9

Camshafts, Valve Trains, Intake and Exhaust Systems

OBJECTIVES: After studying Chapter 9, you should be able to:

1. Prepare for the interprovincial Red Seal certification examination in Appendix I (Engine Repair) on the topics covered in this chapter.
2. Describe how camshafts and valve trains function.
3. Discuss valve train noise and its causes.
4. Explain how a hydraulic lifter works.
5. Discuss the operation of variable-length intake manifolds.
6. Explain the differences between air cleaners for "wet" and "dry" manifolds.
7. Explain the relationship of valve timing to intake runner length.

The cam is driven by timing gears, chains, or belts located at the front of the engine. The gear or sprocket on the camshaft has twice as many teeth, or notches, as the one on the crankshaft. This results in two crankshaft revolutions for each revolution of the camshaft. *The camshaft turns at one-half the crankshaft speed in all four-stroke-cycle engines.*

CAMSHAFT FUNCTION

The camshaft's major function is to operate the valve train. Cam shape or **contour** is the major factor in determining the operating characteristics of the engine. The lobes on the camshaft open the valves against the force of the valve springs. The camshaft lobe changes rotary motion (camshaft) to linear motion (valves).

Cam lobe shape has more control over engine performance characteristics than does any other single engine part. Engines identical in every way except cam lobe shape may have completely different operating characteristics and performance. See Figure 9–1. The camshaft may also operate the following:

- Mechanical fuel pump
- Oil pump
- Distributor

See Figures 9–2 and 9–3.

CAMSHAFT LOCATION

Pushrod engines have the cam located in the block. The camshaft is supported in the block by **camshaft bearings** and driven by the crankshaft with a gear or sprocket and chain drive. See Figure 9–4. Many over-

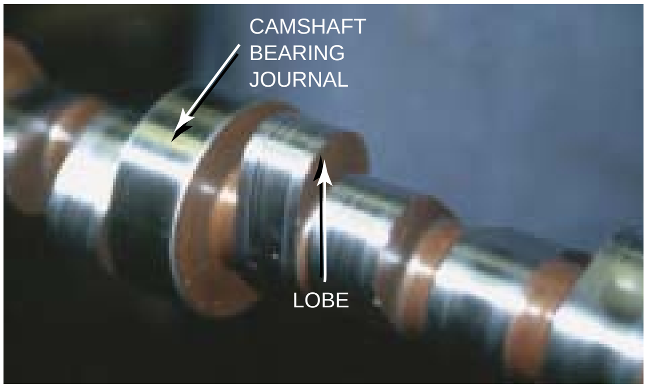


Figure 9–1 This high-performance camshaft has a lobe that opens the valve quickly and keeps it open for a long time.

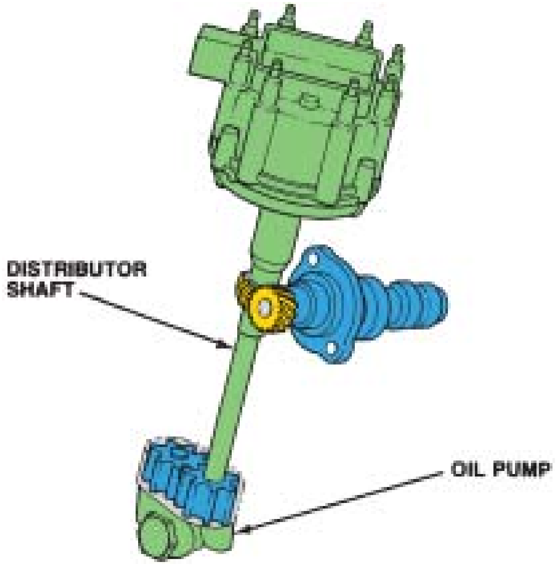


Figure 9–2 In many engines, the camshaft drives the distributor and the oil pump through a shaft from the end of the distributor.

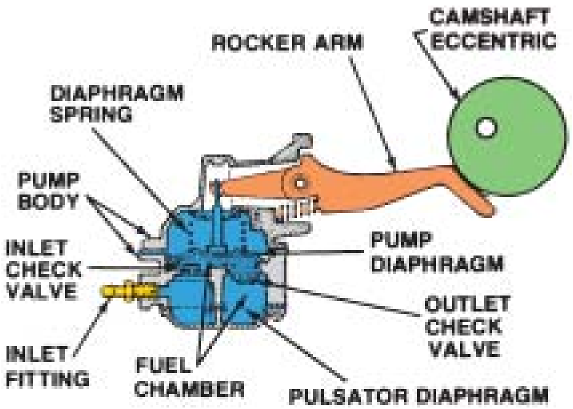


Figure 9–3 The fuel pump plunger rides on the camshaft eccentric.

Figure 9–4 Cutaway of a Chevrolet V-8 showing the valve train components.

TECH TIP

The Rotating Pushrod Test

To quickly and easily test whether or not the camshaft is okay, observe if the pushrods are rotating when the engine is running. This test will work on any overhead valve pushrod engine that uses a flat-bottom lifter. Due to the slight angle on the cam lobe and lifter offset, the lifter (and pushrod) should rotate whenever the engine is running. To check, simply remove the rocker arm cover and observe the pushrods when the engine is running. If one or more pushrods is *not* rotating, the camshaft and/or the lifter for that particular valve is worn and needs to be replaced.

head camshaft (OHC) engines do not use cam bearings; the camshaft runs directly on the aluminum cylinder head. In order to salvage heads with a worn camshaft bore, the aftermarket suppliers often provide camshafts with larger bearing journals. The head is bored (machined) to match the new, larger cam. Another repair method is to bore out the head and install bearings that allow the use of the original camshaft.

CAMSHAFT PROBLEM DIAGNOSIS

A partially worn lobe on the camshaft is often difficult to diagnose. Sometimes a valve "tick tick tick" noise is heard if the cam lobe is worn. The ticking noise can be intermittent, which makes it harder to determine the cause. If the engine has an overhead camshaft (OHC), it is usually relatively easy to remove the cam cover and make a visual inspection of all cam lobes and the rest of the valve train. In an overhead valve (OHV) engine, the camshaft is in the block, where easy visual inspection is not possible. See Figure 9–5 and Tech Tip "The Rotating Pushrod Test."

Push rod engines with flat tappets often use the cam lobe taper and lifter offset to push the camshaft in toward the block. No cam thrust plate (retainer) is required. Camshafts designed for roller lifters have no taper and must use a retainer to keep the camshaft from "walking" back and forth in the block.

CAMSHAFT REMOVAL (PUSHROD ENGINE)

If the engine has an overhead valve design, the camshaft is usually located in the block above the

(a)

(b)

Figure 9–5 (a) Here is what can happen if a roller lifter breaks loose from its retainer. The customer complained of "a little noise from the engine." (b) All engines equipped with roller lifters have some type of retainer for keeping the lifters from rotating.

crankshaft. The timing chain and gears (if the vehicle is so equipped) should be removed after the timing chain (gear) cover is removed. Loosen the rocker arms (or rocker arm shaft) and remove the pushrods. Remove or lift up the lifters before carefully removing the camshaft. See Tech Tip "The Tube Trick."

NOTE: Be sure to keep the pushrods and rocker arms together if they are to be reused.

CAMSHAFT DRIVES

The crankshaft gear or sprocket that drives the camshaft is usually made of sintered iron. When gears are used, the camshaft gear teeth must be made from a soft material to reduce noise. Usually, the whole gear is made of aluminum or fibre. See Figure 9–6. When a chain and sprocket are used, the

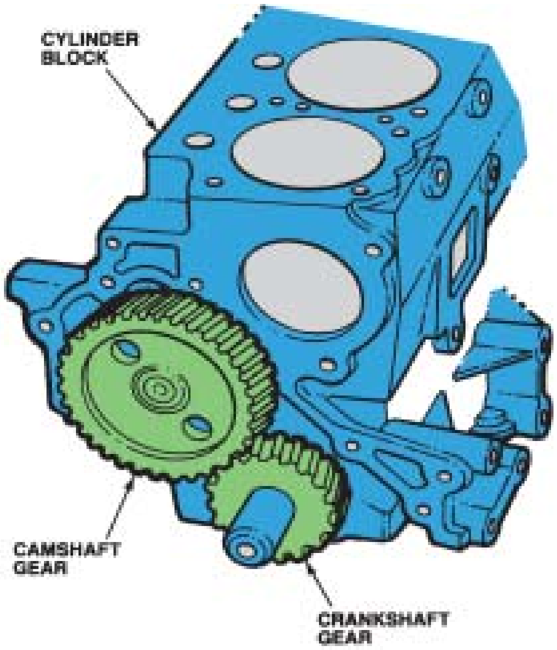


Figure 9–6 The larger camshaft gear is usually made from fibre and given a helical cut to help reduce noise. By making the camshaft gear twice as large as the crankshaft gear, the camshaft rotates one revolution for every two of the crankshaft.

TECH TIP ✔

The Tube Trick

Valve lifters are often difficult to remove because the ends of the lifters become mushroomed (enlarged) where they have contacted the camshaft. Varnish buildup can also prevent the lifters from being removed. Try this method:

Step 1. Raise the lifters upward as far away from the camshaft as possible.

Step 2. Slide in a thin plastic or cardboard tube with slots in place of the camshaft.

Step 3. Push the lifters downward into the tube. Use a long magnet to retrieve the lifters from the end of the tube.

This trick will work on almost every engine that has the camshaft in the block. If the tube is made from plastic, it has to be thin plastic to allow it to flex slightly. The length of the lifters is greater than the diameter of the cam bearings. Therefore, the lifter has to be pushed downward into the tube slightly to allow the lifter room to fall over into the tube.

camshaft sprocket may be made of iron or it may have an aluminum hub with nylon teeth for noise reduction. Two types of timing chains are used.

1. **Silent chain type** (also known as a **flat-link type,** or **Morse** type for its original manufacturer). This type operates quietly but tends to stretch with use. See Figures 9–7 and 9–8.

NOTE: When the timing chain stretches, the valve timing will be retarded and the engine will lack low-speed power. In some instances, the chain can wear through the timing-chain cover and create an oil leak.

2. **Roller chain type.** This type is noisier but operates with less friction and stretches less than the silent type of chain. See Figure 9–9. Roller chains are superior to the silent (flat link) type and last longer. Often, the engine for a passenger car may use a silent chain; the same engine for a truck may come equipped with a roller chain.

Some four-cam "V" type engines use a two-stage camshaft drive system. See Figure 9–10. Some four cylinder, two cam engines use two chains; the primary chain drives one camshaft and the secondary chain connects the two camshafts.

NOTE: Beware of low cost roller chains. They often use inferior materials and poor hardening. Saving money with minimum quality parts will end up costing more when the vehicle returns with a problem.

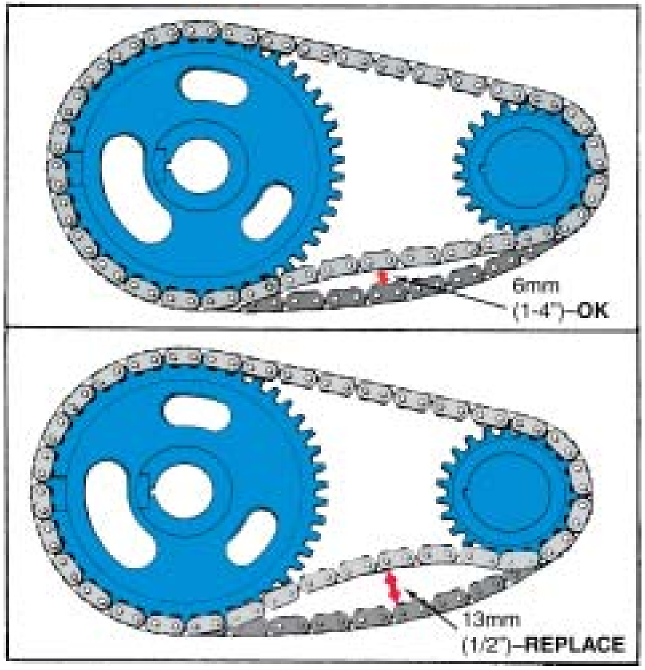


Figure 9–8 The industry standard is to replace a timing chain and sprockets when 13 mm (1/2 in.) or more of slack is measured in the sprockets. However, it is best to replace the timing chain and sprockets anytime the camshaft is replaced or the engine is disassembled for repair or overhaul. (Courtesy of Sealed Power Corporation)

Figure 9–7 A replacement silent chain and sprockets. The original camshaft sprocket was aluminum with nylon teeth to help control noise. This replacement set will not be noticeably louder than the original and should give the owner many thousands of kilometres of useful service.

Figure 9–9 A replacement high-performance double roller chain. Even though a bit noisier than a flat-link chain, a roller chain does not stretch as much and will therefore be able to maintain accurate valve timing for a longer time.

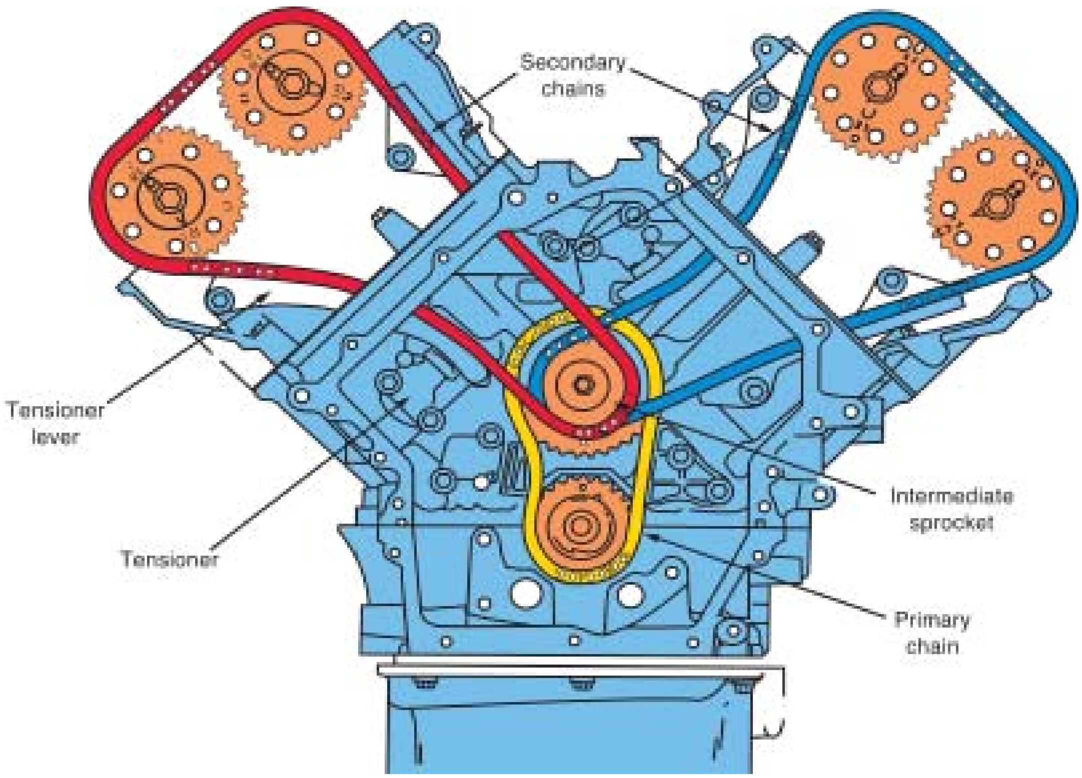


Figure 9–10 Typical dual overhead camshaft V-type engine that uses one primary timing chain and two secondary chains.

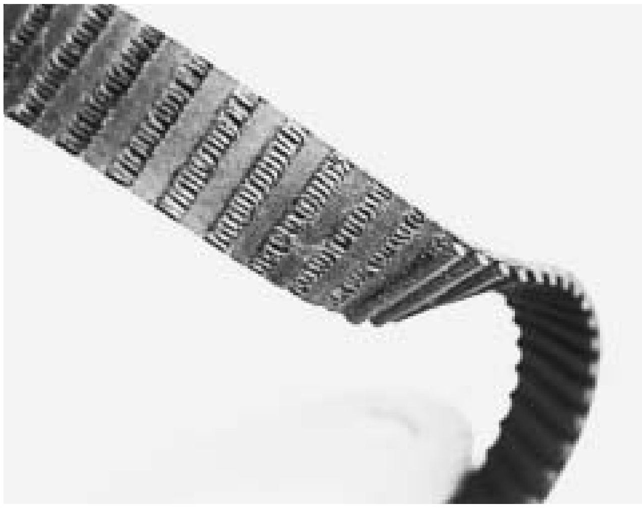


Figure 9–11 Broken timing belt. Also notice the missing teeth. This belt broke at 142 000 km (88 000 mi) because the owner failed to replace it at the recommended interval of 96 000 km (60 000 mi).

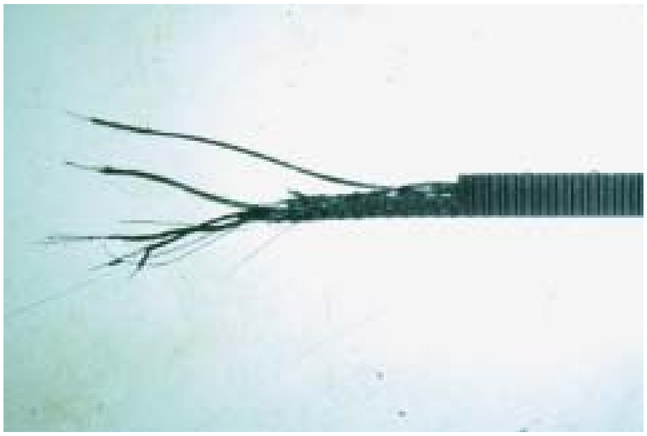


Figure 9–12 This timing belt broke because an oil leak from one of the camshaft seals caused oil to get into and weaken the belt. Many experts recommend replacing all engine seals in the front of the engine when a timing belt is replaced. If the timing belt travels over the water pump, the water pump should also be replaced as a precaution.

CAMSHAFT BELT DRIVES

Many overhead camshaft engines use a timing belt rather than a chain. The belt is generally considered to be quieter, but it requires periodic replacement, usually every 100 000 km (60 000 mi). Unless the engine is **free wheeling,** the piston can hit the valves if the belt breaks. See Figures 9–11 through 9–13.

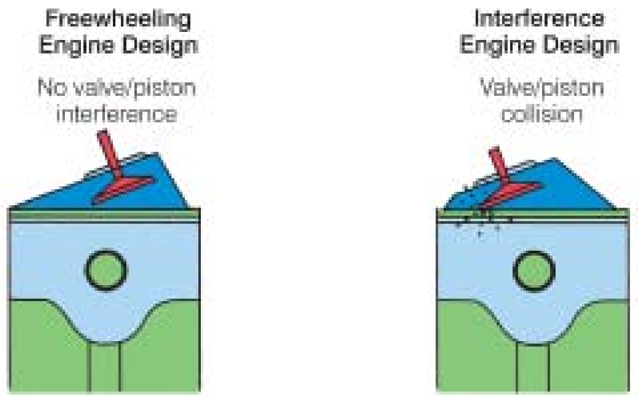


Figure 9–13 Many engines are of the interference design. If the timing belt (or chain) breaks, the piston still moves up and down in the cylinder while the valves remain stationary. With a freewheeling design, nothing is damaged, but in an interference engine, the valves are often bent.

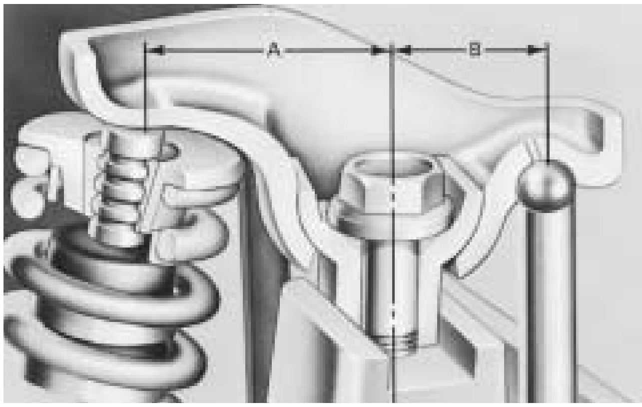


Figure 9–14 A 1.5:1 ratio rocker arm means that dimension A is 1.5 times the length of B. Therefore, if the pushrod is moved up 10 mm (0.400 in.) by the camshaft lobe, the valve will be pushed down (opened) 10 mm (0.400 in.) × 1.5, or 15 mm (0.600 in.).

ROCKER ARMS

Rocker arms reverse the upward movement of the pushrod to produce a downward movement on the tip of the valve. They are designed to reduce the travel of the cam follower or lifter and pushrod while maintaining the required valve lift. This is done by using a rocker arm ratio of approximately 1.5:1, as shown in Figure 9–14. For a given amount of lift on the pushrod, the valve will open up to 1.5 times the pushrod lift distance. This ratio allows the camshaft to be small, so the engine can be smaller. It also results in higher lobe-to-lifter rubbing pressure.

CAUTION: Using rocker arms with a higher ratio than stock can also cause the valve spring to compress too much and actually bind. Valve spring bind occurs when the valve spring is compressed to the point where there is no clearance at all in the spring. (It is completely compressed.) When coil bind occurs in a running engine, bent pushrods, broken rocker arms, or other valve train damage can result.

Rocker arms may be cast, forged, or stamped. See Figure 9–15.

DIAGNOSTIC STORY

Best to Warn the Customer

A technician replaced a timing chain and sprockets. The repair was accomplished correctly, yet, after starting, the engine burned an excessive amount of oil. Before the timing chain replacement, oil consumption was minimal. The replacement timing chain restored proper operation of the engine and increased engine vacuum. Increased vacuum can draw oil from the crankcase past worn piston rings and through worn valve guides during the intake stroke. Similar increased oil consumption problems occur if a valve regrind is performed on a high-mileage engine with worn piston rings and/or cylinders.

To satisfy the owner of the vehicle, the technician had to disassemble and refinish the cylinders and replace the piston rings. Therefore, all technicians should warn customers that increased oil usage may result from almost any repair to a high-mileage engine.

DIAGNOSTIC STORY

The Noisy Camshaft

The owner of an overhead cam four-cylinder engine complained of a noisy engine. After taking the vehicle to several technicians and getting high estimates to replace the camshaft and followers, the owner tried to find a less expensive solution. Finally, another technician replaced the serpentine drive belt on the front of the engine and cured the "camshaft" noise for a fraction of the previous estimates.

Remember, accessory drive belts can often make noises similar to valve or worn-bearing types of noises. Many engines have been disassembled and/or overhauled because of a noise that was later determined to be from one of the following:

- Loose or defective accessory drive belt(s)
- Cracks in the torque converter flex plate (drive plate)
- Defective mechanical fuel pump

Figure 9–15 A high-performance aluminum roller arm. Both the pivot and the tip that contacts the stem of the valve are equipped with rollers to help reduce friction for more power and better fuel economy.

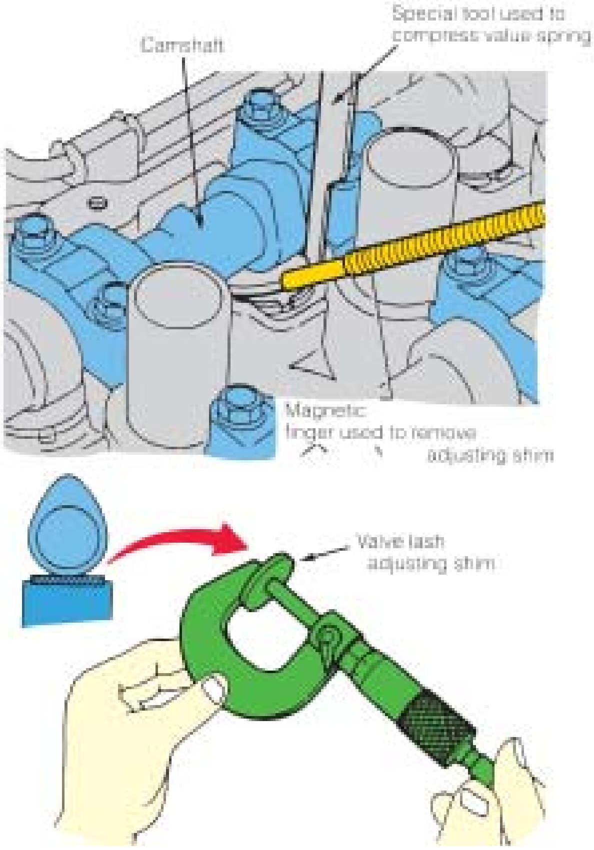


Figure 9–16 Some overhead camshaft engines use a bucket-type cam follower which uses valve lash adjusting shims to adjust the valve lash. A special tool is usually required to compress the valve spring so that a magnet can remove the shim.

1. One type of valve mechanism opens the valves directly with a **cam follower** or **bucket.** See Figure 9–16.
2. The second type uses a **finger follower** that provides an opening ratio similar to that of a rocker arm. Finger followers open the valves by approximately 1 1/2 times the cam lift. The pivot point of the finger follower may have a mechanical or automatic hydraulic adjustment.
3. A third type moves the rocker arm directly through a hydraulic lifter.

NOTE: Some newer engines have the hydraulic adjustment in the rocker arm and are called hydraulic lash adjusters (HLA). See Figure 9–17.

TECH TIP

Varnish on Valve Stems Can Cause Sticking Valves

As oil oxidizes, it forms a varnish. Varnish build-up is particularly common on hot upper portions of the engine, such as valve stems. The varnish restricts clean oil from getting into and lubricating the valve guides. The cam lobe can easily *force* the valves open, but the valve springs often do not exert enough force to fully close the valves. The result is an engine miss, which may be intermittent. Worn valve guides and/or weak valve springs can also cause occasional rough idle, uneven running, or missing. See Figure 9–18.

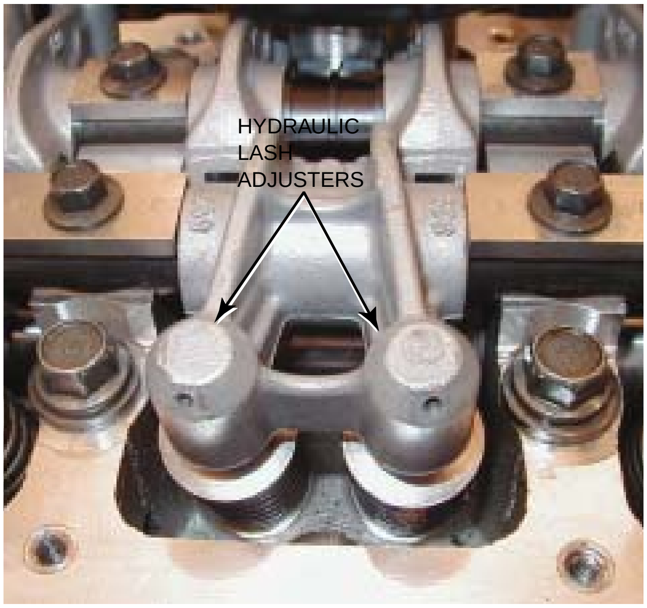


Figure 9–17 This single overhead camshaft engine has four valves per cylinder because each pivot arm opens two valves and each contains a small hydraulic lash adjuster (hydraulic lifter).

CAUTION: Some rockers are offset to the right, or left, for correct rocker tip to valve alignment. Installing a rocker in the wrong position could cause the rocker to slip off the valve. Always check for correct location.

PUSHRODS

Pushrods are designed to be as light as possible and still maintain their strength. They may be either solid or hollow. If they are to be used as passages for oil to lubricate rocker arms, they *must* be hollow. Pushrods have a convex ball on the lower end that seats in the lifter. The rocker arm end is also a convex ball unless there is an adjustment screw in the pushrod end of the rocker arm. In this case, the rocker arm end of the pushrod has a concave socket. It mates with the convex ball on the adjustment screw in the rocker arm. All pushrods should be rolled on a flat surface to check if they are bent. See Figure 9–19.

Some pushrods are hardened at the upper end to reduce wear at the point where they pass through the cylinder head. The hardened end faces up.

Figure 9–18 Some engines today use rocker shafts to support rocker arms such as the V-6 engine with a single overhead camshaft located in the centre of the cylinder head. This engine uses a roller on the rocker arm.

Figure 9–19 When the timing chain broke, it caused the camshaft to go out-of-time, which allowed the pistons and valves to collide on this interference engine. This may also bend the pushrods. Valve-to-piston contact will not occur on freewheeling engines.

CAMSHAFT DURATION, TIMING AND OVERLAP

1. Camshaft duration is the number of degrees of crankshaft rotation during the time the valve is lifted off the valve seat. See Figures 9–20 and 9–21.

   If we follow the cam timing diagram (Figure 9–24, p. 179), we find that the intake valve opens at 15° before top dead centre (TDC), stays open from top dead centre to bottom dead centre (BDC), which is a further 180°, and closes 59° after BDC.

   Adding the three, 15° + 180° + 59° = 254°, gives the duration. The intake valve is open for 254° of crankshaft rotation.

   The exhaust valve opens at 59° before BDC, stays open from BDC to TDC (a further 180°) and closes at 15° after TDC.

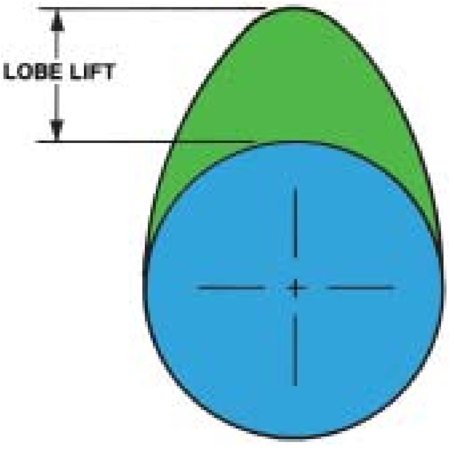


Figure 9–20 The lobe lift is the amount the cam lobe lifts the lifter. Because the rocker arm adds to this amount, the entire valve train has to be considered when selecting a camshaft that has the desired lift and duration.

TECH TIP

Hollow Pushrod Dirt

Many engine rebuilders and remanufacturers do not reuse old hollow pushrods. Dirt, carbon, and other debris are difficult to thoroughly clean from inside a hollow pushrod. When an engine is run with used pushrods, the trapped particles can be dislodged and ruin new bearings and other new engine parts.

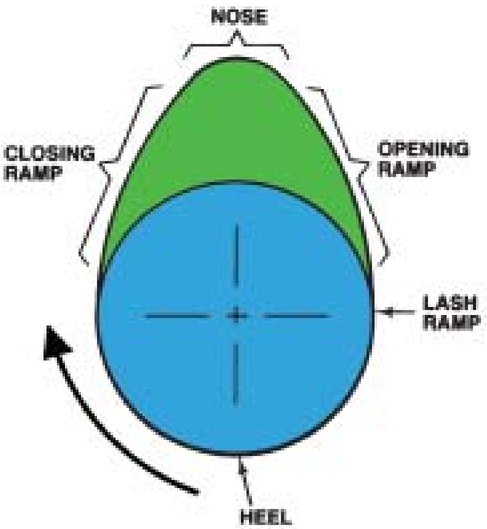


Figure 9–21 The ramps on the cam lobe allow the valves to be opened and closed quickly yet under control to avoid damaging valve train components, especially at high engine speeds.

Adding the three, 59° + 180° + 15° = 254°, gives the duration of the exhaust valve. In this case, both the intake and exhaust have the same duration. This is not always the case as different durations are often used for intake and exhaust valves.

If a hydraulic lifter is used, the valve lash is zero. If a solid lifter is used, duration begins after the specified clearance (lash) has been closed.

Overlap is the time, in crankshaft degrees, that both valves are open at the same time. Overlap on our example would be 15° + 15° = 30°.

2. Advancing the camshaft: the camshaft is moved ahead in relation to the crankshaft. The valve now opens earlier and also closes earlier. The duration does not change.
3. Retarding the camshaft: the camshaft is moved back (behind) in relation to the crankshaft. The valve now opens later and closes later. The duration does not change.

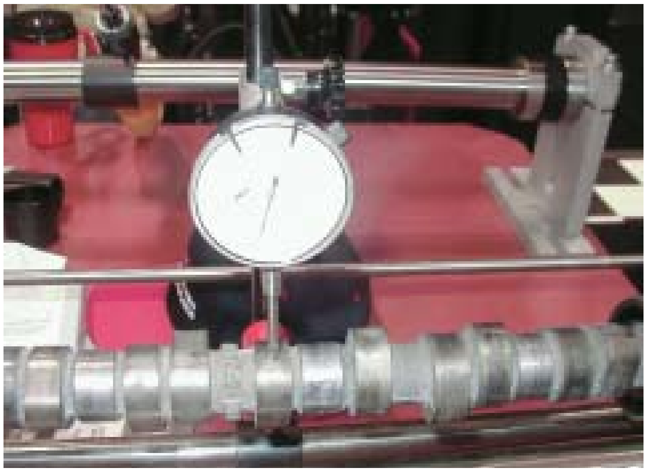


Figure 9–22 A camshaft can be checked for straightness as well as for lift and duration using a dial indicator on a fixture that allows the camshaft to be rotated. This same equipment can be used to check crankshafts.

CAMSHAFT TESTING

The camshaft should be inspected visually for wear and measured with a dial indicator as shown in Figures 9–22 and 9–23.

CAM TIMING CHART

Four Strokes

During the four strokes of a four-cycle gasoline engine, the crankshaft rotates two complete revolutions or 720° (2 × 360° = 720°). The four strokes, of 180° each, are:

- Intake—an air/fuel mixture is drawn into the cylinder.
- Compression—the piston compresses the air into a high temperature mass.
- Power—the compressed air/fuel mass is ignited and the expanding gases push the piston down the cylinder.
- Exhaust—the burned gases are pushed out of the cylinder by the piston.

VALVE TIMING

The timing for these four events is expressed in degrees of crankshaft rotation; camshaft specifications are also given in crankshaft degrees. The usual method of drawing a camshaft timing diagram is a circle illustrating two revolutions (720°) of the crankshaft. See Figure 9–24. We'll use this again as an example.

Figure 9–23 The lift of a camshaft lobe can be quickly determined by using this dial indicator that attaches directly to the camshaft.

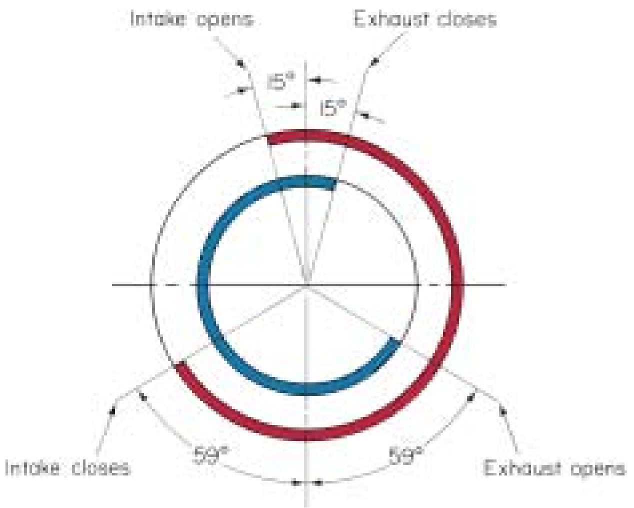


Figure 9–24 Typical cam timing diagram.

Let's begin at TDC. At the beginning of the intake stroke, the intake valve has already started to open and the piston is moving down the cylinder. Air and fuel rush into the low-pressure void (vacuum) caused by the piston movement. When the piston reaches BDC, it reverses direction and starts to move up the cylinder on the compression stroke.

When do we close the intake valve? It depends. The air rushing into the cylinder has both speed and inertia, it doesn't want to stop. The intake valve should close just before the pressure in the cylinder overcomes the velocity of the air. This prevents the air from being pushed back into the intake manifold. We know that air speed varies with engine RPM. The air flow at higher RPM has greater speed and force, therefore the intake valve can be held open longer (later) and use more duration.

Using a camshaft with more duration increases high RPM power, but low RPM power suffers as part of the air/fuel charge is pushed back into the intake manifold. Engine vacuum also suffers. In general, long duration camshafts work well at higher engine speeds and short duration camshafts work well at lower speeds.

Advancing the camshaft will help at low RPM because the intake valve opens earlier, but also closes earlier. Retarding the camshaft helps at high RPM as the intake valve opens later, but also closes later, allowing more of the high velocity charge to enter.

Stretched timing chains and belts allow the valve timing to retard, which affects low-end power. Replacing the belt or chain restores the original valve timing and the engine is much smoother at low speeds.

As the piston moves up the cylinder on the compression stroke, both valves are closed, the air is being compressed, and just before TDC the mixture is ignited. The combustion pressure forces the piston down the cylinder on the power stroke. When do we open and close the exhaust valve? Again, it depends on RPM.

The greatest mechanical leverage between the connecting rod and crankshaft (90°) occurs approximately half way down the cylinder. As the piston gets closer to BDC, we begin to lose this mechanical advantage. Rather than using the remaining pressure in the cylinder to push on the piston, we're going to open the exhaust valve before BDC, which lets the cylinder pressure push the exhaust gases out into the exhaust system. At BDC as the piston reverses direction, it continues to force the spent exhaust gases out of the cylinder. When do we close the exhaust valve?

Our chart shows the valve closing at 15° after TDC, as the piston begins the intake stroke. The exiting exhaust gas also has inertia that creates a vacuum behind it. This vacuum draws out (scavenges) the last of the exhaust from the combustion chamber. We also note that the intake valve started to open before the exhaust valve closed. The period of time that both valves are open together is called the overlap period. During the overlap period (in our example 15° + 15° = 30°), the vacuum created by the exiting exhaust is used to draw in some of the new intake charge.

In general, long (high) overlap camshafts produce good top end power, but kill the low end because the incoming air/fuel charge flows right out the exhaust at low RPM. Reducing the overlap increases low speed power and compression, but top end power suffers.

The camshaft characteristics must match the operating range of the engine; so one engine may list three or more different camshafts, each designed for specific conditions.

Using the correct camshaft is a must!

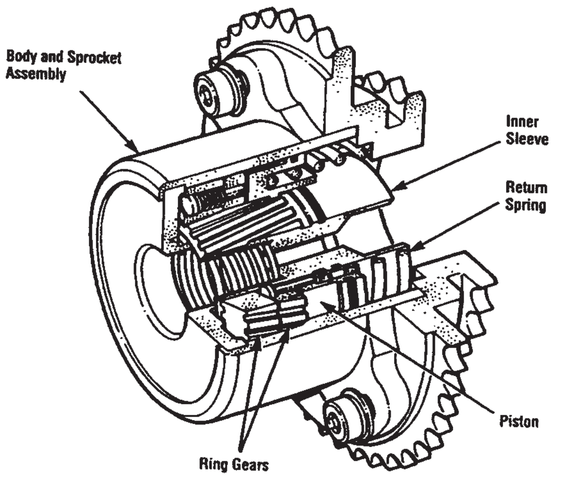
VARIABLE VALVE TIMING

Variable valve timing was developed to improve engine performance at both low and high speeds. This is achieved in a number of ways.

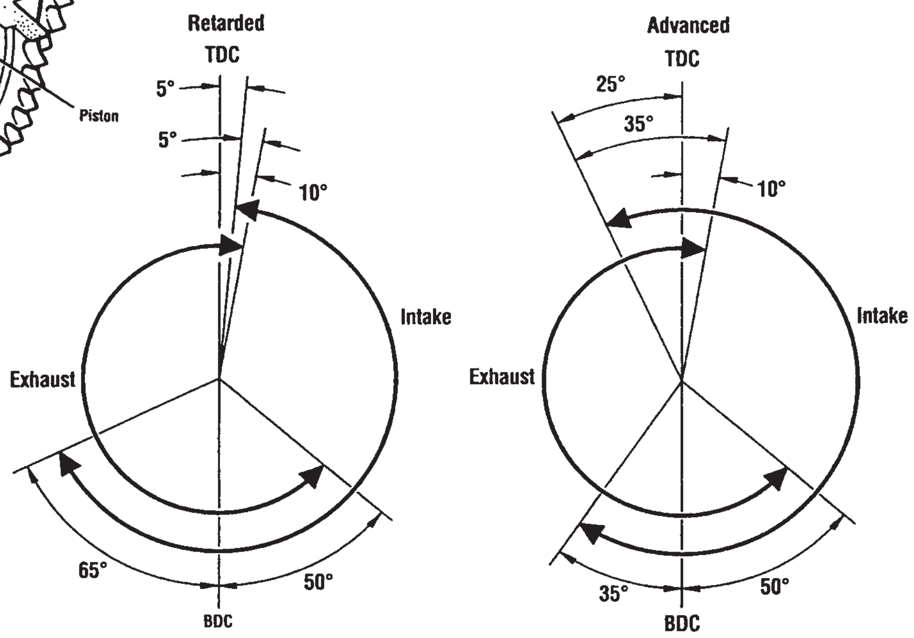
- A moveable sprocket on the front of the camshaft allows the shaft to rotate in relation to the sprocket. Allowing oil pressure into the sprocket body moves the drive along a helical gear, which changes the timing. Oil volume is set by an electrical solenoid which is computer controlled. See Figure 9–25(a).
- Engines with a single camshaft advance the timing at low RPM and retard the timing at higher speeds.
- Dual overhead camshaft engines usually control the intake cam only. This allows the overlap to be adjusted for operating conditions. Low speeds requires short overlap, increasing the speed requires longer overlap. See Figures 9–25(b) and 9–25(c).
- The Honda VTEC variable valve timing uses a different principle. Both short duration low lift cam lobes and a long duration high lift lobe are used. At low speeds, the rocker for the mild lobe is active and the high lift rocker is inactive. Around 4800 rpm, a piston located in the high lift rocker is moved by oil pressure (computer activated) which locks both the low and high speed rockers together. The long duration, high lift cam lobe now controls the valve action. See Figures 9–25(d) and 9–25(e).

INSTALLING THE CAMSHAFT

When the camshaft is installed, the lobes must be coated with a special lubricant containing molydisulfide. This special lube helps to ensure proper initial lubrication to the critical cam lobe sections of the camshaft. Many manufacturers recommend multi-viscosity engine oil such as SAE 5W-30 or SAE 10W-30. Some camshaft manufacturers recommend using

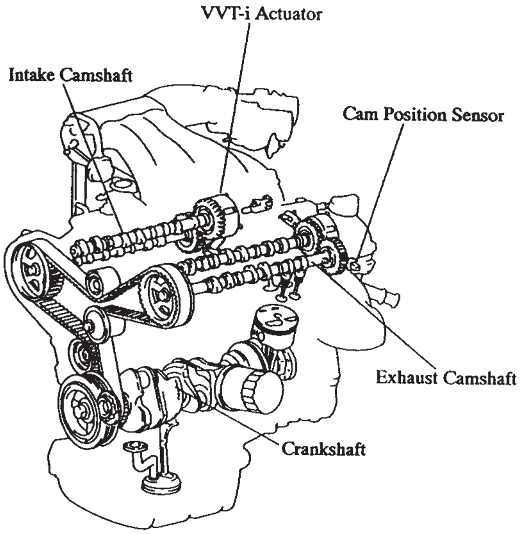


(a)



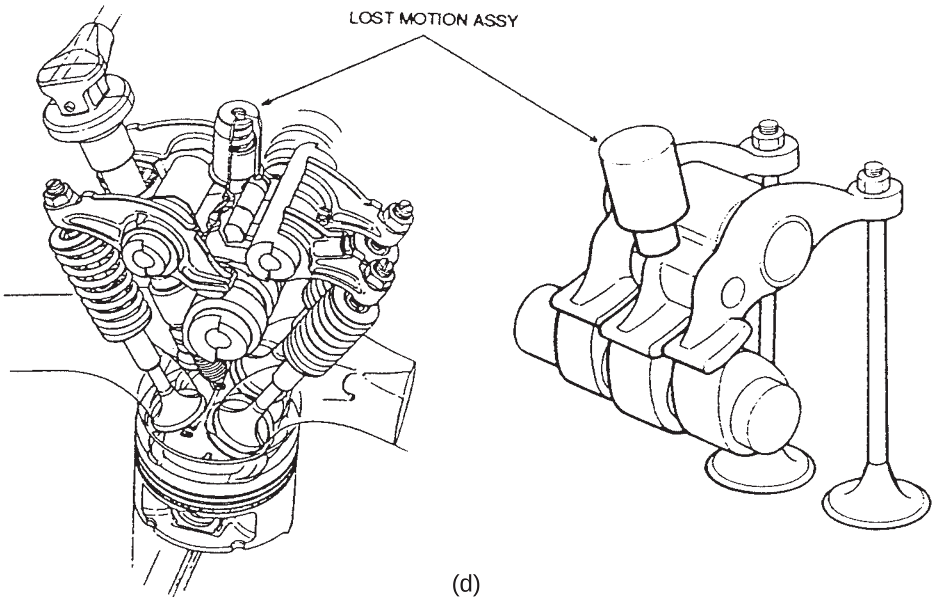
(b)

Figure 9–25 Variable valve timing components. (a) Cross-section of a moveable camshaft drive sprocket. (b) Valve timing chart for intake camshaft control. Advancing one cam only increases valve overlap. (Jaguar Canada and Ford Motor Company trademarks and Jaguar branded products used with permission)

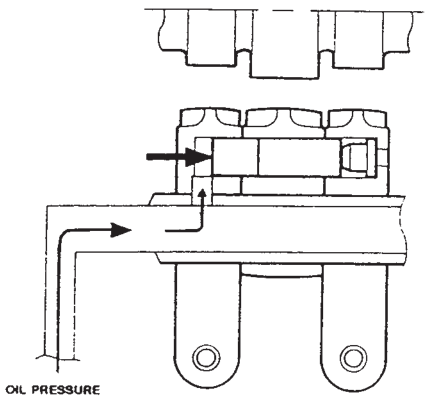


(c)

Figure 9–25 Continued (c) A dual overhead camshaft engine with the moveable camshaft drive sprocket (VVT-iActuator) mounted on the intake camshaft. (Courtesy Toyota Motor Co.) (d) The Honda V-TEC engine uses both outer short-duration cam lobes at low speed. The centre cam and rocker are not connected to the valves. (Courtesy Honda Motor Co.) (e) At higher speeds, a piston, controlled with oil pressure, locks all three rockers together. The centre long-duration cam lobe now overrides the short-duration lobes. (Courtesy Honda Motor Co.)



(d)



(e)

straight SAE 30 or SAE 40 engine oil and not a multi-viscosity oil for the first oil fill. Some manufacturers also recommend the use of an antiwear additive such as zinc dithiophosphate (ZDP). See Figures 9–26 and 9–27.

The camshaft must be broken in by maintaining engine speed above 1500 rpm for the first 10 minutes of engine operation. If the engine speed is decreased to idle (about 600 rpm), the lifter (tappet) or rocker arm will be in contact with and exerting force on the lobe of the cam for a longer period of time than occurs at higher engine speeds. The pressure and volume of oil supplied to the camshaft area are also increased at the higher engine speeds. Therefore, to ensure long camshaft and lifter/rocker life, make certain that the engine will start quickly after a new camshaft and lifters have been installed to prevent long cranking periods and subsequent low engine speeds. When repairing an engine, follow these rules regarding the camshaft and lifters:

1. When installing a new camshaft, always install new valve lifters (tappets).
2. When installing new lifters, if the original cam is not excessively worn and if the pushrods all rotate with the original camshaft, the camshaft may be reused.
3. *Never* use a hydraulic camshaft with solid lifters or hydraulic lifters with a solid lifter camshaft.

NOTE: Some manufacturers recommend that a new camshaft always be installed when replacing valve lifters.

NOTE: Some performance engine builders use a degree wheel (Figure 9–28) to ensure that valve timing is correct.

Figure 9–26 Special lubricant such as this one from General Motors is required to be used on the the lobes of the camshaft and the bottom of the flat-bottomed lifters.

Figure 9–27 Care should be taken when installing a camshaft not to nick or scrape the cam bearings.

(a)

(b)

Figure 9–28 (a) The set-up required to degree a camshaft. (b) Closeup of the pointer and the degree wheel.

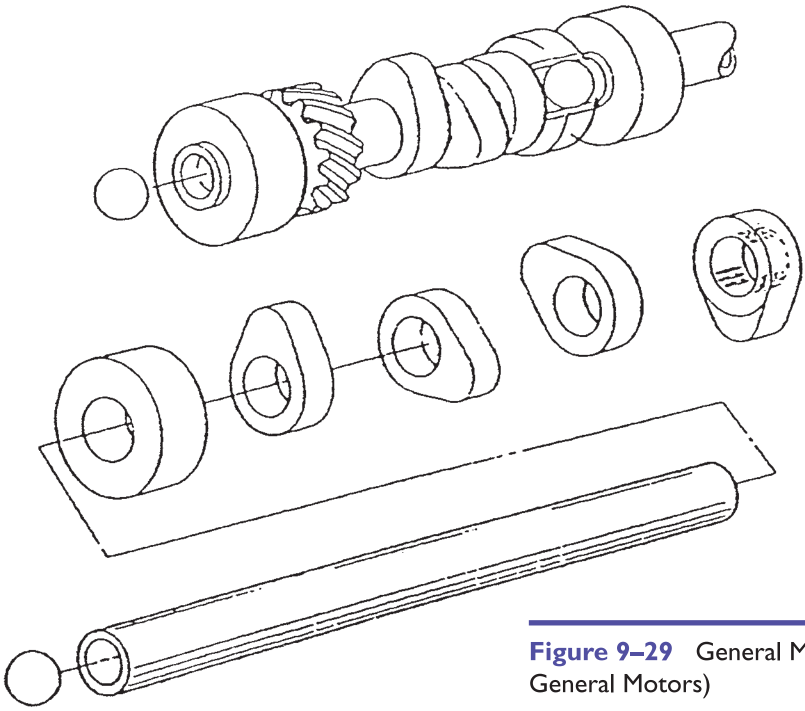


Figure 9–29 General Motors assembled steel camshaft. (Courtesy General Motors)

ASSEMBLED CAMSHAFTS

Camshafts are normally cast or machined in one piece. Several manufacturers are now using assembled camshafts which allows different materials to be combined on a single shaft. General Motors uses three different steel alloys and a cast-iron gear to increase durability.

The manufacturing process starts with individual cam lobes being positioned on a hollow steel shaft. A steel ball, larger than the inside diameter, is forced through the hollow shaft which expands and locks the lobes. See Figure 9–29.

LIFTERS

Valve lifters (also called **tappets**) follow the contour or shape of the camshaft lobe. This arrangement changes the cam motion to a reciprocating motion in the valve train. Most older-style lifters have a slightly convex surface that slides on the cam. See Figure 9–30. Some lifters, however, are designed with a roller to follow the cam contour. Roller lifters are used in production engines to reduce valve train friction (by up to 8%). This friction reduction can increase fuel economy and help to offset the greater manufacturing cost. All roller lifters must use a retainer to prevent lifter rotation.

Camshaft lobes designed for roller lifters must have a very hard surface to match the steel rollers. Some cams are made of steel and others use heat-treated iron. In some cases, the distributor gear material is matched for compatibility with the camshaft gear. Using the incorrect distributor gear will ruin both the camshaft and distributor gear.

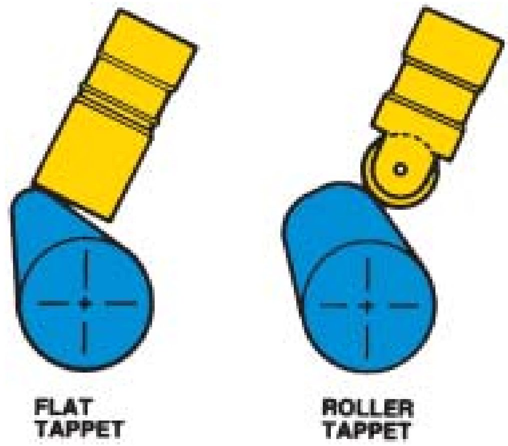


Figure 9–30 Lifters or tappets are made in two styles: flat bottom and roller.

Valve train clearance is also called **valve lash.** Valve train clearance must not be excessive, or it will cause noise or result in premature failure. Two methods are commonly used to make the necessary valve clearance adjustments. One involves a **solid valve lifter** with a mechanical adjustment, and the other involves a lifter with an automatic hydraulic adjustment built into the lifter body, called a **hydraulic valve lifter.**

A hydraulic lifter consists primarily of a hollow cylinder body enclosing a closely fitted hollow plunger, a check valve, and a pushrod cup. Lifters that feed oil up through the pushrod have a metering

HIGH PERFORMANCE TIP

Varying the Valve Timing to Vary Engine Performance

If the camshaft is slightly ahead of the crankshaft, the camshaft is called *advanced.* An advanced camshaft (maximum of 4°) results in more low-speed torque with a slight decrease in high-speed power. Some aftermarket camshaft manufacturers design about a 4° advance into their timing gears or camshaft. This permits the use of a camshaft with more lift and duration, yet still provides the smooth idle and low-speed responses of a milder camshaft.

If the camshaft is slightly behind the crankshaft, the camshaft is called *retarded.* A retarded camshaft (maximum of 4°) results in more high-speed power at the expense of low-speed torque.

If the measured values are different from specifications, special offset pins or keys are available to relocate the cam gear by the proper amount. Some manufacturers provide adjustable cam timing sprockets for overhead cam engines.

Be aware that changing cam timing may cause a rise in emissions.

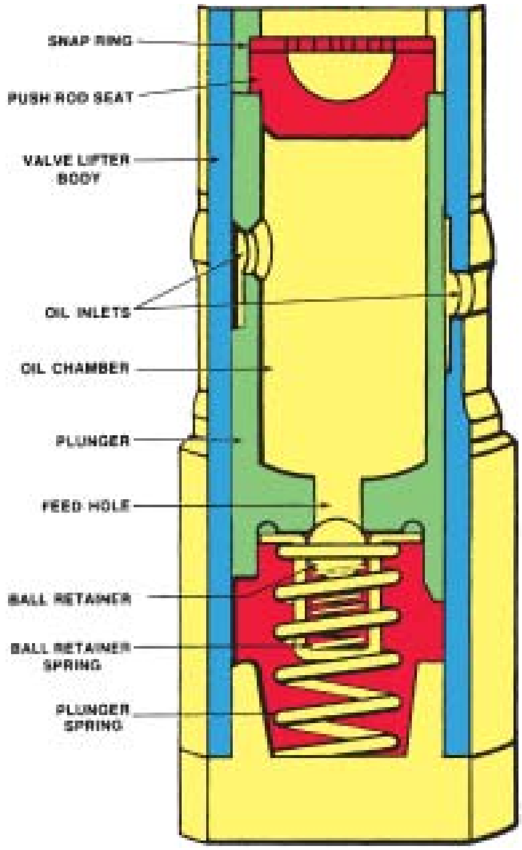


Figure 9–31 A cross-sectional view of a typical flat-bottomed hydraulic lifter.

disk or restrictor valve located under the pushrod cup. Engine oil under pressure is fed through an engine passage to the exterior lifter body. An undercut portion allows the oil under pressure to surround the lifter body. Oil under pressure goes through holes in the undercut section into the centre of the plunger. From there, it goes down through the check valve to a clearance space between the bottom of the plunger and the interior bottom of the lifter body. It fills this space with oil at engine pressure. Slight leakage allowance is designed into the lifter so that the air can bleed out and the lifter can leak down if it should become overfilled. See Figures 9–31 through 9–34.

CAUTION: Using too thick (high viscosity) an engine oil can cause the hydraulic lifters or hydraulic lash adjusters to not bleed down as fast as they should. This slow bleed-down can cause a valve(s) to remain open, which results in an engine miss. Using an SAE 10W-40 instead of the specified SAE 5W-20 could cause the lifters to bleed down more slowly than normal and cause a driveability problem, especially if the oil is not changed at specified intervals.

INTAKE MANIFOLDS

The intake manifold is designed to deliver equal amounts of air (or air and fuel) to each intake port in the cylinder head. Older intake manifolds were made of cast iron or aluminum; newer V-type manifolds are usually made of aluminum (bottom) and the top from a plastic composite. The latest manifolds are often all plastic, although aluminum tubing is still found on some imports. See Figure 9–35.

Manifolds are classified as wet when a carburetor, or throttle-body type of fuel injection (TBI), delivers fuel to the *plenum* (the open area under the carburetor) and both air and fuel pass through the intake manifold. The combination of the manifold passage and the cylinder head intake port is known as the *runner*.

Dry manifolds pass air only through the intake runners. Fuel is injected into the cylinder head intake port or directly into the combustion chamber. See Figure 9–36. Dry manifolds are more efficient than wet because:

1. Intake air does not require heating to vaporize the fuel.

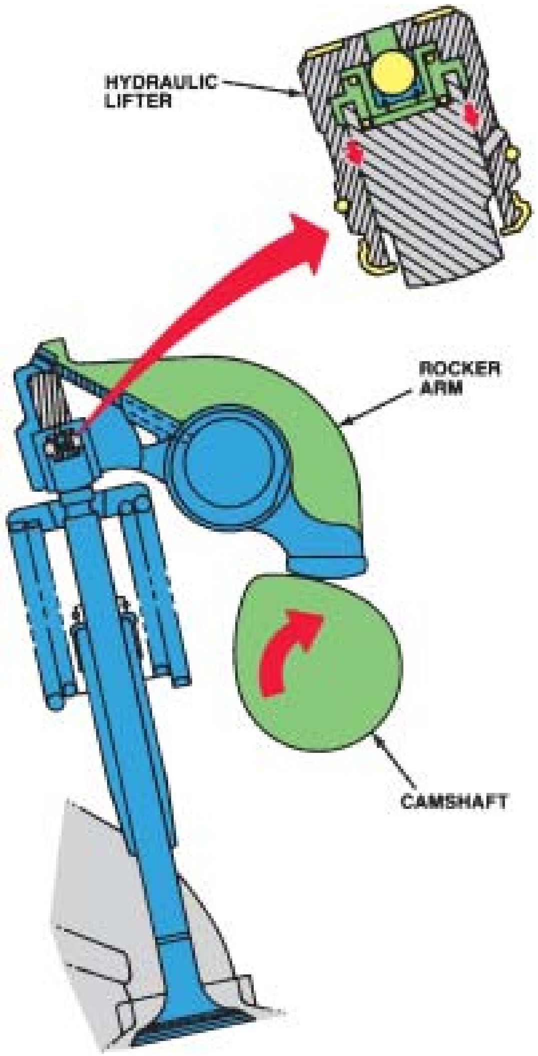


Figure 9–32 Hydraulic lash adjusters (HLA) are built into the rocker arm on some OHC engines.

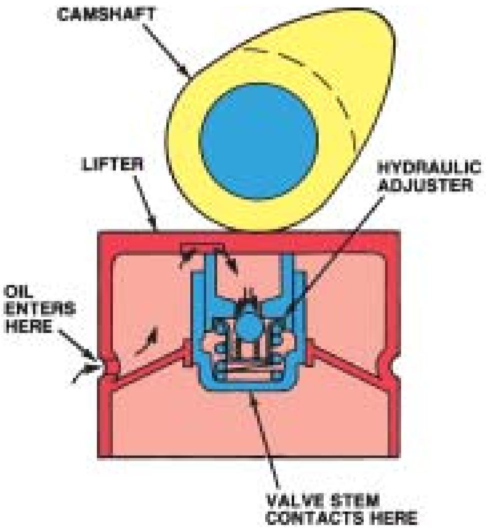


Figure 9–33 Hydraulic lifters are also built into bucket-type lifters on many OHC engines.

Figure 9–34 To correctly adjust hydraulic valve lifters, position the camshaft on the base circle of the camshaft lobe for the valve being adjusted. Remove all clearance by spinning the pushrod and tightening the nut until all clearance is removed. The adjusting nut is then tightened one complete revolution. This is what is meant by the term "zero lash plus 1 turn."

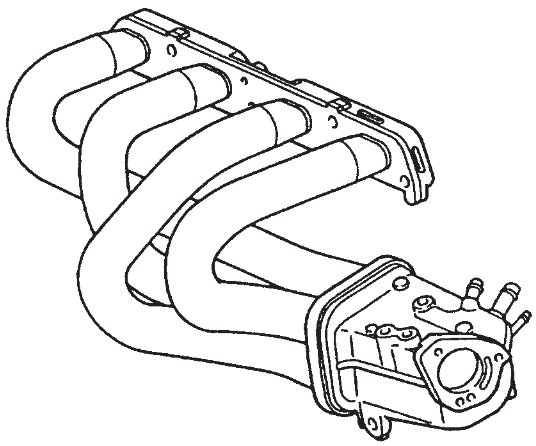


Figure 9–35 This four cylinder all-aluminum tubular intake manifold uses long runners to improve low and mid-range torque. (Courtesy Toyota Canada Inc.)

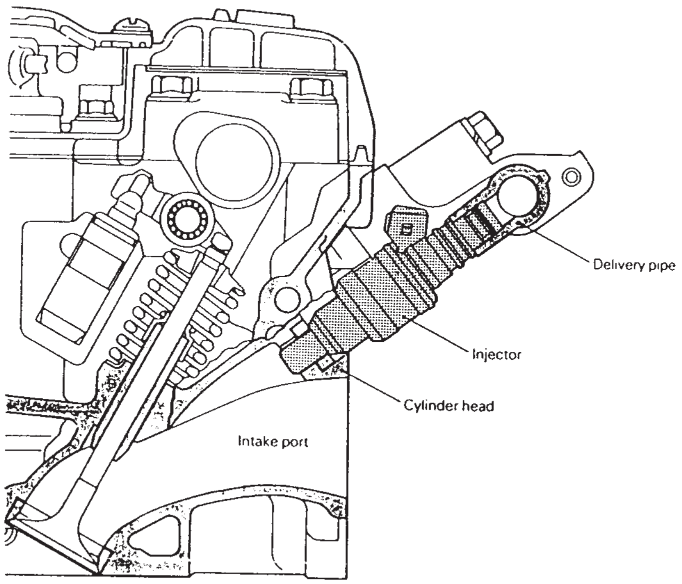


Figure 9–36 Port fuel injection sprays fuel into the cylinder head intake port. This type of intake manifold used is classified as dry since air only passes through the intake runners. (Courtesy Mitsubishi Motor Co.)

2. Fuel does not drop out of suspension in the air and stick to the walls of the intake runner.
3. Equal amounts of fuel are supplied to each cylinder by the fuel injectors.

Dual-Plane Manifolds

Older carburetted (and some TBI) V-8 engines have a concern with unequal air-fuel distribution; cylinders that are side by side and follow each other in firing order often draw mixture from the same corner of the manifold. Dual-plane manifolds are essentially two four-cylinder manifolds joined together at the plenum area. See Figure 9–37. Cylinders close to one another in firing order now draw mixture from opposite sides of the engine correcting the problem.

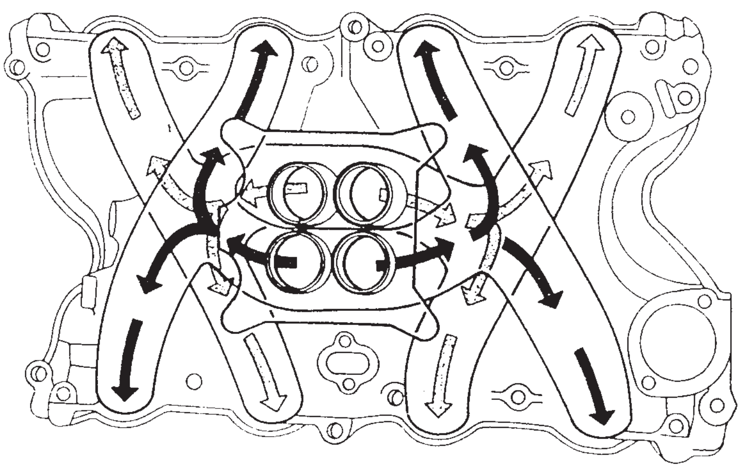


Figure 9–37 Dual plane manifold. Notice that each side of the carburetor feeds two cylinders on the right bank and two on the left bank, *not* all four on the left and all four on the right. (Courtesy Ford Motor Co. of Canada Ltd.)

It is important to understand the manifold layout when diagnosing carburetion problems.

Intake Manifold Heat Control

The air–fuel mixture passing through the intake runners requires engine heat to assist in vaporizing the fuel, making it easier to ignite. When the engine is cold, much of the fuel still remains in liquid form, which makes driveability problems, such as stalling and hesitation, common.

Warming the Mixture

Many engines heat the floor (bottom) of the intake manifold plenum area to vaporize the fuel. V-type engines have an exhaust crossover passage connected to one cylinder head exhaust port in each bank. See Figure 9–38. An exhaust manifold heat riser valve, usually vacuum controlled, closes off one exhaust manifold when the engine is cold. Exhaust from that bank must pass through the crossover passage in order to leave the engine: This heats the intake manifold. As the engine comes up to temperature, a vacuum switching valve cuts off manifold vacuum to the heat riser valve and the valve opens, allowing the exhaust to leave from both exhaust manifolds. A very small amount of exhaust now passes under the plenum and the intake manifold cools.

Heat riser valves that stick in the open position cause cold driveability problems; engine operation is normal after warm-up. Valves that stay closed cause problems with a warm engine, such as carburetor percolation (fuel overheating), hard starting, and loss of power from the restricted exhaust.

The system is simple to test—applying vacuum to the heat riser diaphragm should cause the valve to close without sticking. The vacuum should hold. Releasing the vacuum allows the valve to open. Place a vacuum gauge in the line at the heat riser. The vacuum switching valve (VSV), which is threaded into the cooling system, should pass manifold vacuum when cold and restrict vacuum when the engine is warm. Vacuum lines to the VSV and heat riser should be inspected for cracks or blockage.

The crossover passage in the manifold may plug with carbon, usually on high-kilometre oil-burning engines. If the manifold below the

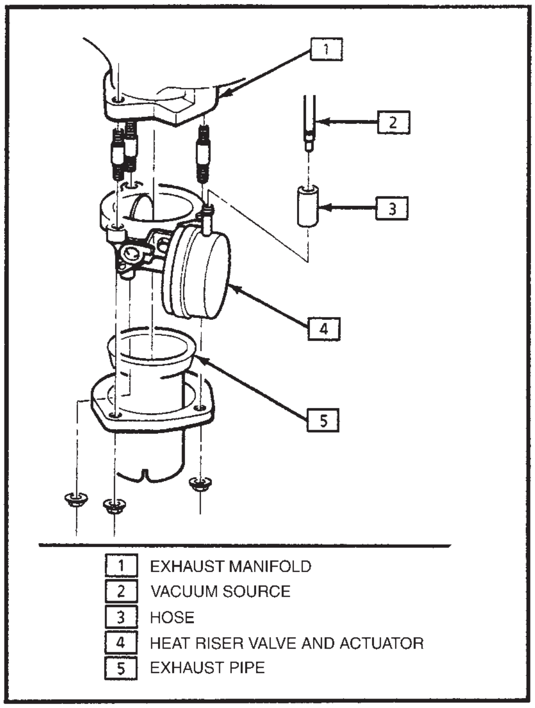
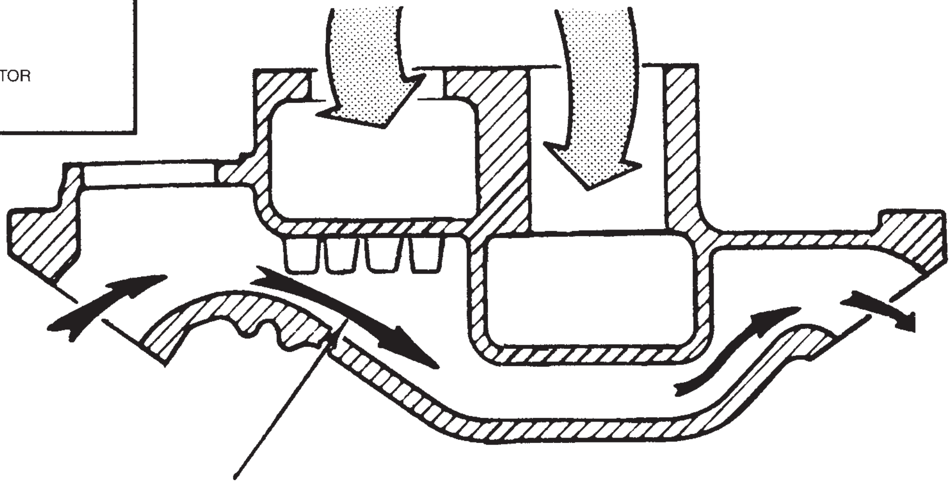


Figure 9–38 Closing one exhaust outlet ("V" engines) with a heat riser valve causes hot exhaust gases to pass through the intake manifold. (Courtesy General Motors)



carburetor base does not warm up quickly on a cold engine, suspect a plugged manifold (if the heat riser valve is closing). Lack of power and stalling, cold, is another indication. The manifold must be removed for cleaning.

Older in-line engines (and some V-8s) use a spring-loaded damper as a heat riser valve. Exhaust heat causes the spring to unwind and the damper opens. The damper shaft should be lubricated with a special heat-riser penetrating oil at every tune-up to prevent sticking.

Tuned Intake Manifolds

The section on valve timing stated that the intake valve should close just before cylinder pressure (piston coming up on the compression stroke) overcomes the speed and pressure of the air rushing into the cylinder. Engines running at high RPM could keep the valve open later because of the increased air speed in the intake runner.

Tuning the intake manifold runner length to the normal operating range of the engine will improve cylinder filling (volumetric efficiency). In general, long, small diameter runners increase air speed (ram effect) at lower RPM for good low and mid-range torque. This type of manifold limits air flow at higher RPM and top-end power suffers. See Figure 9–39.

Long, narrow runners increase intake air speed at lower RPM, good for low-medium RPM power. Short, wide runners do not restrict the incoming air and rely on high RPM for increasing the air speed: good for mid-range and top-end power.

Shorter, larger diameter runners work well at higher RPM; however, at low speeds the air mass slows down and low-end power suffers.

Many larger V engines run at lower RPM and utilize long, narrow runners. Four-cylinder engines usually operate at higher RPM and require short, wide runners. It is important to match the camshaft and the intake manifold to the usual operating range of the engine.

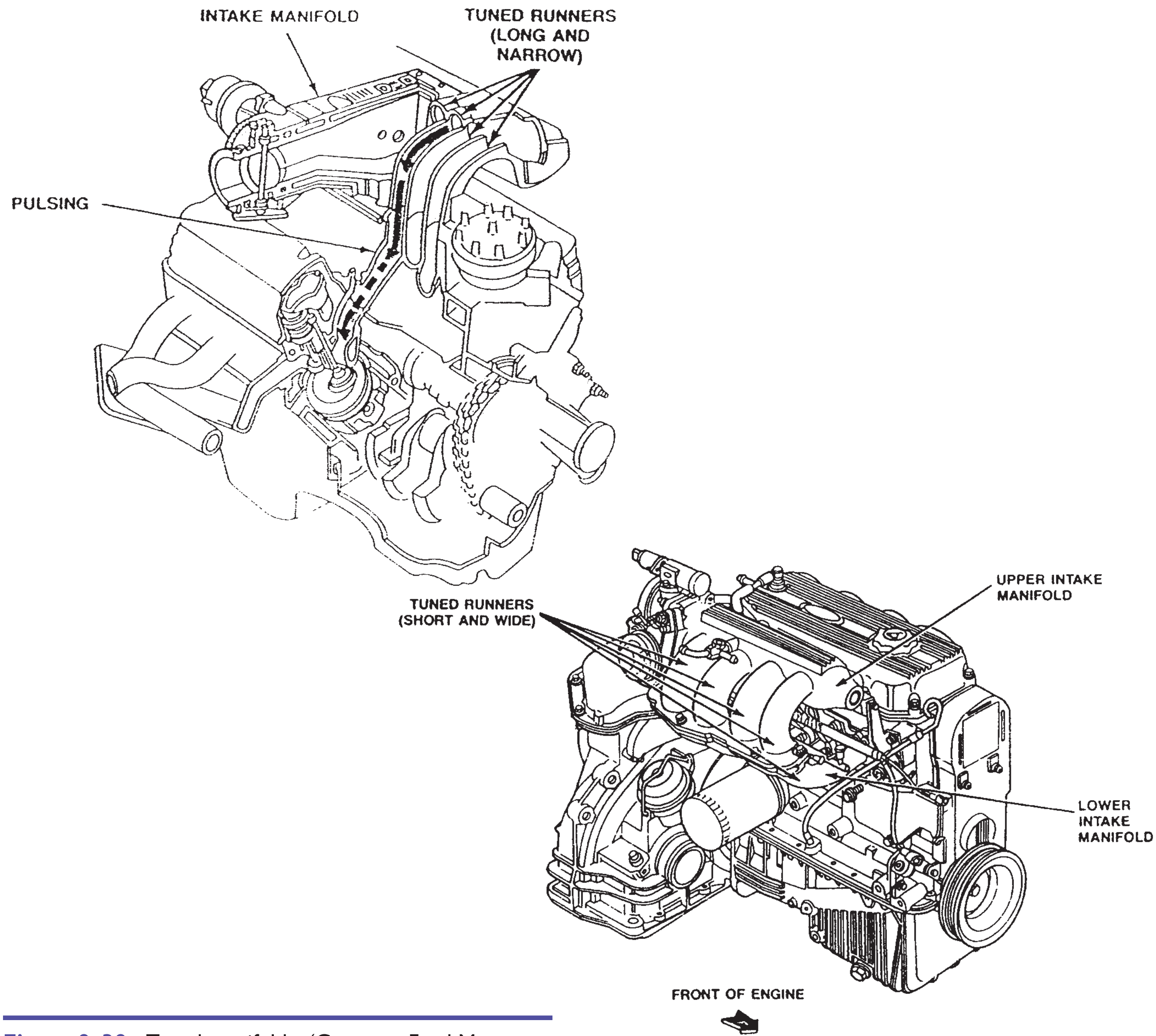


Figure 9–39 Tuned manifolds. (Courtesy Ford Motor Company of Canada Ltd.)

Variable Induction Systems

Variable induction systems have the advantage of changing the runner size or length, to match the operating RPM of the engine.

The Toyota manifold in Figure 9–40 fits a four-cylinder engine with a four-valve (two intake, two exhaust) cylinder head. Each intake valve has its own runner. At lower RPM, the four intake air control valves (not to be confused with the throttle plate) are closed. All of the air must pass through a single runner for each cylinder. This increases air speed providing a ram effect for improved cylinder filling. At higher RPM, the air control valves open, intake air now flows through all runners, and top end power increases.

Closing the four intake air control valves causes the air speed to increase in the four open runners. Although two intake valves are open (four-valve head), only one is functional until the second runner is opened.

At higher speeds, about 4000 to 5500 rpm, the powertrain control module (PCM) energizes an electrical vacuum switching valve (VSV), which allows vacuum to reach the actuator. This opens the air control valves and all eight runners now function.

Another type of variable manifold is on the Ford high-output V-6. See Figure 9–41. The short runners are closed at low speed with a throttling valve—air enters through the long runners only. At higher speeds (RPM), the valve opens and air now passes via the short runners.

V-6 engines often use a variable tuning control valve to change the runner length. See Figure 9–42(a). This General Motors intake manifold has a normally closed tuning valve (IMTV), which splits the manifold into two separate plenums. See Figure

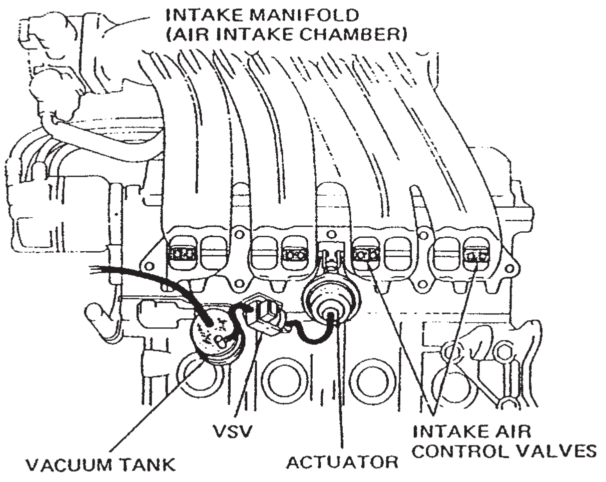


Figure 9–40 Toyota four-cylinder variable induction system. (Courtesy Toyota Canada Inc.)

9–42(b). This effectively increases the runner length. At higher RPM the IMTV opens and the operating length shortens as it now begins at the common plenum.

AIR INTAKE SYSTEMS

The air intake system has a number of functions, including

- Filtering the incoming air
- Heating the air to prevent throttle-plate icing
- Reducing noise levels
- Holding positive crankcase ventilation (PCV) filters
- Providing a mounting for the electronic engine sensors on some models, such as mass airflow sensors or intake air temperature sensors

Throttle-Plate Icing

Throttle-plate icing, also known as carburetor icing, happens when moisture from the incoming air freezes on the throttle plate (and venturi area with carburetors), blocking airflow and causing the engine to stall. It does not usually occur when temperatures are very low, below freezing, or above 10°C (50°F). It is a major problem in areas with high humidity—such as Vancouver, Toronto, and Halifax—when ambient temperatures are in the range of 1° to 10°C (34° to 50°F). Heating the air before it reaches the low-pressure, low-temperature area around the throttle prevents freezing. This is one function of the air cleaner.

Air Temperature Control

The air intake system supplies heated air from around the exhaust manifold during cold weather operation. See Figure 9–43. As the engine comes up to temperature, the damper valve gradually shuts off heated air and opens to cool air. See Figure 9–44.

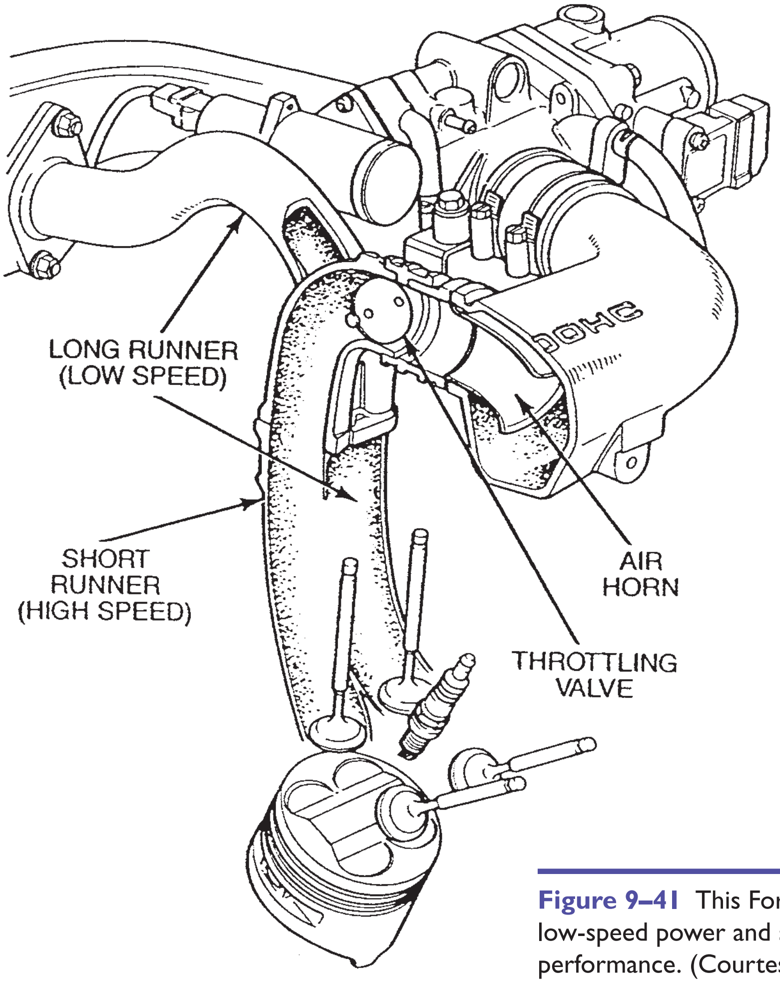
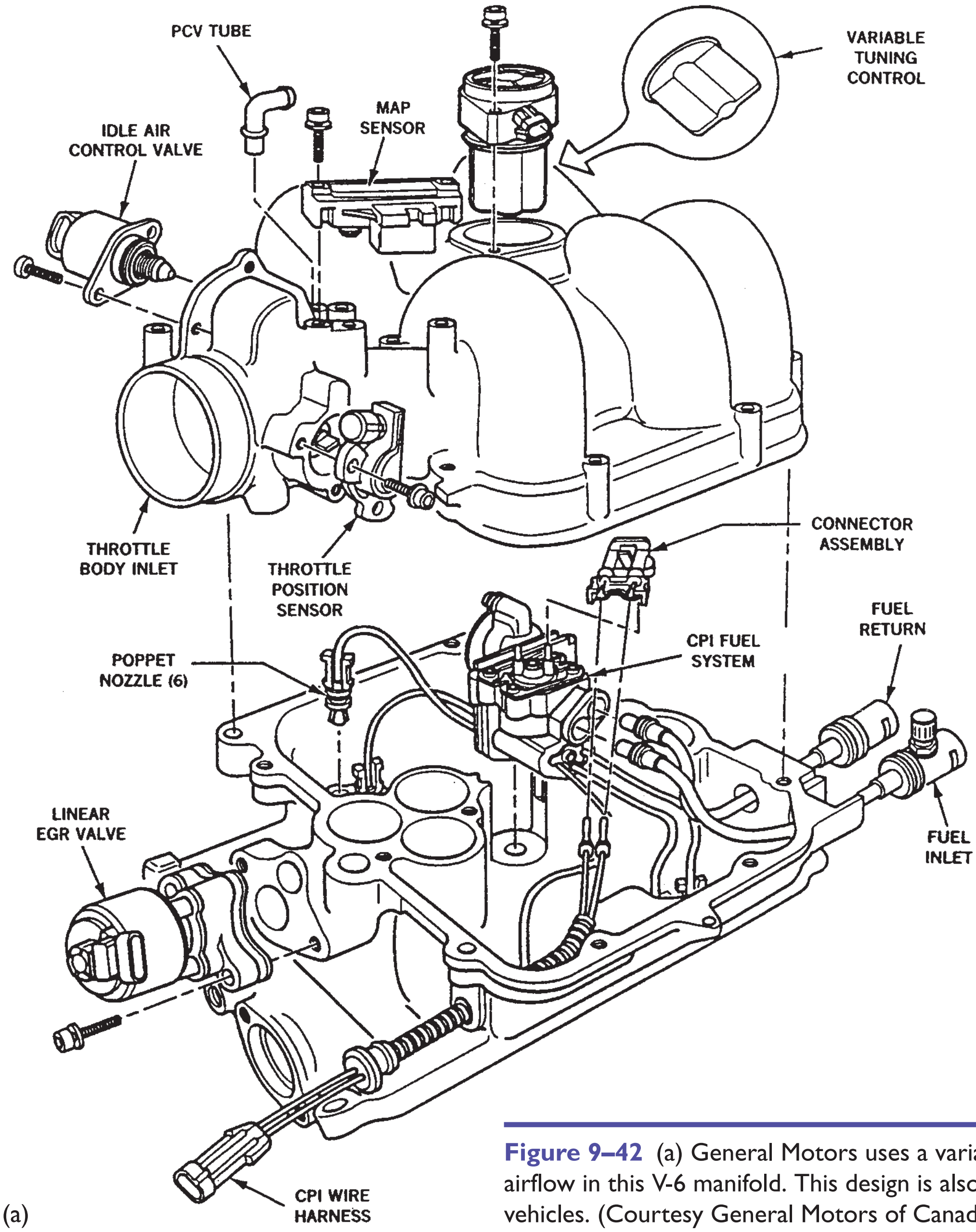
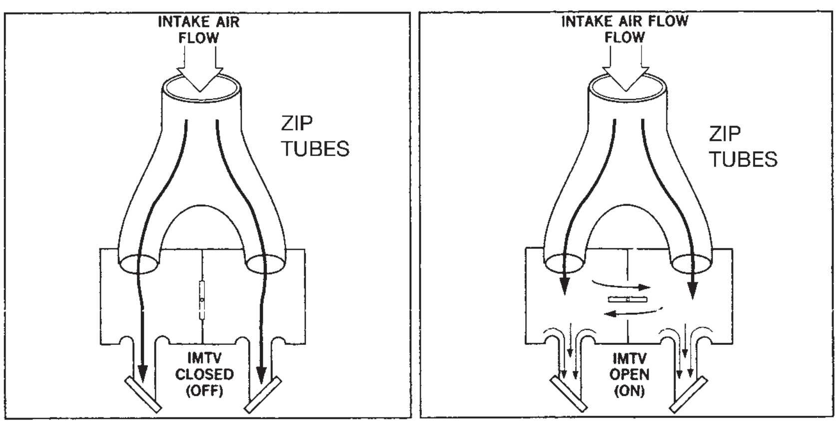


Figure 9–41 This Ford V-6 manifold uses long runners for improved low-speed power and short runners for enhanced high-speed performance. (Courtesy Ford Motor Co. of Canada)



(a)

Figure 9–42 (a) General Motors uses a variable tuning valve to control airflow in this V-6 manifold. This design is also found on some Asian vehicles. (Courtesy General Motors of Canada Ltd.)



(b)

Figure 9–42 (b) Runner length (long) includes the "zip" tubes when the intake manifold tuning valve (IMTV) is closed. Opening the IMTV effectively shortens the runner length, which now begins at the plenum area. (Courtesy General Motors of Canada Ltd.)

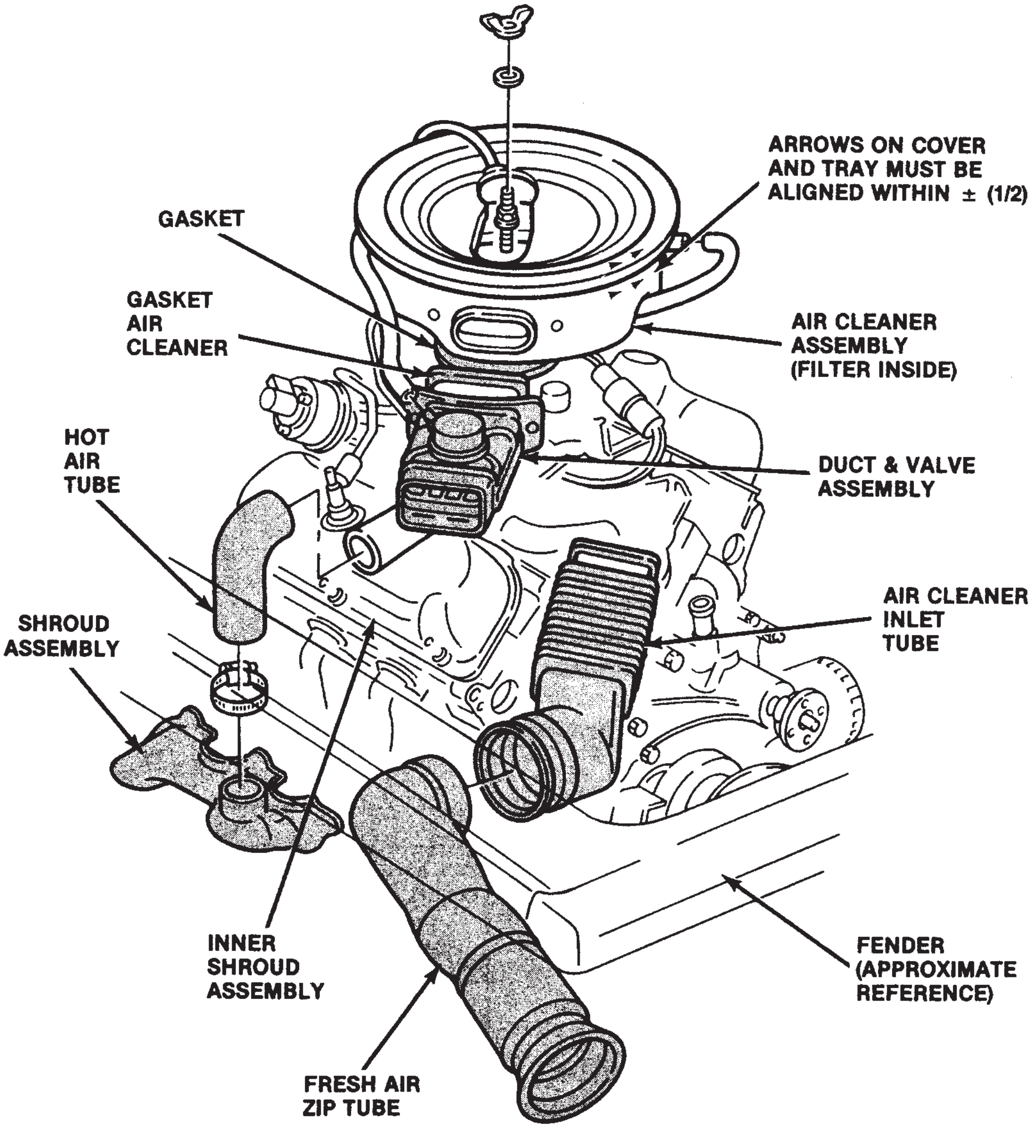


Figure 9–43 This air cleaner, found on carbureted engines, has both hot and cold air pickups. During cold engine operation, hot air from around the exhaust manifold mixes with fuel at the carburetor. This provides better fuel vaporization and reduces, or eliminates throttle-plate icing. As the engine warms up, the damper door closes the hot air pickup and opens to cold air delivery. (Courtesy Ford Motor Co. of Canada Ltd.)

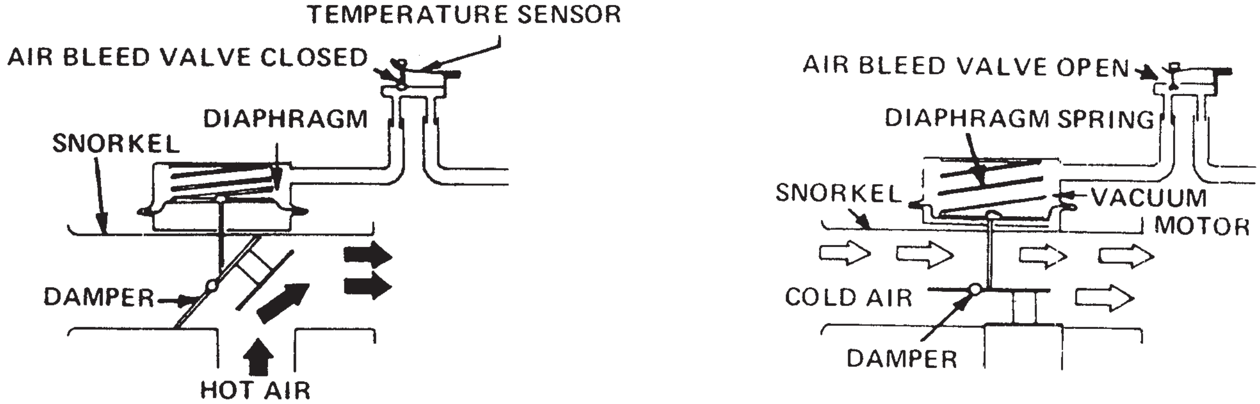
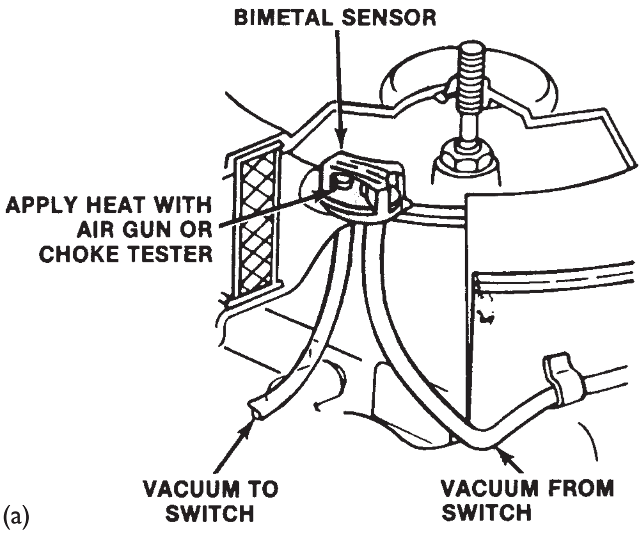
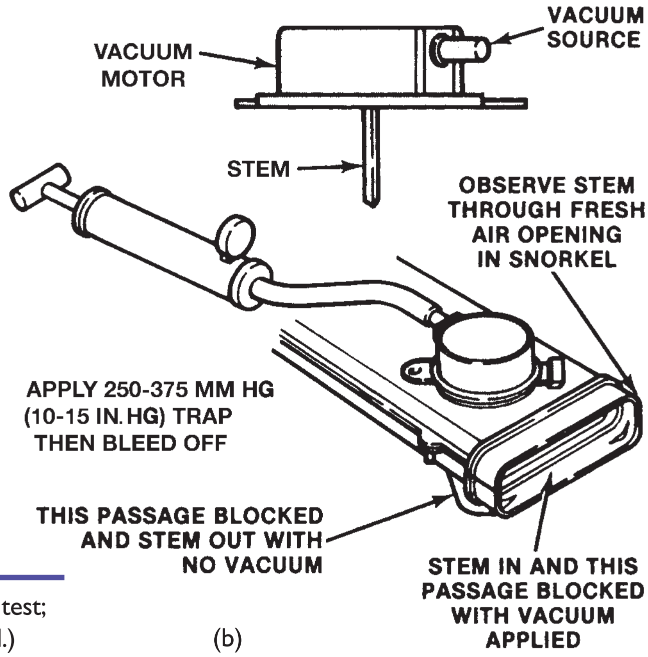


Figure 9–44 Intake manifold vacuum passes through the temperature sensor (mounted inside the air cleaner) to the vacuum motor at the snorkel. This raises the damper, allowing hot air into the engine. (Courtesy Ignition Manufacturers Institute, *Automotive Emission Controls and Tune-Up Procedures* [Prentice Hall, 1980])



(a)



(b)

Figure 9–45 Checking the heated air system: (a) bimetal sensor test; (b) vacuum motor test. (Courtesy Ford Motor Co. of Canada Ltd.)

The bimetal spring in the temperature sensor bends from the incoming warm air; this creates an air leak at the bleed valve; vacuum is lost and the diaphragm spring forces the damper to gradually close the hot air duct. Cold air now enters.

Wet versus Dry Manifolds

Heated air cleaners also play a large part in cold engine driveability. Warm incoming air helps the liquid fuel to vaporize and ignite easily until the engine temperature rises. This is not a problem with dry manifolds, as air only passes through the manifold. Fuel is injected, usually, at the intake valve.

Throttle-plate icing is still a concern with dry manifolds; the moisture in the air freezes, not the fuel. These engines often have a heated grid or a hot water pocket at the throttle body to prevent icing.

Testing the Heated Air System

These systems are also simple to test.

- Place a thermometer inside the air cleaner.
- Start the engine and observe the damper; it should be closed to cold air.
- As the engine warms up, note when the damper begins to open. Remove the thermometer from inside the air cleaner and record the temperature. Compare the reading to the service manual specification. An incorrect opening temperature indicates a faulty bimetal sensor, provided there are no leaks in the hoses or vacuum motor.
- The bimetal sensor can also be tested by applying heat to the sensor with a heat gun (normally used to collapse shrink tubing), and checking the vacuum signal at the vacuum motor hose. See Figure 9–45(a).
- The vacuum motor is tested by applying vacuum from a hand-held vacuum pump to the motor. Vacuum should hold and the damper should close. Releasing vacuum will allow the damper to open with no signs of dragging on the snorkel. See Figure 9–45(b).

Air Cleaner Filter Element

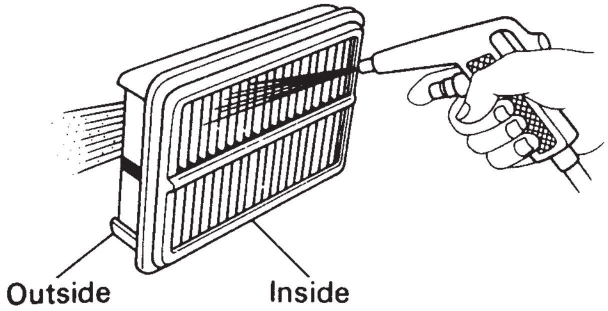
These filters are usually made of pleated paper and are replaced at a given number of kilometres or elapsed time. Vehicles driven on dusty roads will need more frequent replacement. If the filter looks clean on a visual inspection and light from a trouble lamp can be seen through the filter, it may be reinstalled after being blown out with compressed air. See Figure 9–46. If in doubt, replace the filter element.

Air Filter Restriction Indicators

Some vehicles are equipped with filter indicators (sometimes called filter minders) that change colour when the filter becomes restricted. See Figure 9–47.

EXHAUST SYSTEMS

The original purpose of the exhaust system was to route spent gases to the rear of the vehicle and lower exhaust noise.



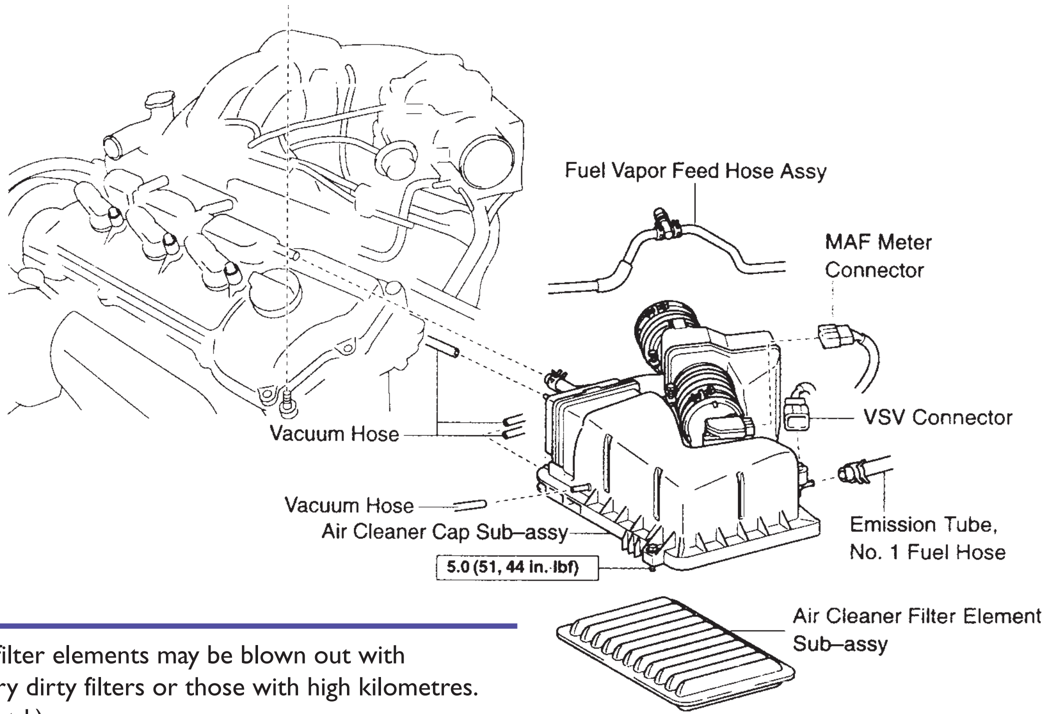


Figure 9–46 Air cleaner filter elements may be blown out with compressed air; replace very dirty filters or those with high kilometres. (Courtesy Toyota Canada Ltd.)

Since the introduction of emission controls, the exhaust system also

- Provides air injection mountings in the manifold
- May contain one to six oxygen sensors that monitor engine air-fuel ratios and catalytic converter(s) condition
- Includes three-way (hydrocarbon, carbon monoxide and oxides of nitrogen) converters in the exhaust manifold or front pipes
- May contain an adsorber to store hydrocarbons or oxides of nitrogen. See Figure 9–48.

This section will cover the standard exhaust items found on passenger cars and light trucks. Catalytic converters and other emission related components are found in Chapter 30: "Emission Control Device Operation, Diagnosis and Service."

Exhaust Manifolds

Exhaust manifolds are usually made of lightweight stainless steel tubing. Individual tubes for each cylinder are tuned for maximum power at the normal operating range. See Figure 9–49. Cast-iron manifolds are still used on some heavy vehicles where weight is not a major concern, or on passenger cars that require a lower noise level. Tubular "header" style manifolds are generally noisier than cast iron—iron dampens exhaust pulse noises.

Iron manifolds are prone to crack when mounted on inline four- and six-cylinder aluminum cylinder heads because of differing expansion rates. Only high quality exhaust gaskets should be used and torquing is a must. Over-torquing stops the manifold from "sliding" on the head and a crack often develops.

The Honda Insight casts the exhaust manifold and cylinder head in one unit. This reduces weight

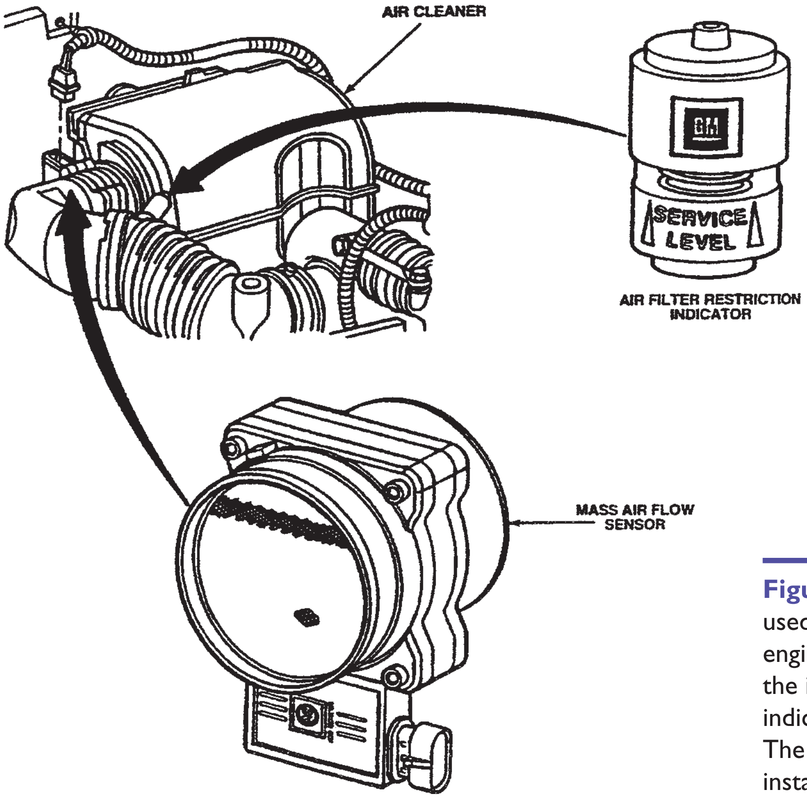


Figure 9–47 Air filter restriction indicators (if used) are located between the air cleaner and the engine. If the air filter becomes clogged or restricted, the increase in intake hose vacuum will cause this indicator to change colour, from green to orange. The indicator must be reset when a new filter is installed. (Courtesy General Motors of Canada Ltd.)

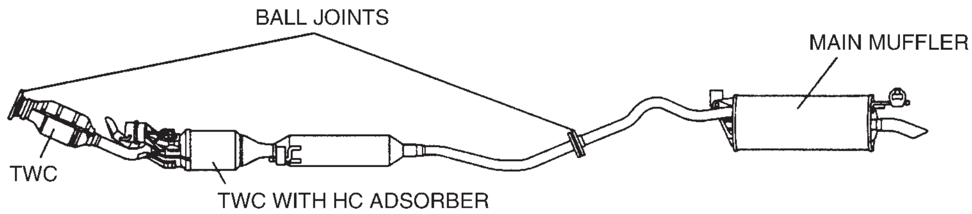


Figure 9–48 A typical exhaust system with three-way catalytic converters, a hydrocarbon adsorber, and a main muffler. (Courtesy Toyota Canada Inc.)

and allows the catalytic converter to heat up more quickly. See Figure 9–50.

Catalyst Location

Catalytic converters require a great deal of engine exhaust heat in order to function. The closer to the engine, the better. Some vehicles have the converter bolted directly to the exhaust manifold (see Figure 9–51); others build the converter and manifold as one unit. One-piece converter-manifolds are replaced as an assembly. Bolt-on or weld-on converters are also located in the front exhaust pipe(s).

Mufflers and Resonators

The most common original equipment muffler is the reverse-flow type. See Figure 9–52. These mufflers are very quiet; however, they limit power at higher speeds because of the restrictive design (back pressure).

Straight-through mufflers reduce back pressure. They are usually found on some factory high-performance vehicles and many aftermarket sports exhausts. Straight-through mufflers use fibreglass or steel-wool packing for noise control; this often burns out or compacts with carbon, increasing noise levels.

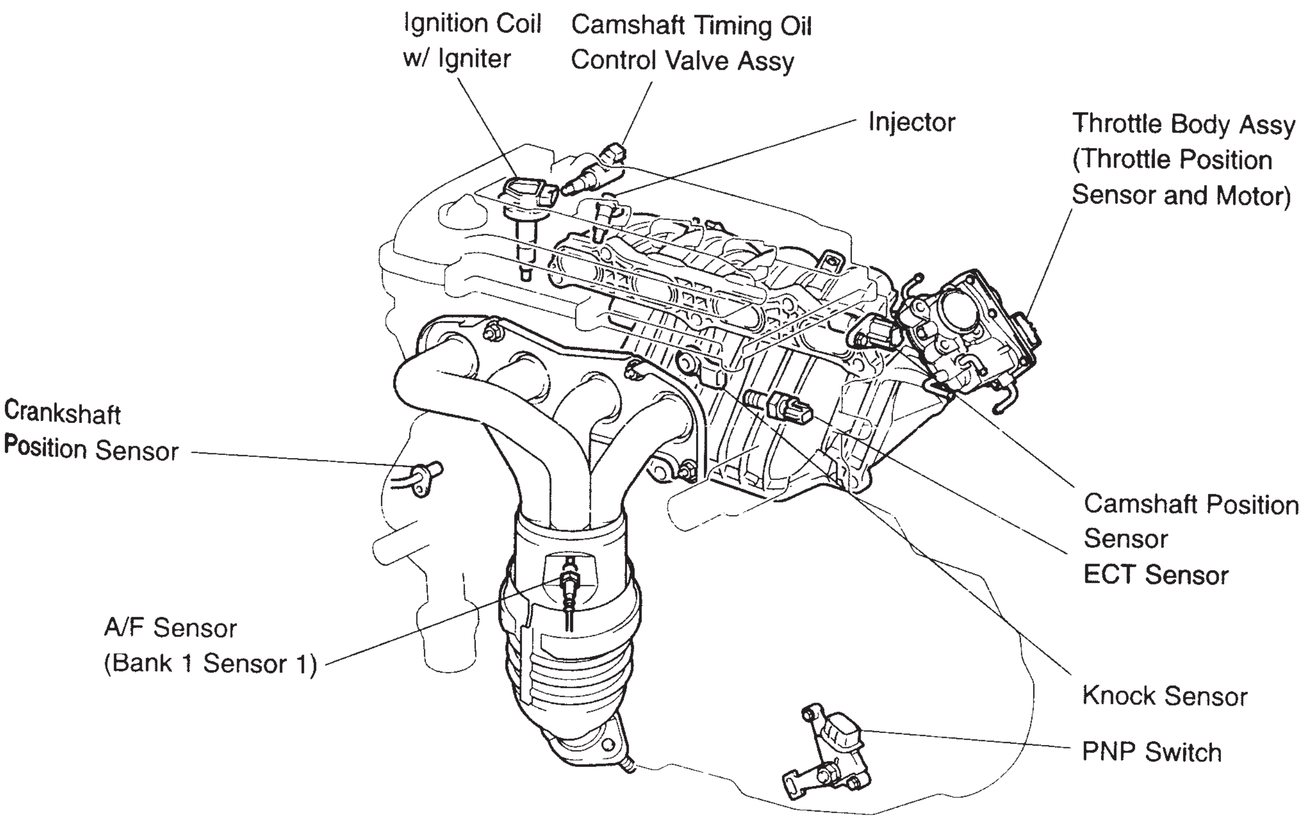


Figure 9–49 Stainless steel tubular exhaust manifolds are lighter and usually more efficient than cast-iron manifolds. Note the air–fuel (oxygen) sensor mounted very close to the engine. (Courtesy Toyota Motor Co.)

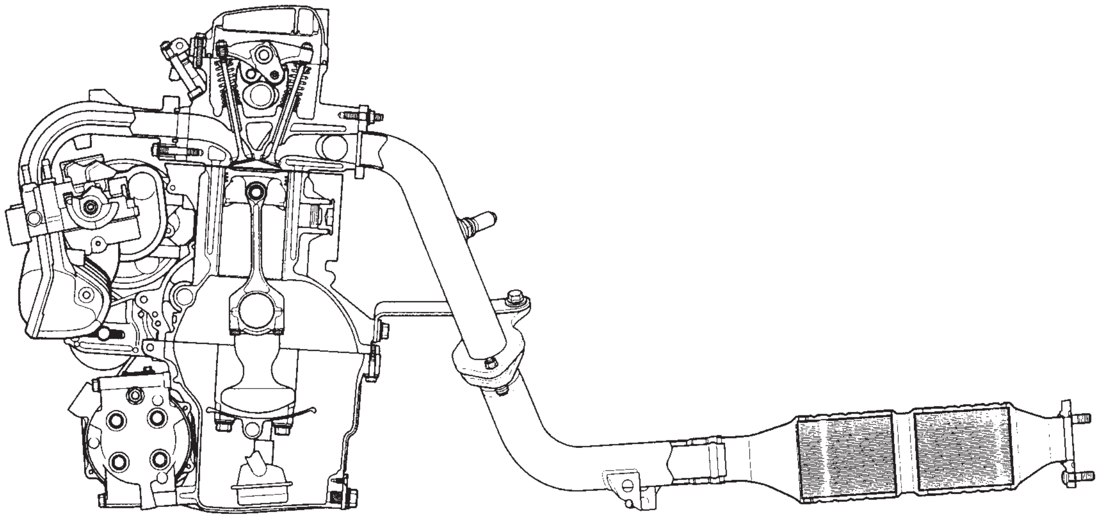


Figure 9–50 The Honda Insight combines the exhaust manifold and cylinder head into one unit. (Courtesy Honda Motor Co.)

A newer design reverse-flow muffler uses a spring-loaded damper that opens at high exhaust pressure. This decreases back pressure. See Figure 9–53.

Resonators are smaller secondary mufflers installed to further reduce exhaust noise and resonance. They can be straight-through or reverse-flow; both designs are used. They mount after the muffler (most common) or before, depending on space limitations.

Exhaust Mounting

Transverse mounted engines rock front-to-rear and longitudinal engines rock side-to-side. Each creates

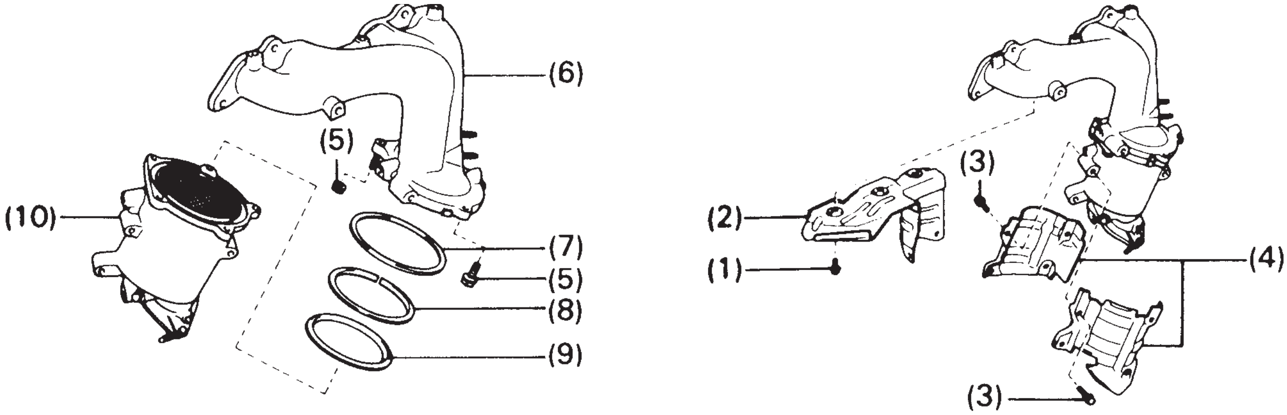


Figure 9–51 A cast-iron exhaust manifold (#6) and bolt-on catalytic converter (#10) use heat shields (#2, 3, 4) to protect adjoining components from high temperatures. The shields also allow the converter to retain much of its internal heat needed for proper operation. (Courtesy Toyota Canada Inc.)

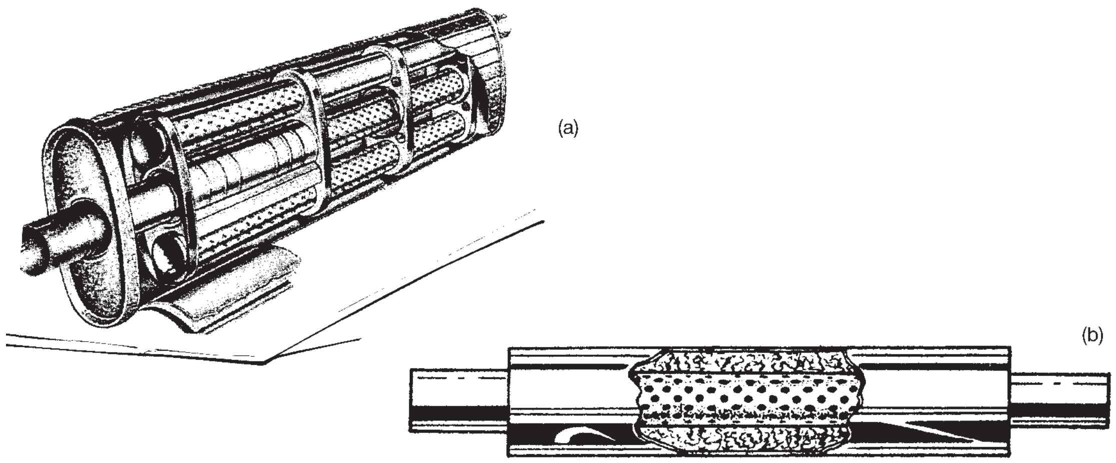


Figure 9–52 Muffler designs: (a) reverse-flow (b) straight-through. (McCord Manufacturing)

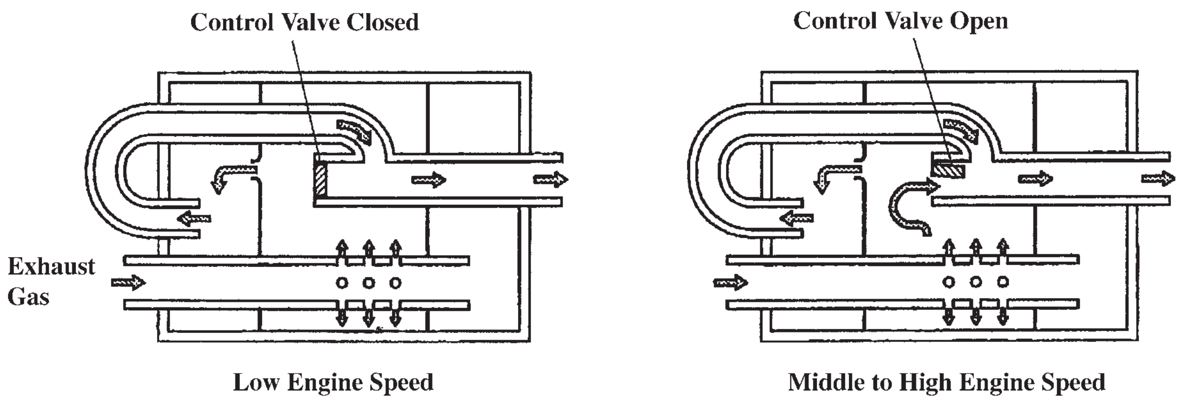


Figure 9–53 Schematic of a Toyota muffler with two-way exhaust control. The control valve, a spring-loaded damper, is closed at low engine speeds: exhaust noise is decreased. At higher engine speeds, the exhaust pressure overcomes spring pressure and the control valve opens, reducing system back pressure. (Courtesy Toyota Canada Inc.)

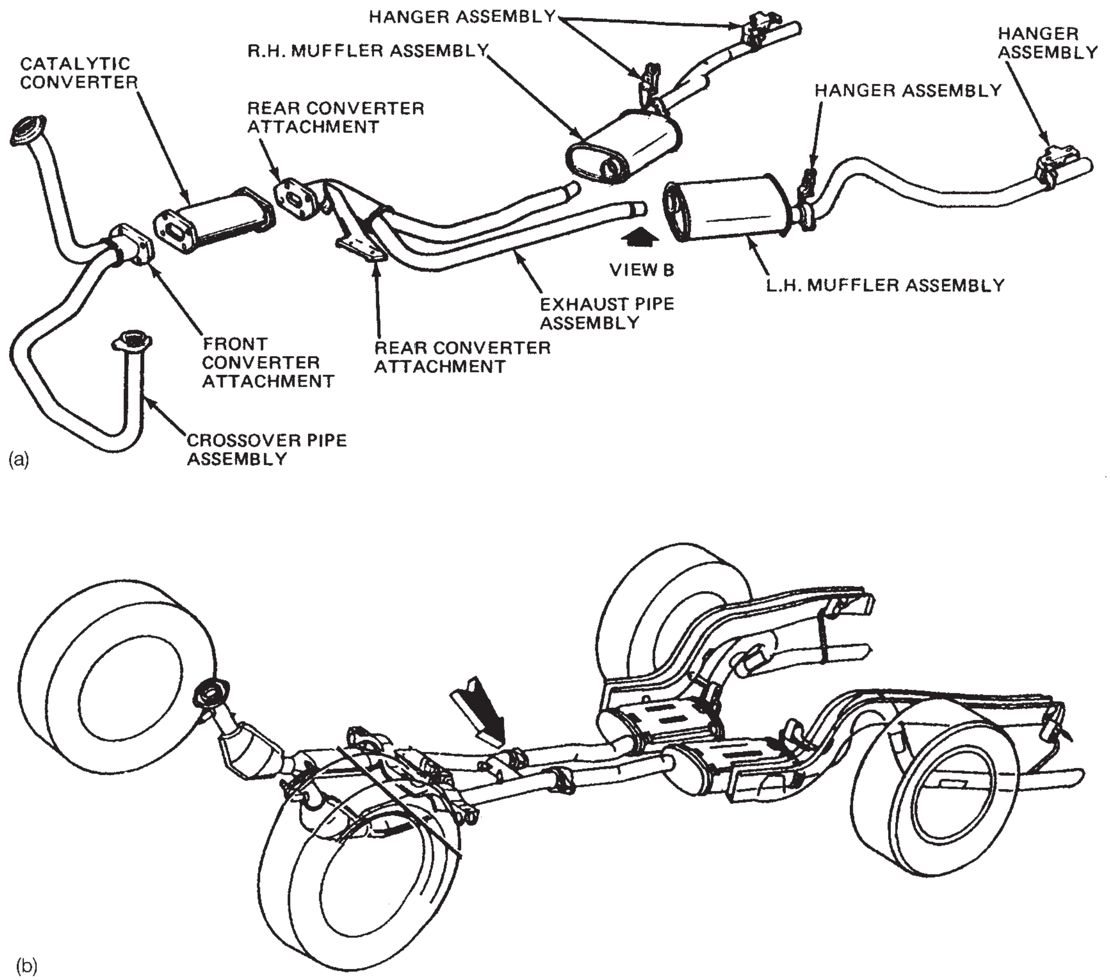


Figure 9–54 Two examples of a dual exhaust: (a) "cat" back system; (b) full length dual exhaust—note the equalizer tube between the front pipes. (Courtesy General Motors of Canada Ltd.; Ford Motor Co. of Canada Ltd.)

different stresses on the exhaust system. Transverse engines require ball-type joints, often spring loaded, or a flexible pipe to relieve pipe loading. Longitudinal engines absorb the twisting over a greater length and usually do not need flexible joints.

Exhaust systems are suspended from the chassis by high-temperature rubber straps, O-rings or "doughnuts" that insulate exhaust vibrations from the body. These mounts should be inspected for cracks or hardening whenever the vehicle is raised for service.

Exhaust Pipes

Most pipes are made of aluminized steel (a coating of aluminum on the inside and outside of the pipe) to resist corrosion. Pipes and mufflers do not burn out, they rust out internally from acids, water and contaminants created by engine combustion. These items last much longer when the system is equipped with a catalytic converter; the heat from the converter keeps moisture to a minimum.

Early vehicles joined the exhaust pipes and muffler with slip-joints and clamps. These are difficult to remove and usually require heat from a welding torch. Many recent vehicles use flanges that bolt together (with a gasket), making removal and replacement much easier.

Single and Dual Exhausts

Single exhaust systems are standard with most in-line and V-type engines. Dual exhausts are usually found on longitudinally mounted V-8s, either factory high-performance or installed aftermarket. Factory installed duals often have an equalizer pipe (joining the two head pipes) balancing the pressure between the two sides. See Figure 9–54.

SUMMARY

1. The camshaft rotates at one-half the crankshaft speed.
2. The pushrods should be rotating while the engine is running if the camshaft and lifters are okay.
3. On overhead valve pushrod engines, the camshaft is usually placed in the block above the crankshaft. The lobes of the camshaft are usually lubricated by splash lubrication.
4. Silent chains are quieter than roller chains but tend to stretch with use.
5. The lift of a cam is usually expressed in decimal inches and represents the distance that the valve is lifted off the valve seat.
6. In many engines, camshaft lift is transferred to the tip of the valve stem to open the valve by the use of a rocker arm or follower.
7. Pushrods transfer camshaft motion upward from the camshaft to the rocker arm.
8. Camshaft duration is the number of degrees of crankshaft rotation for which the valve is lifted off the seat.
9. Valve overlap is the number of crankshaft degrees for which both valves are open.
10. Camshafts should be installed according to the manufacturer's recommended procedures. Flat lifter camshafts should be thoroughly lubricated with extreme pressure lubricant.
11. If a new camshaft is installed, new lifters should also be installed.
12. Wet intake manifolds require heating (during cold operation) to vaporize the fuel.
13. Long intake runners improve low RPM cylinder filling.
14. Tubular stainless steel exhaust manifolds improve exhaust flow and decrease weight.
15. Some vehicles use a one-piece exhaust manifold-catalytic converter; being close to the engine heats the converter quickly and keeps it at a high temperature.

REVIEW QUESTIONS

1. Explain why the lift and duration of the camshaft determines the power characteristics of the engine.
2. Describe the operation of a hydraulic lifter.
3. Describe how to adjust hydraulic lifters.

RED SEAL CERTIFICATION-TYPE QUESTIONS

1. The camshaft makes _____ for every revolution of the crankshaft.
   - **a.** One-quarter revolution
   - **b.** One-half revolution
   - **c.** One revolution
   - **d.** Two revolutions
2. Valve lifters rotate during operation because of the _____ of the camshaft.
   - **a.** Taper of the lobe
   - **b.** Thrust plate
   - **c.** Chain tensioner
   - **d.** Bearings
3. Advancing the camshaft (SOHC) will result in ________________.
   - **a.** A rougher idle
   - **b.** Less low-speed torque
   - **c.** Better high-speed performance
   - **d.** More low-speed torque
4. Which timing chain type is also called a "silent chain"?
   - **a.** Roller
   - **b.** Double roller
   - **c.** Double belt
   - **d.** Morse
5. On an engine equipped with a timing belt, engine damage can occur if the engine is which design?
   - **a.** Freewheeling
   - **b.** Interference
6. Many technicians always use new pushrods because ____________________.
   - **a.** It is less expensive to buy than clean
   - **b.** All of the dirt cannot be cleaned out from the hollow centre
   - **c.** Pushrods wear at both ends
   - **d.** Pushrods shrink in length if removed from an engine
7. A DOHC V-6 has how many camshafts?
   - **a.** 4
   - **b.** 3
   - **c.** 2
   - **d.** 1
8. The intake valve opens at 39° BTDC and closes at 71° ABDC. The exhaust valve opens at 78° BBDC and closes at 47° ATDC. Which answer is correct?
   - **a.** Intake valve duration is 110°
   - **b.** Exhaust valve duration is 125°
   - **c.** Overlap is 86°
   - **d.** Overlap is 149°
9. Fuel injection systems that inject fuel into the cylinder head intake port may require heat at the throttle body to
   - **a.** Vaporize the incoming fuel
   - **b.** Stop throttle-plate icing
   - **c.** Cause turbulence in the intake runner
   - **d.** Stop the fuel from freezing at low temperatures
10. Mufflers on catalytic converter equipped vehicles last longer because
    - **a.** The converter reduces the exhaust volume
    - **b.** Converters require water to function
    - **c.** The heat from the converter reduces water in the muffler
    - **d.** They are made of high temperature steel compatible with the converter