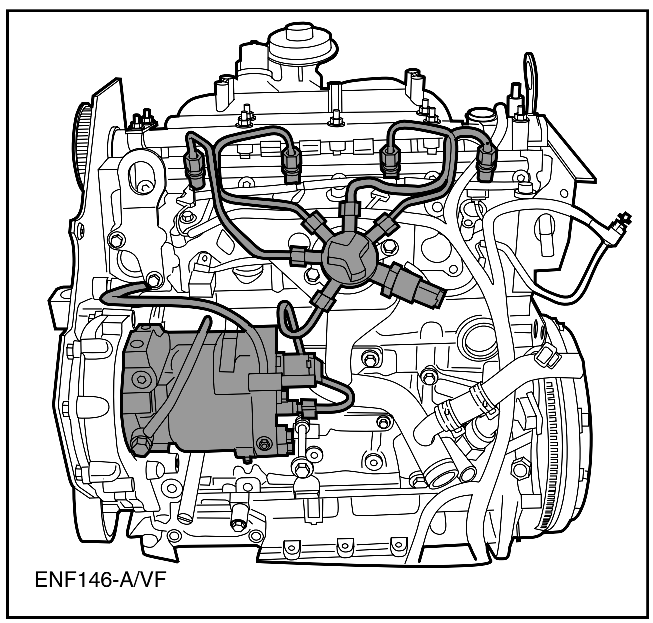


Conventional design

1 Filter
2 High-pressure pump
3 Fuel Rails
4 Fuel injectors (8)
5 Fuel tank

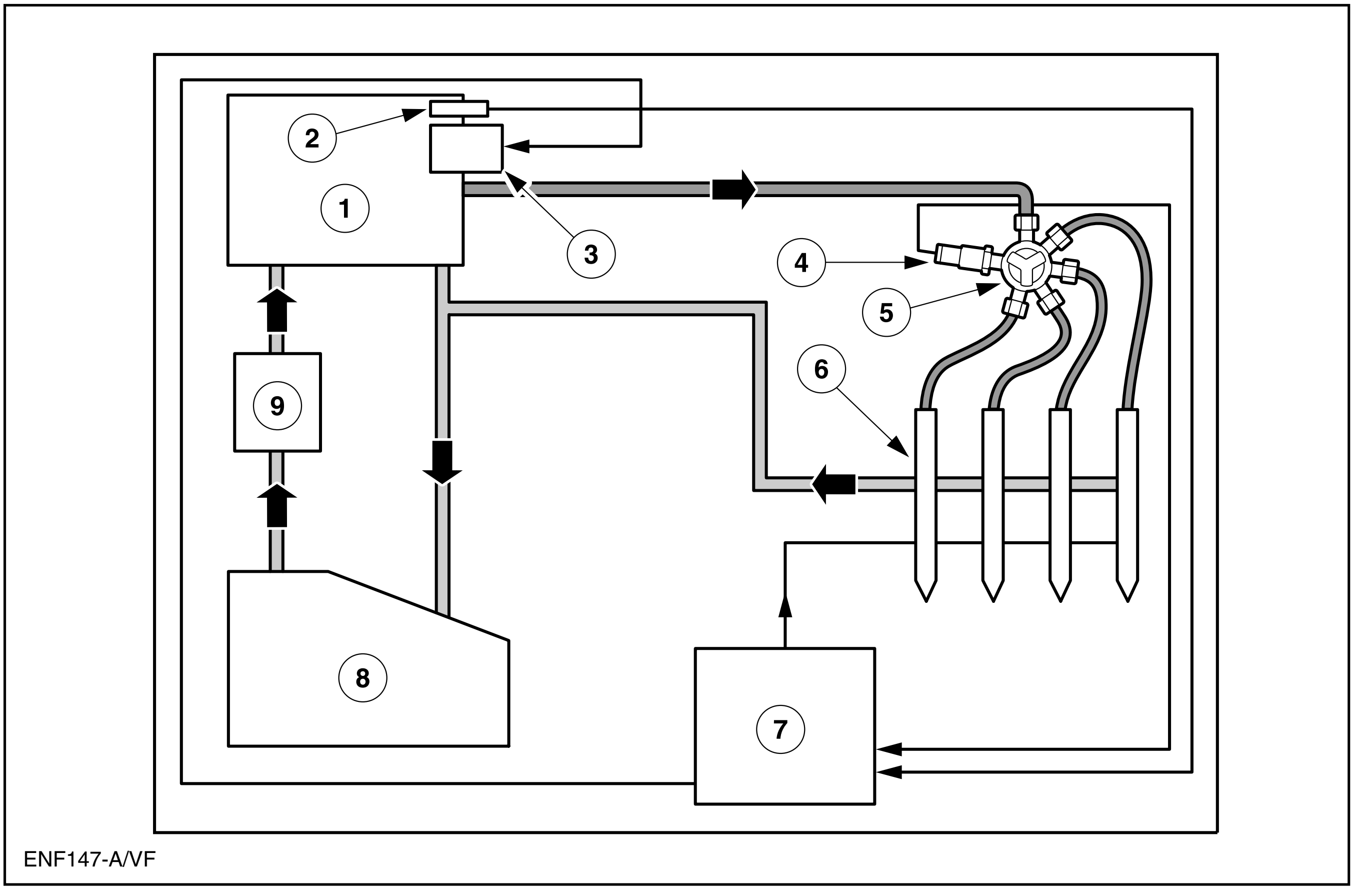
Common rail design

Common rail-type diesel engines use independent fuel pressure and fuel injection systems. A high-pressure fuel pump draws fuel from the tank and delivers it through a pressure regulator to a common fuel rail. The high-pressure pump consists of a low-pressure transfer pump and a high-pressure chamber. Fuel injection is controlled by the Powertrain Control Module (PCM) and an Injector Driver Module (IDM) which regulates injector on-time based on engine operating conditions.



Common rail diesel

Fuel delivery system (continued)



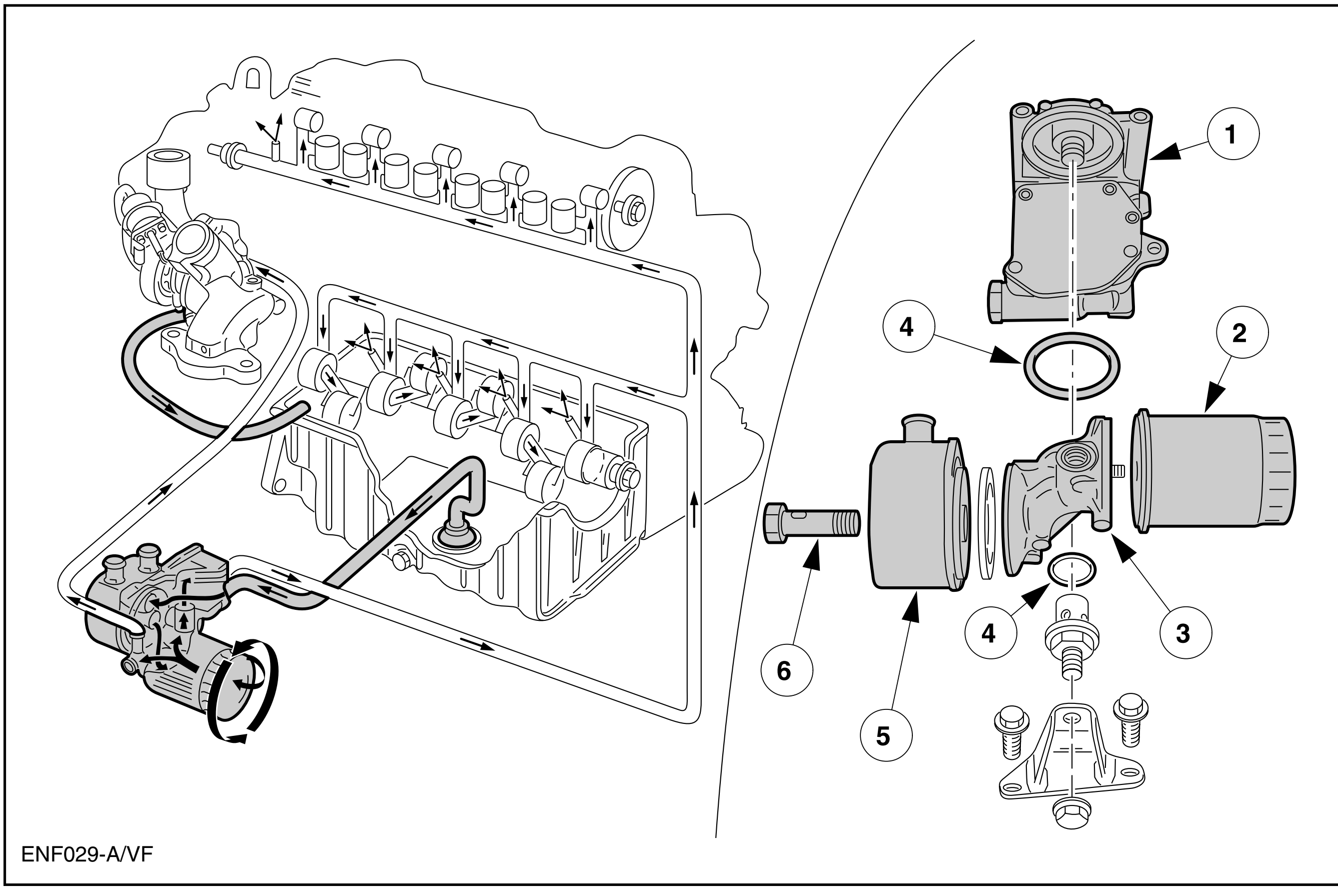
Common rail fuel injection system

1 High-pressure pump
2 Fuel temperature sensor
3 Fuel metering valve
4 Fuel pressure sensor
5 Fuel injection supply manifold
6 Fuel injectors
7 Injector driver module (IDM)
8 Fuel tank
9 Fuel filter

In the common rail design, exhaust emission levels are greatly reduced, and operating noise minimized, due to greater control of the combustion process. Fuel pressure regulation and injector timing are controlled by the IDM and PCM, and injector design has been modified allowing for pre and post-combustion fuel injection events to take place at various stages of the compression and power strokes.

The improved fuel delivery control helps produce cleaner, more consistently timed combustion and cylinder pressures. This has the effect of lowering emission levels and reducing operating noise.

Lubrication system



Diesel lubrication system

1 Oil pump
2 Oil filter
3 Adapter
4 O-ring
5 Oil cooler
6 Oil cooler retaining bolt

The lubrication system used on diesel engines is similar in operation to gasoline engines. Most diesels will have some type of oil cooler to help remove heat from the oil. The oil flows under pressure through the galleries of the engine and returns to the crankcase.

The lubricating oil used on diesel engines is different from that used in gasoline engines. A special oil is needed because diesel operation produces more oil contamination than in a gasoline engine. High carbon content in diesel fuel causes oil in diesel engines to become discolored soon after being put into service. Only engine oil specifically manufactured for diesel engines should be used.

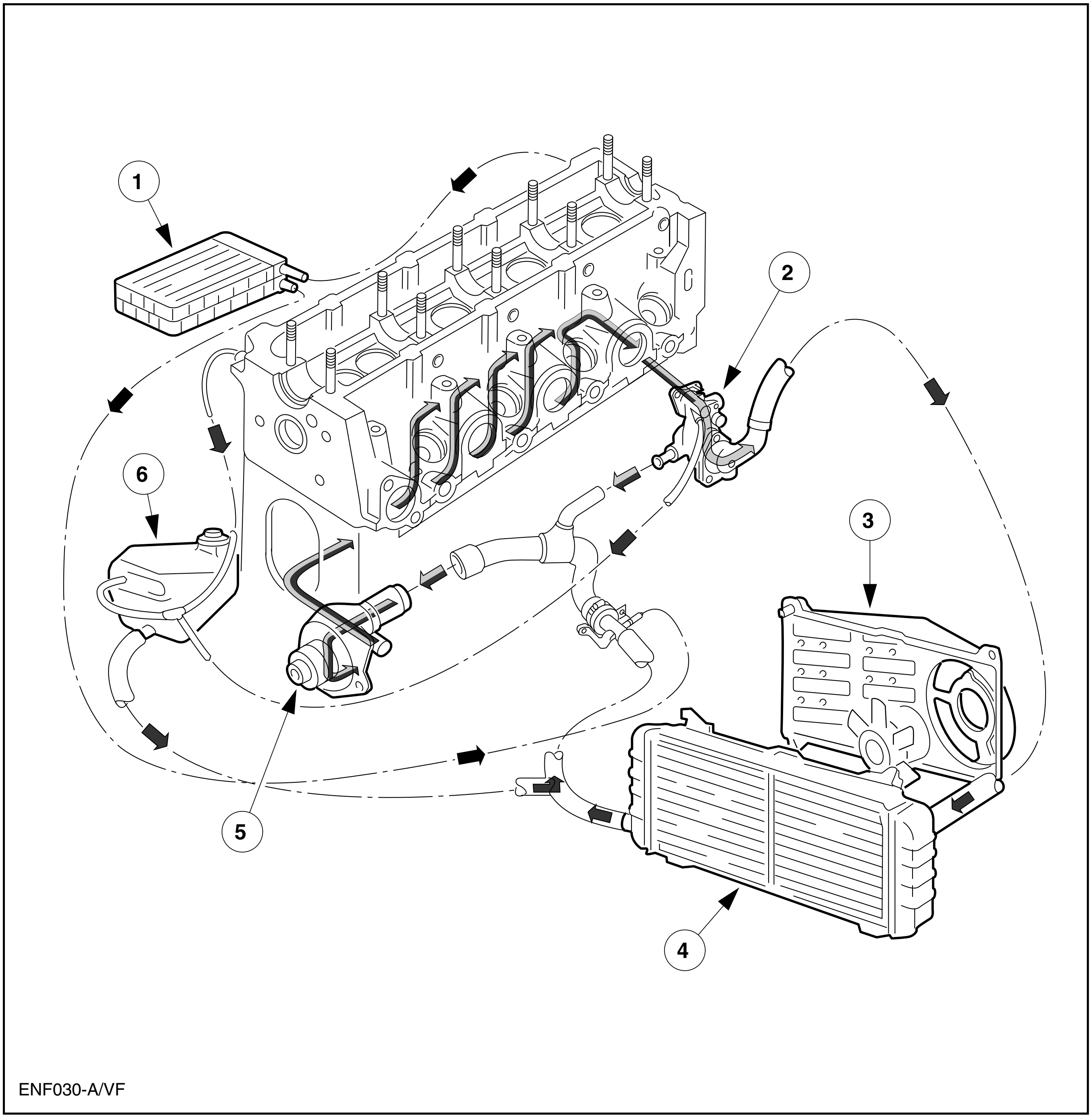
Cooling system

Diesel engine cooling systems normally have a larger capacity cooling system than a gasoline engine cooling system. The temperature inside a diesel engine must be closely controlled because it relies on heat to burn its fuel. If the engine temperature is too low, the following problems develop:

- Excessive wear
- Poor fuel economy
- Accumulation of water and sludge in the crankcase
- Loss of power

If the engine temperature is too high, the following problems develop:

- Excessive wear
- Scoring
- Knock
- Burned pistons and valves
- Lubrication failure
- Seizure of moving parts
- Loss of power



Diesel cooling system

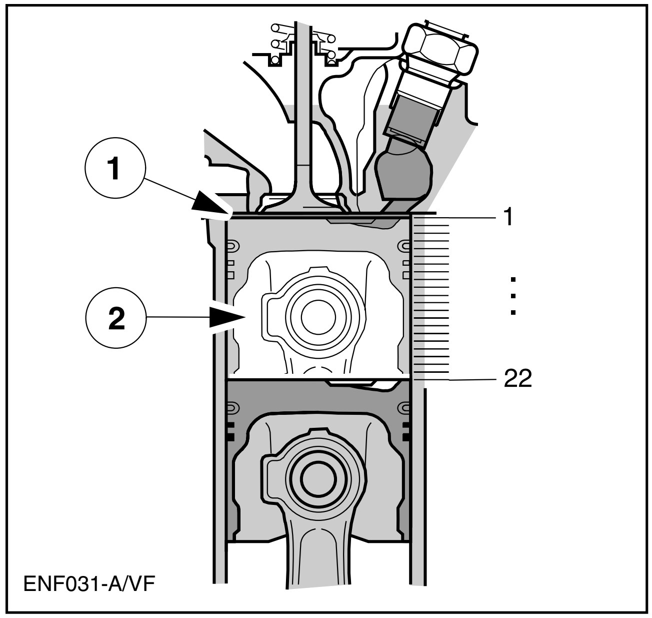
1 Heater core
2 Thermostat
3 Fan shroud
4 Radiator
5 Coolant pump
6 Coolant expansion tank

Fuel injection system

The diesel engine operates on the spontaneous combustion, or self-ignition, principle. Intake air and fuel are squeezed so tightly into the combustion chamber that the molecules heat up and ignite without the aid of an external spark. The compression ratio of a diesel engine is much higher than the compression ratio of a gasoline engine. Compression ratios in naturally aspirated diesel engines are approximately 22:1. Turbo-diesel engines will have compression ratios in the range of 16.5 – 18.5:1. Compression pressures are produced and the air temperature rises to approximately 500º to 800º C (932º to 1,472º F).

Diesel engines can only be operated with a fuel injection system. Mixture formation takes place only during the fuel injection and combustion phase.

At the end of the compression stroke, fuel is injected into the combustion chamber where it mixes with the hot air and ignites. The quality of this combustion process depends on the formation of the mixture. Since the fuel is injected so late, it does not have much time to mix with the air. In a diesel engine the air to fuel ratio is maintained at greater than 17:1 at all times so that all of the fuel will burn. Refer to Engine Performance for further details.



Compression

1 Volume of cylinder at BDC
2 Compression volume at TDC

Objectives

Upon completion of this lesson, you will be able to:

- Explain the purpose and function of the symptom-to-system-to-component-to-cause diagnostic process.

- Explain the symptom-to-system-to-component-to-cause diagnostic process.

Symptom-to-system-to-component-to-cause diagnostic process

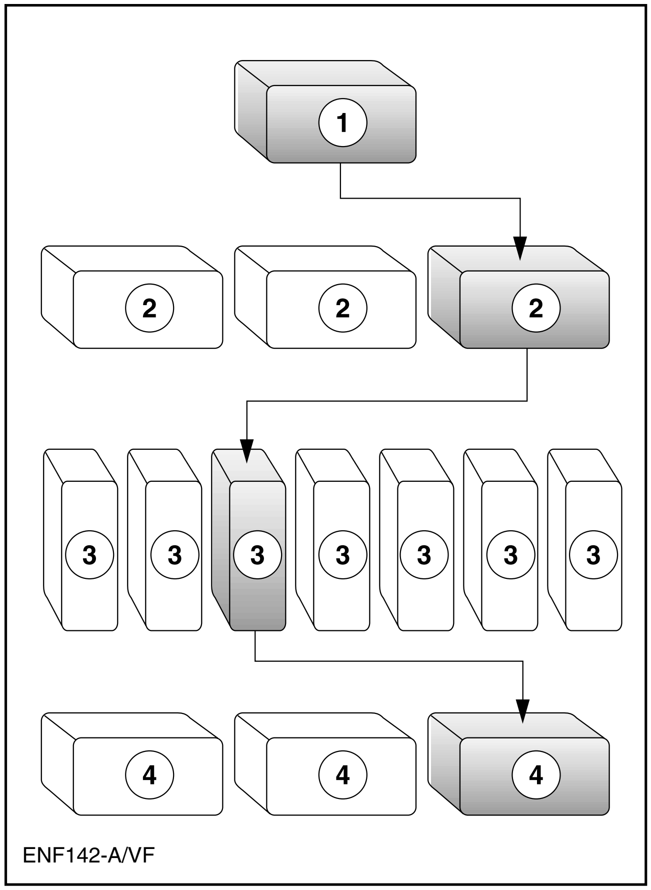
Diagnosis requires a complete knowledge of the system operation. As with all diagnosis, a technician must use symptoms and clues to determine the cause of a vehicle concern. To aid the technician when diagnosing vehicles, the strategies of many successful technicians have been analyzed and incorporated into a diagnostic strategy and into many service publications.

The symptom-to-system-to-component-to-cause process

Using the Symptom-to-System-to-Component-to-Cause (SSCC) diagnostic process provides you with a logical method for correcting customer concerns:

- First, confirm the "Symptom" of the customer's concern.
- Next, determine which "System" on the vehicle could be causing the symptom.
- Once you identify the particular system, determine which "Component(s)" within that system could be the cause for the customer concern.
- After determining the faulty component(s) you should always try to identify the cause of the failure.

In some cases parts just wear out. However, in other instances something other than the failed component is responsible for the problem.



Symptom-to-system-to-component-to-cause diagnostic process

1 Symptom
2 Vehicle systems
3 Components
4 Causes

For example, the customer concern is engine noise when the vehicle is driven after sitting overnight. After letting the engine cool, a test drive verifies the concern. A test drive validates the “Symptom.” Next, isolate the system(s) that are affected by the symptom. Visual inspection does not show any obvious causes. There are mechanical causes of engine noise as well as electric or electronic causes. In this case there are no other indications of mechanical damage. Using the appropriate electronic diagnostic equipment, diagnostic trouble code information indicates a problem with spark timing. Spark timing is controlled by the Powertrain Control Module (PCM) and the electronic engine control system. The test data validates the “System” portion of the diagnostic process.

Next, isolate the component(s) that relate to the system and symptom. In this case, spark timing is adjusted by the PCM reacting to sensor input. Using the procedures in the appropriate workshop manual, an engine speed sensor is identified as giving faulty input to the PCM. The sensor is the component at fault. Following the workshop manual procedures provides validation of the “Component” portion of the diagnostic process.

Finally, the diagnostic process determines what the “Cause” of the component failure is. In this case investigation finds a broken wire in the wiring harness to the sensor. This validates the “Cause” relating to the component failure. Repair the wiring harness.

Workshop literature

The vehicle workshop literature contains information for diagnostic steps and checks such as: preliminary checks, verifying customer concern, special driving conditions and road test and diagnostic pinpoint tests.

BDC — **B**ottom **D**ead **C**enter position of piston in the cylinder

Collets — Keepers

DOHC — **D**ouble **O**ver**H**ead **C**amshaft engine design

Coolant Pump — Water pump

IDM — **I**njection **D**river **M**odule

Keepers — Collets

Inlet — Intake

IMRC — **I**ntake **M**anifold **R**unner **C**ontrol

IMTV — **I**ntake **M**anifold **T**uning **V**alve

OAT — **O**rganic **A**cid **T**echnology coolant

OEM — **O**riginal **E**quipment **M**anufacturer

OHC — **O**ver**h**ead **C**amshaft engine design

OHV — **O**ver**H**ead **V**alve engine design. Also known as pushrod-type engine.

Petrol — Gasoline

PCM — **P**owertrain **C**ontrol **M**odule

PSI — **P**ounds per **S**quare **I**nch

Pushrod-type engine — Overhead Valve (OHV) design

SAE — **S**ociety of **A**utomotive **E**ngineers

SOHC — **S**ingle **O**ver**H**ead **C**amshaft engine design

TDC — **T**op **D**ead **C**enter position of piston in the cylinder

VCT — **V**ariable **C**amshaft **T**iming. Also known as Variable Valve Timing (VVT).

VVT — **V**ariable **V**alve **T**iming. Also known as Variable Camshaft Timing (VCT).

Water Pump — Coolant pump