CHAPTER 22

CYLINDER HEAD AND VALVE GUIDE SERVICE

OBJECTIVES

After studying Chapter 22, the reader will be able to:

1. Prepare for Engine Repair (A1) ASE certification test content area "B" (Cylinder Head and Valve Train Diagnosis and Repair).
2. Identify combustion chamber types.
3. Explain the operation of a stratified charge combustion chamber.
4. List the steps necessary to recondition a cylinder head.
5. Describe how to inspect and measure valve guides.
6. Discuss valve guide repair options.

KEY TERMS

Arithmetic Average Roughness Height (RA) (p. 384)
Bend (p. 383)
Bronze Guide Liners (p. 391)
Cam Tunnel (p. 384)
Cast-Iron Guides (p. 391)
Concentric (p. 387)
Cross Flow Head (p. 376)
Distortion (p. 383)
Fire Deck (p. 383)
Grinder (p. 384)
Microinch (p. 384)
Milling (p. 384)
Oversize (OS) Stems (p. 388)
Port (p. 378)
Porting (Relieving) (p. 378)
Quench Area (p. 375)
Root-Mean-Square (RMS) (p. 384)
Seasoned Engine (p. 383)
Siamese Port (p. 378)
Spiral Bronze Alloy Bushing (p. 391)
Squish Area (p. 375)
Surface-to-Volume Ratio (p. 375)
Thin-Walled Bronze Alloy Sleeve Bushing (p. 391)
Twist (p. 383)
Unshrouding (p. 376)
Valve Duration (p. 377)
Valve Guide Knurling (p. 389)
Valve Guides (p. 387)
Valve Seat Inserts (p. 387)
Valve Shrouding (p. 376)
Warpage (p. 383)

Cylinder heads are the most frequently serviced engine components. The highest temperatures and pressures in the entire engine are located in the combustion chamber. Its valves must open and close thousands of times each time the engine is operated.

CYLINDER HEADS

Cylinder heads support the valves and valve train as well as passages for the flow of intake and exhaust gases. In an overhead camshaft design engine, the cylinder head also supports all of the valve train components including the camshaft, rocker arms, or followers, as well as the intake and exhaust valves and valve guides. See Figure 22-1.

Most cylinder designs incorporate the following design factors to achieve fast burning of the air–fuel mixture and to reduce exhaust emissions. These factors include:

- **Squish area**—This is an area of the combustion chamber where the piston nearly contacts the cylinder. When the piston is moving upward toward the cylinder head, the air-fuel mixture is rapidly pushed out of the squish area, causing turbulence. Turbulence helps mix the air and fuel, ensuring a more uniform and complete combustion. See Figure 22-2.
- **Quench area**—The squish area can also be the quench area where the air–fuel mixture is cooled by the cylinder head, thereby helping to reduce detonation caused by the auto ignition of the end gases in the combustion chamber.

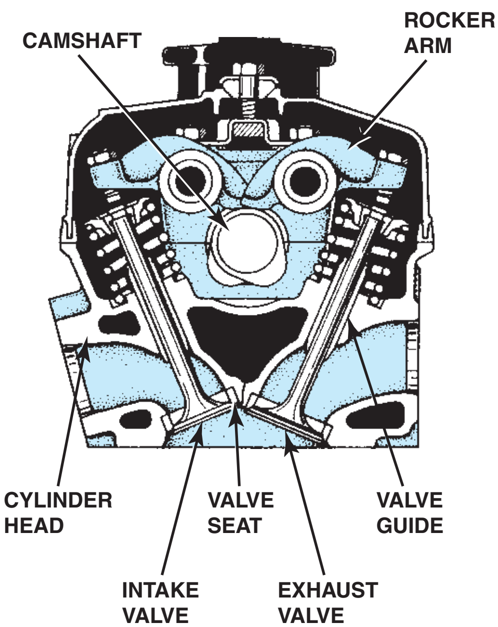


FIGURE 22-1 The seats and guides for the valves are in the cylinder head as well as the camshaft and the entire valve train if it is an overhead camshaft design.

- **Spark plug placement**—The best spark plug placement is the center of the combustion chamber. See Figure 22-3. The closer to the center, the shorter the flames travel to all edges of the combustion chamber, which also reduces abnormal combustion (ping or spark knock). While it is best to have the spark plug in the center, some combustion chamber designs do not allow this due to valve size, combustion chamber design, and valve placement. See Figure 22-4 for an example of a two spark plug combustion chamber used in a hemispherical (Hemi) cylinder head design.
- **Surface-to-volume ratio**—The surface-to-volume ratio is an important design consideration for combustion chambers. A typical surface-to-volume ratio is 7.5:1, which means the surface area of the combustion chamber divided by the volume is 7.5. If the ratio is too high, there is a lot of surface area where fuel can adhere, causing an increase in unburned hydrocarbon (HC) emissions. The cool cylinder head causes some of the air–fuel mixture to condense, causing a layer of liquid fuel on the surfaces of the combustion chamber. This layer of

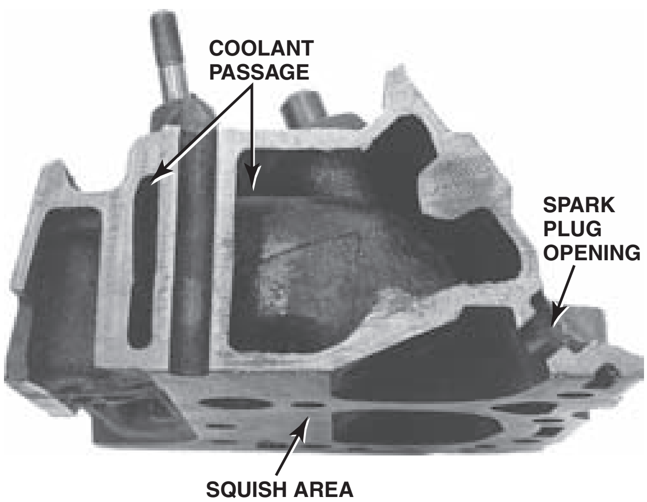


FIGURE 22-2 A wedge-shaped combustion chamber showing the squish area where the air–fuel mixture is squeezed, causing turbulence that pushes the mixture toward the spark plug.

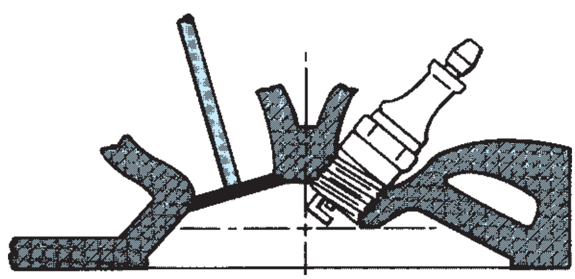


FIGURE 22-3 Locating the spark plug in the center of the combustion chamber reduces the distance the flame front must travel.

condensed fuel will not burn because it is not surrounded by oxygen needed for combustion. As a result, this unburned fuel is pushed out of the cylinder by the piston on the exhaust stroke.

FREQUENTLY ASKED QUESTION

WHAT IS CARBON KNOCK?

Carbon knock was a common occurrence in older engines that were equipped with carburetors and had high compression ratios. As carburetors aged, the mixture would tend to be richer-than-normal due to a leaking needle and seat, as well as a fuel-saturated float. This richer mixture would often cause carbon deposits to form in the combustion chamber. During light load conditions when the spark advance was greatest, a spark knock would occur, caused by a combination of the high compression ratio and the carbon deposits. This knocking was often very loud and sounded like a rod bearing noise. Many engines were disassembled in the belief that the cause of the knocking sound was a bearing, only to discover that the bearings were OK.

Carbon knock can still occur in newer engines, especially if there is a fault in the fuel system that would allow a much richer-than-normal air–fuel mixture, causing excessive carbon deposits to form in the combustion chamber. Often a decarbonization using chemicals will correct the knocking.

FIGURE 22-4 The combustion chamber of the 5.7 liter Chrysler Hemi cylinder head showing the two spark plugs used to ensure rapid burn for best power and economy with the lowest possible exhaust emissions.

- **Valve shrouding**—Shrouding means that the valve is kept close to the walls of the combustion chamber to help increase mixture turbulence. See Figure 22-5. While shrouding the intake valve can help swirl and increase turbulence, it also reduces the flow into the engine at higher engine speeds.
- **Cross flow valve placement**—Valve placement in the cylinder head is an important factor in breather efficiency. By placing the intake and the exhaust valves on the opposite sides of the combustion chamber, an easy path from the intake port through the combustion chamber to the exhaust port is provided. This is called a **cross flow head** design. See Figure 22-6.

TECH TIP

UNSHROUD THE INTAKE VALVE FOR MORE POWER

If an engine is being rebuilt for high performance, most experts recommend that the shrouded section around the intake valve be removed, thereby increasing the airflow and, therefore, the power that the engine can achieve, especially at higher engine speeds. This process is often called **unshrouding.**

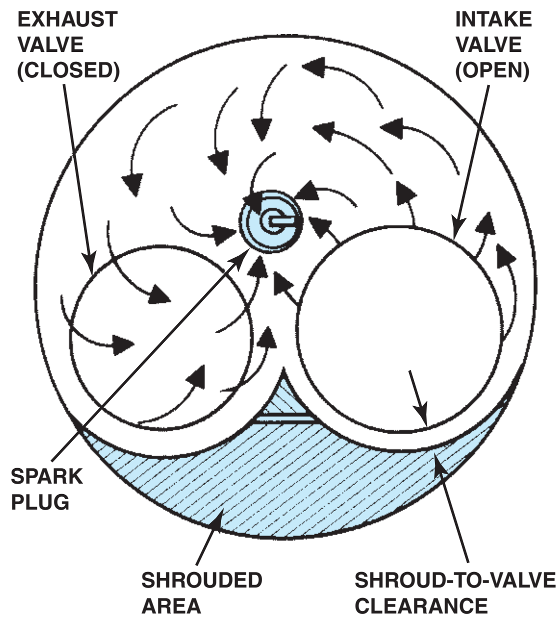


FIGURE 22-5 The shrouded area around the intake valve causes the intake mixture to swirl as it enters the combustion chamber.

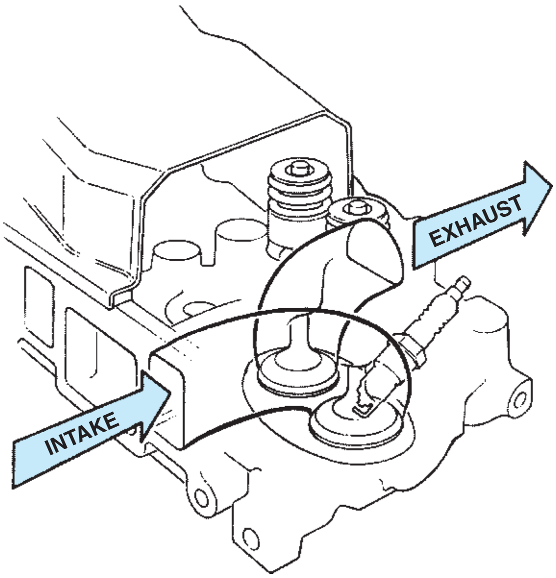


FIGURE 22-6 A typical cross flow cylinder head design where the flow into and out of the combustion chamber is from opposite sides of the cylinder head.

Combustion chambers can be cast or machined depending on the design and are referred to as polyspherical, hemi-wedge, kidney-shaped, or pentroof designs, depending on the shape.

MULTIPLE-VALVE COMBUSTION CHAMBER

The power that any engine produces is directly related to the amount of air–fuel mixture that is ignited in the cylinder. Increasing cylinder displacement is a common method of increasing engine power. Turbocharging and supercharging also increase engine power, but these increase engine cost as well.

Adding more than two valves per cylinder permits more gas to flow into and out of the engine with greater velocity without excessive valve duration. **Valve duration** is the number of degrees by which the crankshaft rotates when the valve is off the valve seat. Increased valve duration increases valve overlap. The valve overlap occurs when both valves are off their seats at the end of the exhaust stroke and at the beginning of the intake stroke. At lower engine speeds, the gases can move back and forth between the open valves. Therefore, the greater valve duration hurts low engine speed performance and driveability, but it allows for more air–fuel mixture to enter the engine for better high-speed power.

The maximum amount of gas moving through the opening area of a valve depends on the distance around the valve and the degree to which it lifts open. See Figure 22-7. The normal opening lift is about 25% of the valve head diameter. For example, if the intake valve is 2.00 inches in diameter, the normal

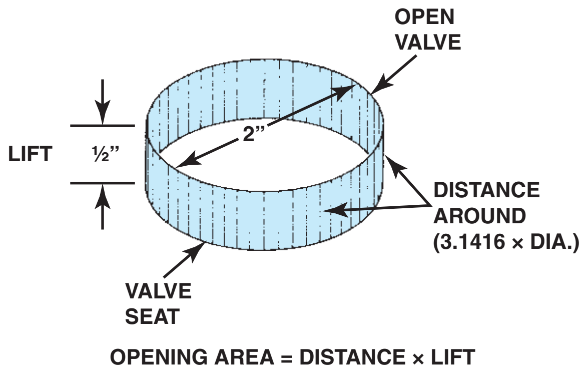


FIGURE 22-7 Method for measuring the valve opening space.

amount of lift off the seat (not cam lobe height) is 25% of 2.00 inches or 1/2 (0.500) inch. However, the amount of air–fuel mixture that can enter a cylinder depends on the total area around the valve and not just the amount of lift. The distance around a valve is calculated by the equation pi × *D* (3.1416 × valve diameter). See Figure 22-8.

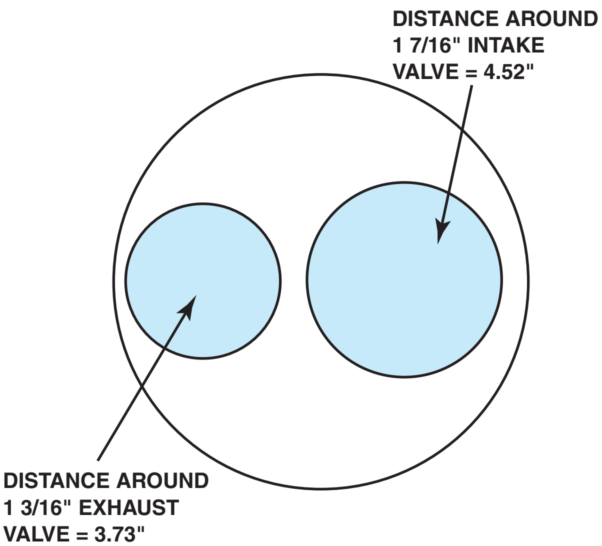
More total area under the valve is possible when two smaller valves are used rather than one larger valve at the same valve lift. The smaller valves allow smooth low-speed operation (because of increased velocity of the mixture as it enters the cylinder as a result of smaller intake ports). Good high-speed performance is also possible because of the increased valve area and lighter-weight valves. See Figure 22-9.

When four valves are used, either the combustion chamber has a pentroof design, with each pair of valves in line (Figure 22-10), or it is hemispherical, with each valve on its own axis. Four valves on the pentroof design will be operated with dual overhead camshafts or with single overhead

TECH TIP

HORSEPOWER IS AIRFLOW

To get more power from an engine, more air needs to be drawn into the combustion chamber. One way to achieve more airflow is to increase the valve and port size of the cylinder heads along with a change in camshaft lift and duration to match the cylinder heads. One popular, but expensive, method is to replace the stock cylinder heads with high-performance cast-iron or aluminum cylinder heads such as shown in Figure 22-11 on page 379. Some vehicle manufacturers such as Audi go to a great deal of expense to design high-flow rate cylinder heads by installing five valve cylinder heads on some of their high-performance engines. See Figure 22-12 on page 379.



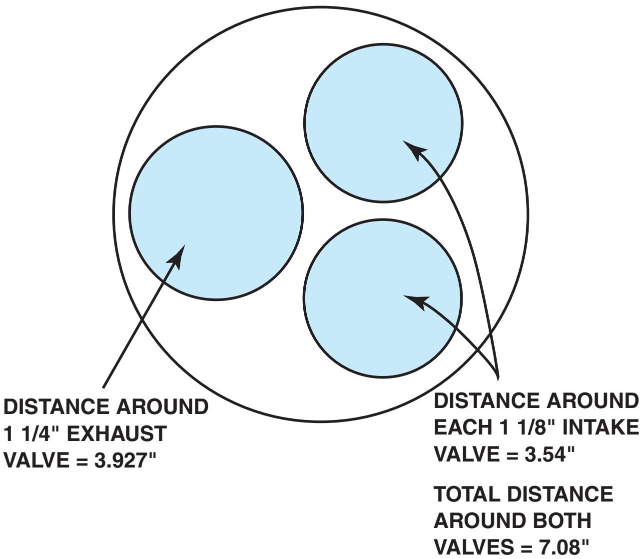


FIGURE 22-8 Comparing the valve opening areas between a two- and three-valve combustion chamber when the valves are open.

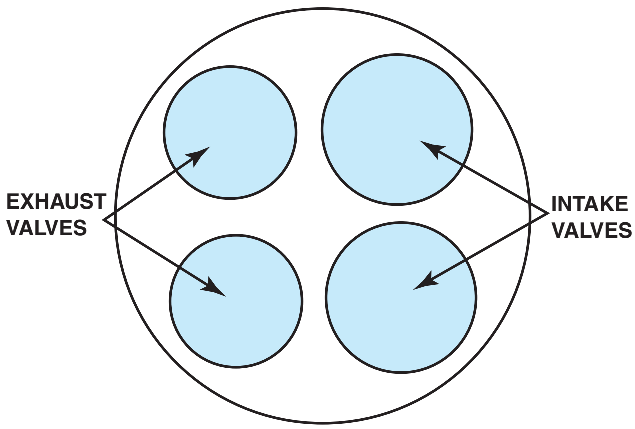


FIGURE 22-9 Typical four-valve head. The total area of opening of two small intake valves and two smaller exhaust valves is greater than the area of a two-valve head using much larger valves. The smaller valves also permit the use of smaller intake runners for better low-speed engine response.

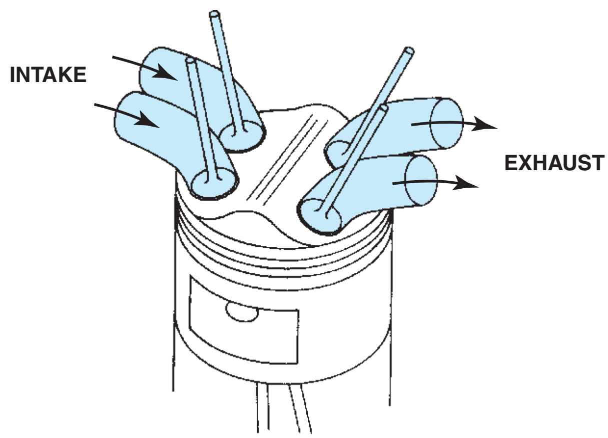


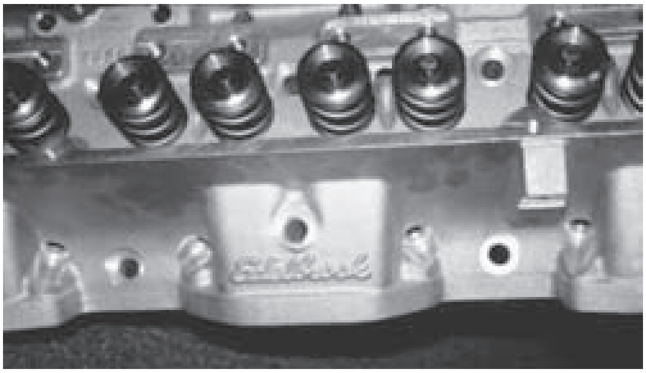
FIGURE 22-10 Four valves in a pentroof combustion chamber.

camshafts and rocker arms. When four valves are used, it is possible to place the spark plug at the center of the combustion chamber. This is the best spark plug location for fast-burning combustion.

INTAKE AND EXHAUST PORTS

The part of the intake or exhaust system passage that is cast in the cylinder head is called a **port.** Ports lead from the manifolds to the valves. The most desirable port shape is not always possible because of space requirements in the head. Space is required for the head bolt bosses, valve guides, cooling passages, and pushrod openings. Inline engines may have both intake and exhaust ports located on the same side of the engine. Often, two cylinders share the same port because of the restricted space available. Shared ports are called **Siamese ports.** See Figure 22-13. Each cylinder uses the port at a different time. Larger ports and better breathing are possible in engines that have the intake port on one side of the head and the exhaust port on the opposite side. Sometimes a restricting hump within a port may actually increase the airflow capacity of the port. See Figure 22-14. It does this by redirecting the flow to an area of the port that is large enough to handle the flow. Modifications in the field, such as **porting** or **relieving,** would result in restricting the flow of such a carefully designed port.

The intake port in a cylinder head designed for use with a carburetor or throttle-body-type fuel injection is relatively long,



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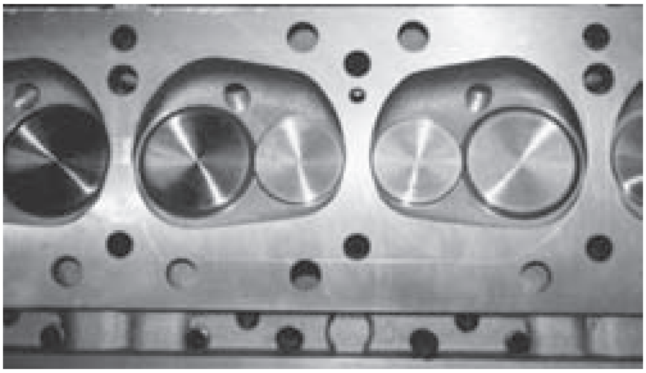

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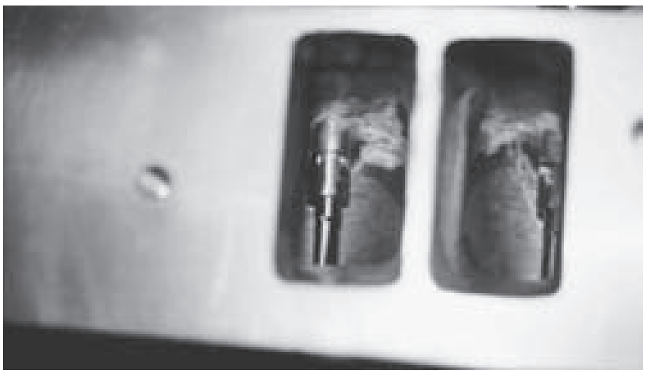


(c)

FIGURE 22-11 (a) A high-performance aftermarket aluminum cylinder head. (b) The valves are larger than the stock cast-iron cylinder head. (c) The ports are also straighter and larger than the stock cast-iron cylinder heads, requiring that a special intake manifold be used with these aluminum heads.

whereas the exhaust port is short. The long intake port wall is heated by coolant flowing through the head. The heat aids in vaporizing the fuel in the intake charge. The exhaust port is short so that the least amount of exhaust heat is transferred to the engine coolant. On engines designed for use with port fuel injection, the cylinder head ports are designed to help promote swirl in the combustion chamber, as shown in Figure 22-15.

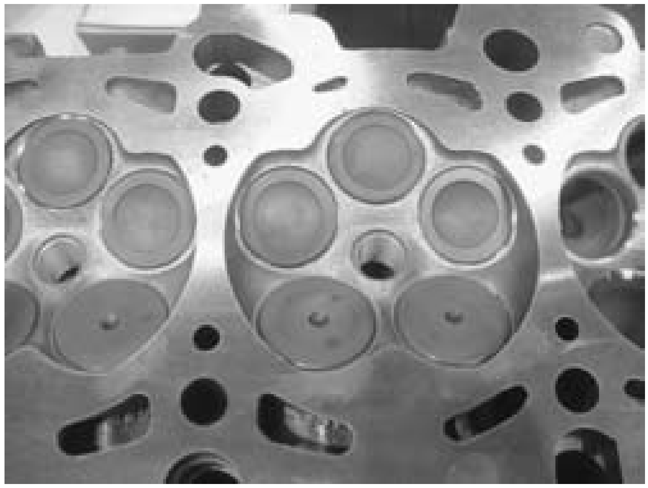


FIGURE 22-12 An Audi five-valve cylinder head, which uses three intake valves and two exhaust valves.

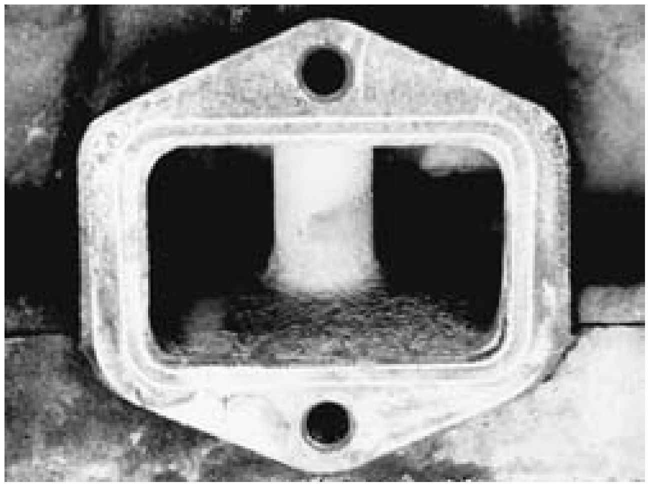


FIGURE 22-13 Close-up view of a Siamese exhaust port.

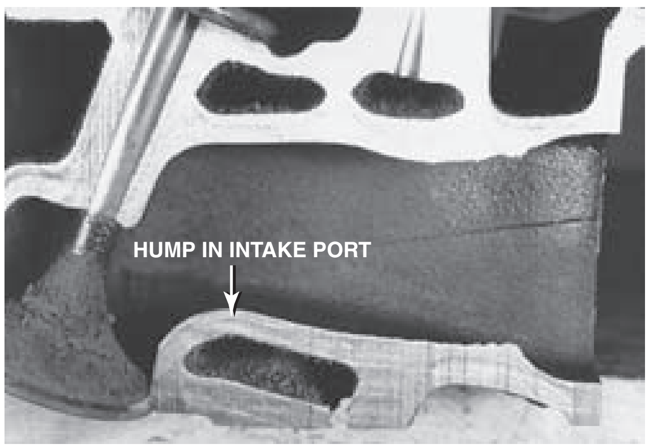


FIGURE 22-14 A hump in the intake port that actually increases the airflow capacity of the port.

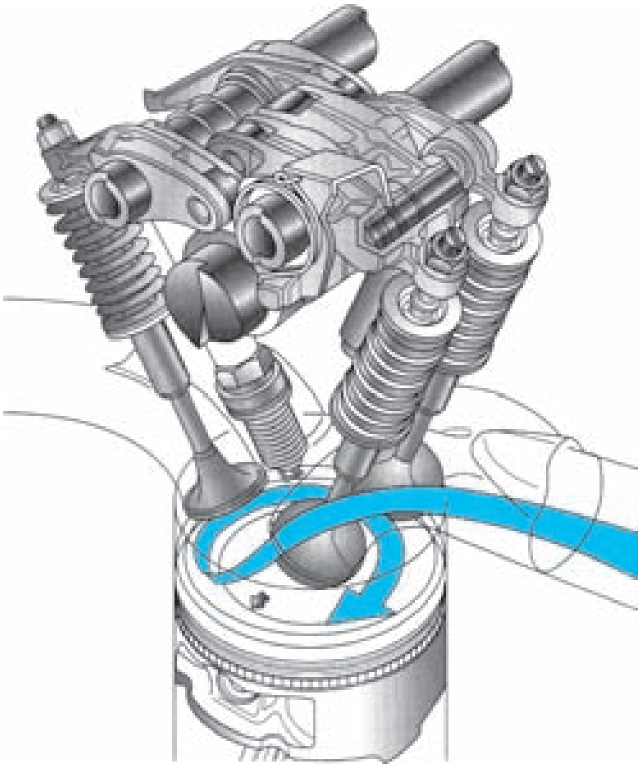


FIGURE 22-15 The intake manifold design and combustion chamber design both work together to cause the air–fuel mixture to swirl as it enters the combustion chamber.

TECH TIP

SNEAKY ACID PORTING

Some classifications of motor sports racing forbid any porting (enlarging) of the cylinder head ports.

If the cylinder head is ported using a grinder, the surface is smooth and does not resemble the as-cut appearance of a stock cylinder head, so some racers use acid to enlarge the ports of cast-iron cylinder heads. The appearance after the acid treatment is the same rough casting look of a completely stock cylinder head. See Figure 22-16. It just goes to show that the old saying may be right: "There are two types of racers—cheaters and losers."

FIGURE 22-16 The top cylinder head is stock and the bottom cylinder head has been ported using two different methods. The first inch from the gasket surface has been ground using a grinder to make the opening in the cylinder head match the intake manifold. The rest of the port between the valve and the gasket surfaces has been enlarged using acid. This acid treatment is a common "trick" used to increase the flow characteristics of a stock class cylinder head. The acid treatment gives the same rough cast-like surface as a completely stock cylinder head.

CYLINDER HEAD COOLANT PASSAGES

The engine is designed so that coolant will flow from the coolest portion of the engine to the warmest portion. The water pump takes the coolant from the radiator. The coolant is pumped into the block, where it is directed all around the cylinders. The coolant then flows upward through the gasket to the cooling passages cast into the cylinder head. The heated coolant is collected at a common point and returned to the radiator to be cooled and recycled.

NOTE: Reversed-flow cooling systems, such as that used on the Chevrolet LT1 V-8, send the coolant from the radiator to the cylinder heads first. This results in a cooler cylinder head and allows for more spark advance without engine-damaging detonation.

Typical coolant passages in a head are shown in Figure 22-17.

There are relatively large holes in the gasket surface of the head leading to the head cooling passages. The large holes are necessary to support the cooling passage core through these openings while the head is being cast. After casting, the core is broken up and removed through these same openings. Core support openings to the outside of the engine are closed with expansion plugs or soft plugs. These plugs are often mistakenly called freeze plugs. The openings between the head and the block are usually too large for the correct coolant flow. When the openings are too large, the head gasket performs an important coolant flow function. Special-size holes are made in the gasket. These holes correct the coolant flow rate at each opening. Therefore, it is important that the head gasket be installed correctly for proper engine cooling. A head gasket with special-size holes to cover the head openings is shown in Figure 22-18.

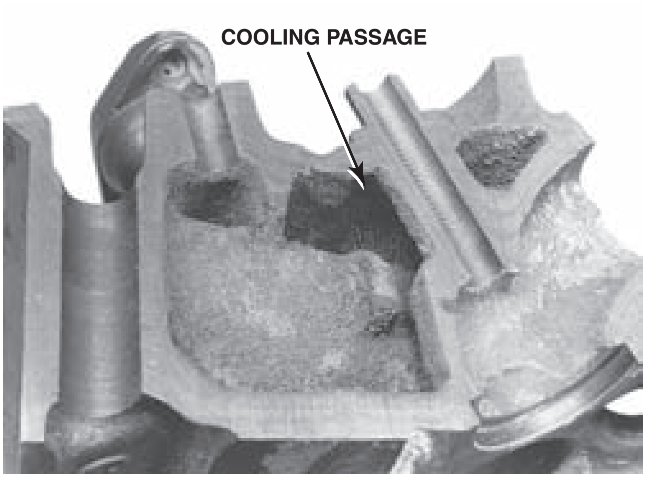
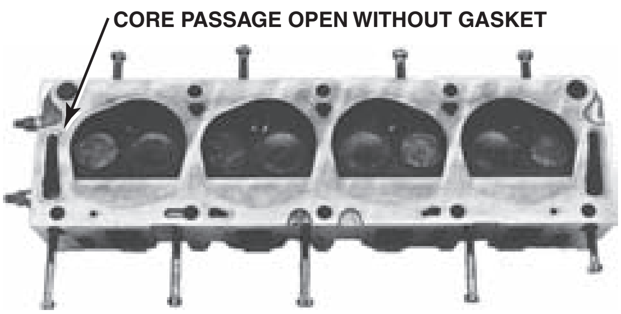
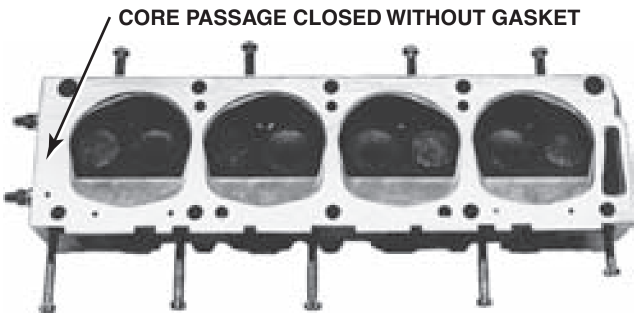


FIGURE 22-17 Coolant passages can be seen in this section of a cylinder head.



(a)



(b)

FIGURE 22-18 Coolant flow control. (a) Head core passages open without a gasket. (b) Gasket covering the left-hand core passage opening.

Carefully located openings, or deflectors, may be designed into the head. They direct the coolant toward a portion of the head where localized heat must be removed. Usually, this is in the area of the exhaust valve. Some of the deflectors are cast in the cooling passages.

LUBRICATING OVERHEAD VALVES

Lubricating oil is delivered to the overhead valve mechanism, either through the valve pushrods or through drilled passages in the head and block casting. There are special openings in the head gasket to allow the oil to pass between the block and head without leaking. After the oil passes through the valve mechanisms, it returns to the oil pan through oil return passages. Some engines have drilled oil return holes, but most engines have large cast holes that allow the oil to return freely to the engine oil pan. The cast holes are large and do not easily become plugged.

NOTE: **Many aluminum cylinder heads have smaller-than-normal drain-back holes. If an engine has excessive oil consumption, check the drain holes before removing the engine.**

REMOVING THE OVERHEAD CAMSHAFT

The overhead camshaft will have either one-piece bearings in a solid bearing support or split bearings and a bearing cap. When one-piece bearings are used, the valve springs will have to be compressed with a fixture or the finger follower will have to be removed before the camshaft can be pulled out endwise. When bearing caps are used, they should be loosened alternately so that bending loads are not placed on either the cam or bearing caps. See Figures 22-19 and 22-20.

DISASSEMBLY OF THE CYLINDER HEAD

As discussed in Chapter 21, the cylinder head should be disassembled, cleaned, and checked for cracks or damage before performing any service work. See Figure 22-21. Many aluminum cylinder heads, especially those with overhead camshafts and multiple valves, require special valve spring compressors. Cleaning an aluminum head should only be done with tools and procedures that will not harm the cylinder head or gasket surface. Use a wooden or plastic scraper to remove old gaskets (never use a metal scraper to avoid nicking or damaging aluminum cylinder head surfaces).

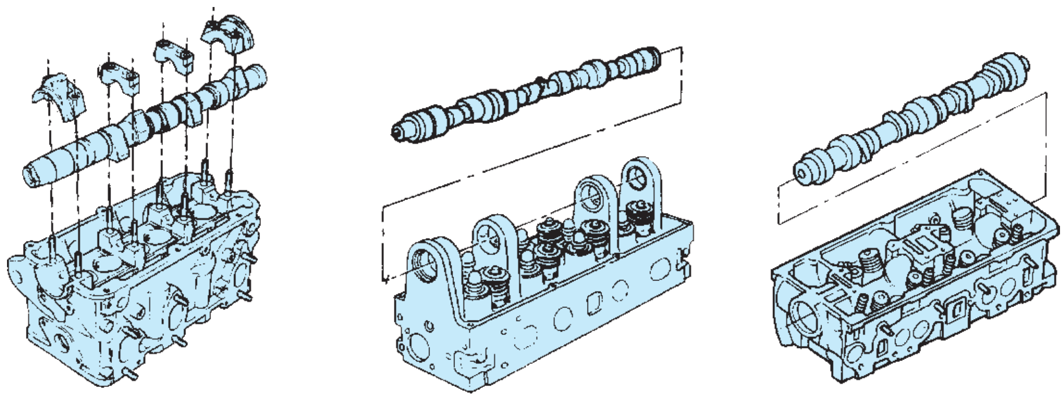


FIGURE 22-19 Overhead camshafts may be held in place with (a) bearing caps, (b) supported by towers, or (c) fitted into bearing bores machined directly into the head.

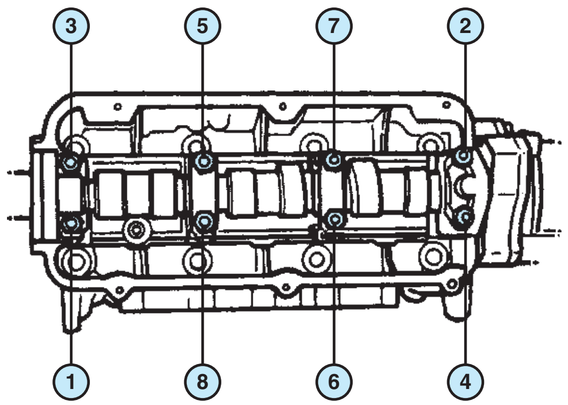


FIGURE 22-20 Always follow the specified loosening sequence to prevent valve spring tension from bending the camshaft.

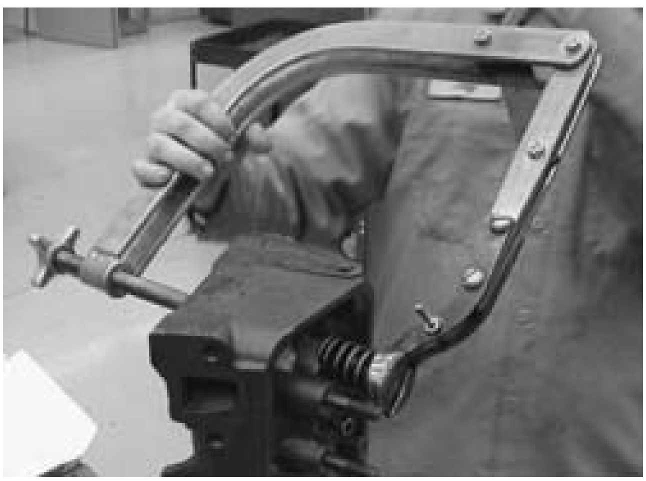


FIGURE 22-21 A valve spring compressor being used to compress the valve springs so the valve locks (keepers) can be removed and the valve removed from the cylinder head.

CYLINDER HEAD RECONDITIONING SEQUENCE

Although not all cylinder heads require all service operations, cylinder heads should be reconditioned using the following sequence.

1. Disassemble and thoroughly clean the heads (see Chapter 21).
2. Check for cracks and repair as necessary (see Chapter 21).
3. Check the surface that contacts the engine block and machine, if necessary.
4. Check valve guides and replace or service, as necessary.
5. Grind valves and reinstall them in the cylinder head with new valve stem seals (see Chapter 17).

CYLINDER HEAD RESURFACING

All valve train components that are to be reused must be kept together. As wear occurs, parts become worn together. Pushrods can be kept labeled if stuck through a cardboard box, as shown in Figure 22-22. Be sure to keep the top part of the pushrod at the top. Intake and exhaust valve springs are different and must be kept with the correct valve.

The surface must be thoroughly cleaned and inspected as follows:

Step 1 After removing the old gasket material, use a file and draw it across the surface of the head to remove any small burrs. See Figure 22-23.

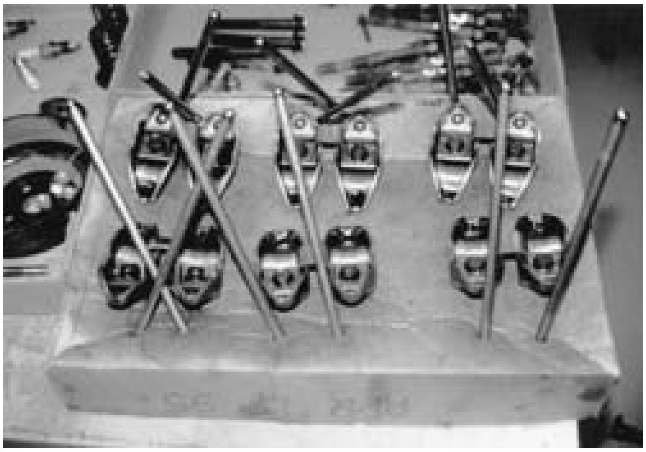


FIGURE 22-22 Individual parts become worn together; therefore, cardboard is a crude but effective material to use to keep all valve train parts together and labeled exactly as they came from the engine.

FIGURE 22-23 After scraping the gasket surface with a scraper, use a file and draw across the surface. When a file is drawn across the head sideways, little (if any) material is removed, but burrs and other surface imperfections are removed or highlighted.

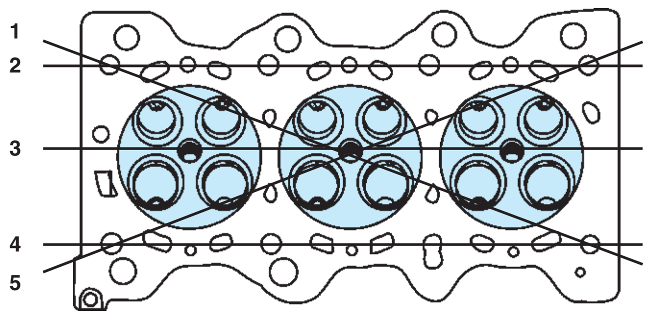


FIGURE 22-24 Cylinder heads should be checked in five planes for warpage, distortion, bend, or twist.

FREQUENTLY ASKED QUESTION

WHAT IS A SEASONED ENGINE?

A new engine is machined and assembled within a few hours after the heads and block are cast from melted iron. Newly cast parts have internal stresses within the metal. The stress results from the different thickness of the metal sections in the head. Forces from combustion in the engine, plus continued heating and cooling, gradually relieve these stresses. By the time the engine has accumulated 20,000 to 30,000 miles (32,000 to 48,000 kilometers), the stresses have been completely relieved. This is why some engine rebuilders prefer to work with used heads and blocks that are stress relieved. Used engines are often called **seasoned** because of the reduced stress and movement these components have as compared with new parts. The head will usually have some warpage when the engine is disassembled.

Step 2 The head should be checked in five planes, as shown in Figure 22-24. Checking the cylinder head gasket surface in five planes checks the head for **warpage, distortion, bend,** and **twist.**

These defects are determined by trying to slide a 0.004-inch (0.10-millimeter) feeler gauge under a straightedge held against the head surface.

NOTE: The cylinder head surface that mates with the top deck of the block is often called the fire deck.

The head should not vary by over 0.002 inch (0.05 millimeter) in any 6-inch (15-centimeter) length, or by more than 0.004 inch overall. Always check the manufacturer's recommended specifications.

NOTE: Always check the cylinder head thickness and specifications to be sure that material can be safely removed from the surface. Some manufacturers do not recommend *any* machining, but rather require cylinder head replacement if cylinder head surface flatness is not within specifications.

ALUMINUM CYLINDER HEAD STRAIGHTENING

Aluminum expands at about twice the rate of cast iron when heated. Aluminum cylinder heads used on cast-iron blocks can warp and/or crack if they are overheated. The expanding cylinder head first hits the head bolts. Further expansion of the head causes the head to expand upward and bow in the center. If a warped (bowed) cylinder head is resurfaced, the stresses of expansion are still present, and if the cylinder head uses an overhead camshaft, further problems exist. With a D-shape cylinder head (see Figure 22-25), the camshaft centerline bearing supports must also be restored. To restore the straightness of the cam-bearing bore (sometimes called the **cam tunnel**), align boring and/or honing may be necessary.

The best approach to restore a warped aluminum cylinder head (especially an overhead camshaft head) is to relieve the stress that has caused the warpage *and* to straighten the head before machining.

Step 1 Determine the amount of warpage with a straightedge and thickness (feeler) gauge. Cut shim stock (thin strips of metal) to one-half of the amount of the warpage. Place shims of this thickness under each end of the head.

Step 2 Tighten the center of the cylinder head down on a strong, flat base. A 2-inch-thick piece of steel that is 8 inches wide by 20 inches long makes a good support for the gasket surface of the cylinder head (use antiseize compound on the bolt thread to help in bolt removal).

Step 3 Place the head and base in an oven for 5 hours at 500°F (260°C). Turn the oven off and leave the assembly in the oven.

NOTE: If the temperature is too high, the valve seat inserts may fall out of the head! At 500°F, a typical valve seat will still be held into the aluminum head with a 0.002-inch interference fit based on calculations of thermal expansion of the aluminum head and steel insert.

Allow the head to cool in the oven for 4 or 5 hours to relieve any stress in the aluminum from the heating process. For best results, the cooling process should be allowed to occur overnight. Several cylinder heads can be "cooked" together.

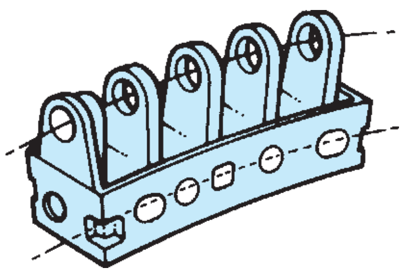


FIGURE 22-25 Warped overhead camshaft cylinder head. If the gasket surface is machined to be flat, the camshaft bearings will still not be in proper alignment. The solution is to straighten the cylinder head or to align bore the cam tunnel.

If the cylinder head is still warped, the heating and cooling process can be repeated. After the head is straightened and the stress relieved, the gasket surface (fire deck) can be machined in the usual manner. To prevent possible camshaft bore misalignment problems, do not machine more than 0.010 to 0.015 inch (0.25 to 0.38 millimeter) from the head gasket surface.

RESURFACING METHODS

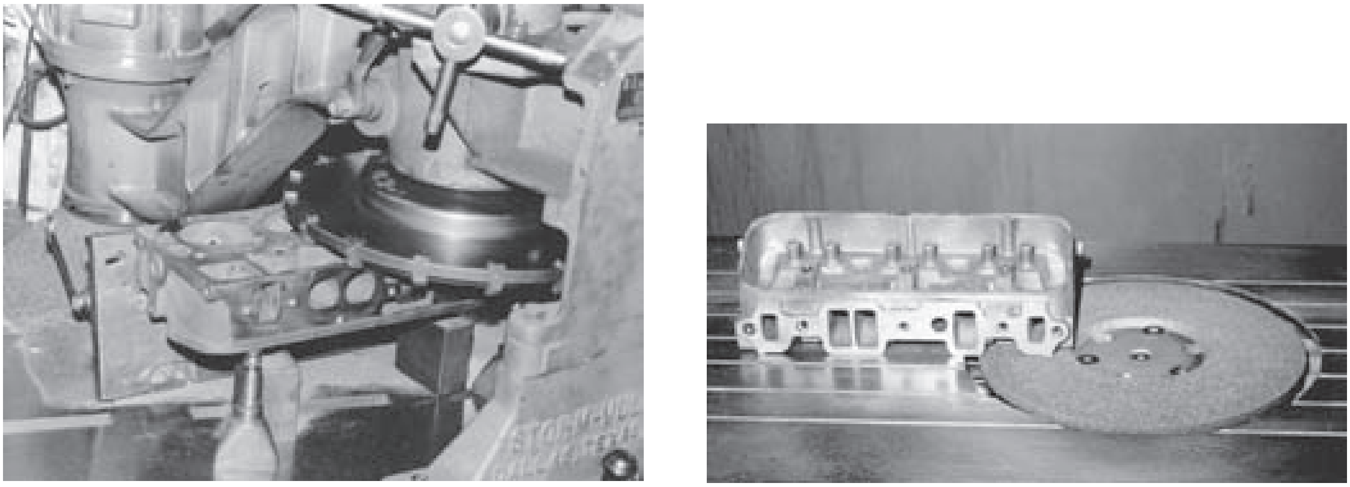
Two common resurfacing methods are used: milling and grinding. A **milling** type of resurfacer uses metal-cutting tool bits fastened in a disk. The disk is the rotating work head of the mill. This can be seen in Figure 22-26. The surface **grinder** type uses a large-diameter abrasive wheel. Both types of resurfacing can be done with table-type and with precision-type surfacers. With a table-type surfacer, the head or block is passed over the cutting head that extends slightly above a worktable. The abrasive wheel is dressed before grinding begins. The wheel head is adjusted to just touch the surface. At this point, the feed is calibrated to zero. This is necessary so that the operator knows exactly the size of the cut being made. Light cuts are taken. The abrasive wheel cuts are limited to 0.005 inch (0.015 millimeter). The abrasive wheel surface should be wire brushed after each five passes, and the wheel should be redressed after grinding each 0.100 inch (2.50 millimeters). The mill-type cutting wheel can remove up to 0.030 inch (0.075 millimeter) on each pass. A special mill-cutting tool or a dull grinding wheel is used when aluminum heads are being resurfaced.

NOTE: Resurfacing the cylinder head changes the compression ratio of the engine by about 1/10 point per 0.010 inch of removed material. For example, the compression ratio would be increased from 9.0:1 to 9.2:1 if 0.020 inch were removed from a typical cylinder head.

SURFACE FINISH

The surface finish of a reconditioned part is as important as the size of the part. Surface finish is measured in units called **microinches** (abbreviated **μ in**). The symbol in front of the inch abbreviation is the Greek letter *mu.* One microinch equals 0.000001 inch [0.025 micrometer (μ m)]. The finish classification in microinches gives the distance between the highest peak and the deepest valley. The usual method of expressing surface finish is by the **arithmetic average roughness height (RA),** that is, the average of the distances of all peaks and valleys from the mean (average) line. Surface finish is measured using a machine with a diamond stylus. See Figures 22-27 and 22-28.

Another classification of surface finish, which is becoming obsolete, is called the **root-mean-square (RMS).** The



(a) (b)

FIGURE 22-26 (a) Milling-type resurfacer machining the gasket surface of a cylinder head. (b) Grinder-type resurfacer.

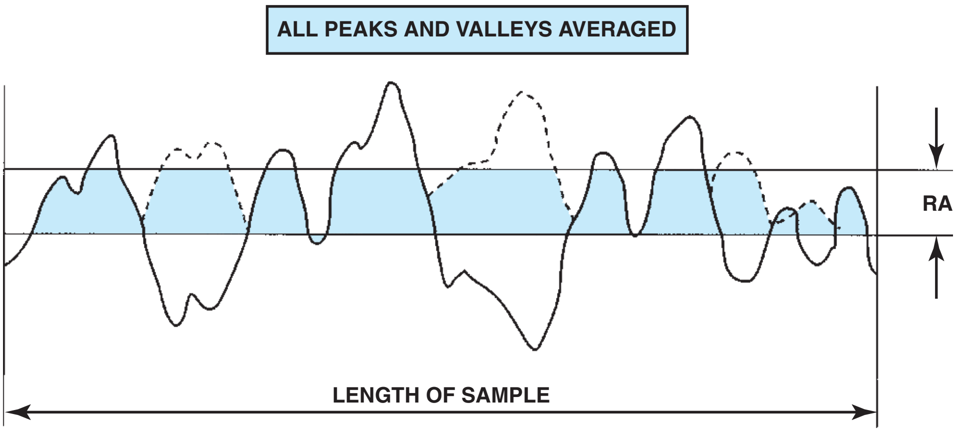


FIGURE 22-27 A graph showing a typical rough surface as would be viewed through a magnifying glass. RA is an abbreviation indicating the average height of all peaks and valleys.

FIGURE 22-28 A commercially available surface finish comparator is often used to judge the surface finish without the expense of an expensive electronic tester.

RMS is a slightly higher number and can be obtained by multiplying RA × 1.11.

Typical surface finish roughness recommendations for cast-iron and aluminum cylinder heads and blocks include the following:

Cast Iron

Maximum:	110 RA (125 RMS) (Rough surfaces can limit gasket movement and conformity.)
Minimum:	30 RA (33 RMS) (Smoother surfaces increase the tendency of the gasket to flow and *reduce* gasket sealing ability.)
Recommended range:	60 to 100 RA (65 to 110 RMS)

Aluminum

Maximum:	60 RA (65 RMS)
Minimum:	30 RA (33 RMS)
Recommended range:	50 to 60 RA (55 to 65 RMS)

The rougher the surface is, the higher the microinch finish measurement will be.

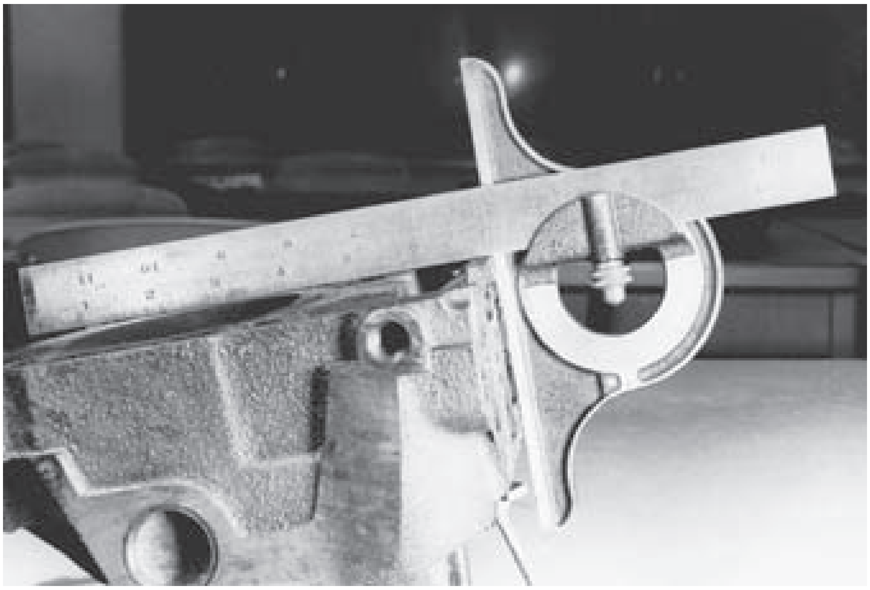
Typical preferred microinch finish standards for other engine components include the following:

Crank and rod journal: 10 to 14 RA (12 to 15 RMS)
Honed cylinder: 18 to 32 RA (20 to 35 RMS)
Connecting rod big end: 45 to 72 RA (50 to 80 RMS)

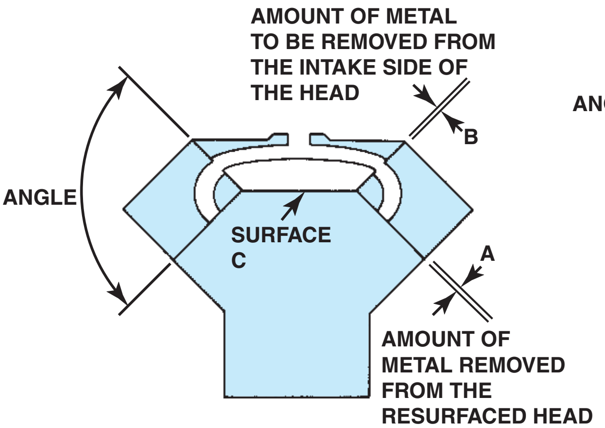
CORRECTING INTAKE MANIFOLD ALIGNMENT

The intake manifold of a V-type engine may no longer fit correctly after the gasket surfaces of the heads are ground. The ports and the assembly bolt holes may no longer match. The intake manifold surface must be resurfaced to remove enough metal to rematch the ports and bolt holes. The amount of metal that must be removed depends on the angle between the head gasket surface and the intake manifold gasket surface. Figure 22-29 shows how this is calculated. Automotive machine shops doing head resurfacing have tables that specify the exact amount of metal to be removed. It is usually necessary to remove some metal from both the front and the back gasket surface of closed-type intake manifolds used on V-type engines. This is necessary to provide a good gasket seal that will prevent oil leakage from the lifter valley.

CAUTION: Do not remove any more material than is necessary to restore a flat cylinder head-to-block surface. Some manufacturers limit *total* material that can be removed from the block deck and cylinder head to 0.008 inch (0.2 millimeter). Removal of material from the cylinder head of an overhead camshaft engine shortens the distance between the camshaft and the crankshaft. This causes the valve timing to be *retarded* unless a special copper spacer shim is placed between the block deck and the gasket to restore proper crankshaft-to-camshaft centerline dimension.



(a)



ANGLE	AMOUNT TO BE REMOVED FROM B
90°	A × 1.000
85°	A × 1.100
80°	A × 1.233
75°	A × 1.414
70°	A × 1.673
65°	A × 2.067
60°	A × 2.733

(b)

FIGURE 22-29 (a) Measuring the angle between the intake manifold and the head gasket surface. (b) The material that must be removed for a good manifold fit.

VALVE GUIDES

The valve guide supports the valve stem so that the valve face will remain perfectly centered, or **concentric,** with the valve seat. The valve guide is generally **integral** with the head casting in cast-iron heads for better heat transfer and for lower manufacturing costs. **Valve guides** and **valve seat inserts** are always used in aluminum heads. See Figure 22-30.

No matter how good the valves or seats are, they cannot operate properly if the valve guide is not accurate. In use, the valve operating mechanism pushes the valve tip sideways. This is the major cause of valve stem and guide wear. The valve normally rotates a little each time it is opened to keep wear even all around the stem. The valve guide, however, always has the wear in the same place. This causes both the top and bottom ends of the guide to wear until the guide has bell-mouth shapes at both ends. See Figure 22-31.

VALVE STEM-TO-GUIDE CLEARANCE

Engine manufacturers usually recommend the following valve stem-to-valve guide clearances.

- Intake valve: 0.001 to 0.003 inch (0.025 to 0.076 millimeter)
- Exhaust valve: 0.002 to 0.004 inch (0.05 to 0.10 millimeter)

Be sure to check the exact specifications for the engine being serviced. The exhaust valve clearance is greater than the intake valve clearance because the exhaust valve runs hotter and therefore expands more than the intake valve.

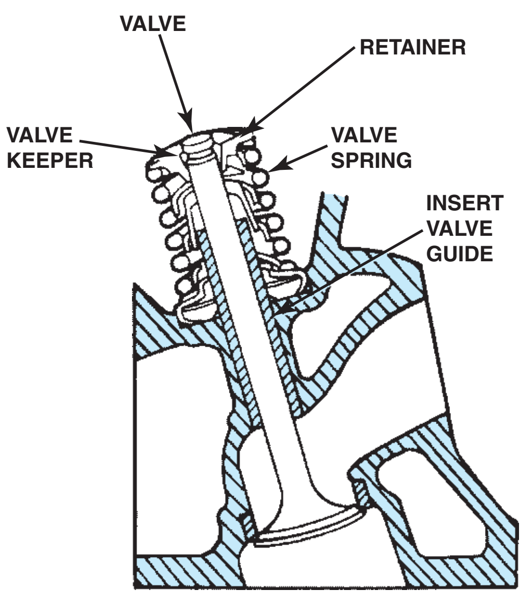


FIGURE 22-30 Insert valve guides are removable tubes driven into the head. Integral valve guides are part of the head casting.

Excessive valve stem-to-guide clearance can cause excessive oil consumption. The intake valve guide is exposed to manifold vacuum that can draw oil from the top of the cylinder head down into the combustion chamber. In this situation, valves can also run hotter than usual because much of the heat in the valve is transferred to the cylinder head through the valve guide.

NOTE: **A human hair is about 0.002 inch (0.05 millimeter) in diameter. Therefore, the typical clearance between a valve stem and the valve guide is only the thickness of a human hair.**

TECH TIP

THE POTATO CHIP PROBLEM

Most cylinder heads are warped or twisted in the shape of a typical potato chip (high at the ends and dipped in the center). After a cylinder head is ground, the surface *should* be perfectly flat. A common problem involves grinding the cylinder head in both directions while it is being held on the table that moves to the left and right. Most grinders are angled by about 4 degrees. The lower part of the stone should be the cutting edge. If grinding occurs along the angled part of the stone, then too much heat is generated. This heat warps the head (or block) upward in the middle. The stone then removes this material, and the end result is a slight (about 0.0015 inch) depression in the center of the finished surface. To help prevent this from happening, always feed the grinder in the forward direction only (especially during removal of the last 0.003 inch of material).

FIGURE 22-31 Valve guides often wear to a bell-mouth shape to both ends due to the forces exerted on the valve by the valve train components.

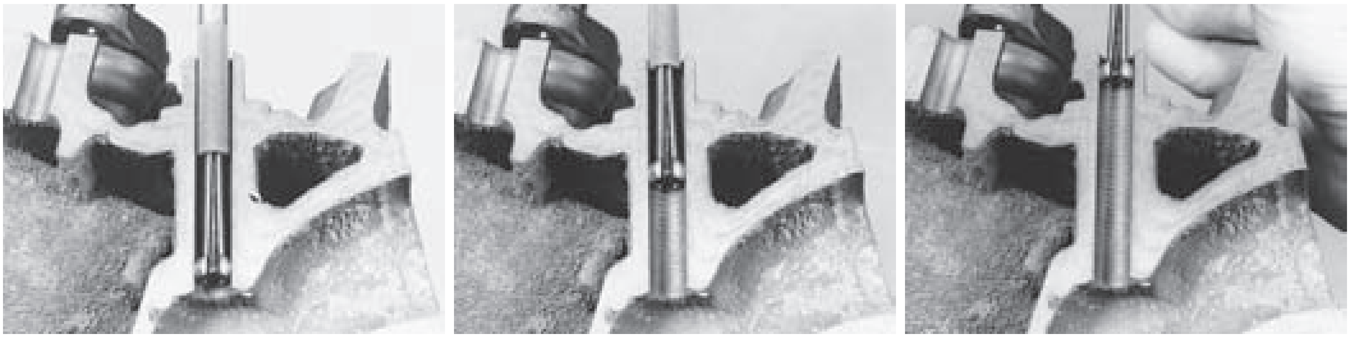
MEASURING VALVE GUIDES FOR WEAR

Valves should be measured for stem wear before valve guides are measured. The valve guide is measured in the middle with a small-hole gauge. The gauge size is checked with a micrometer. The guide is then checked at each end. This is shown using a cut-away valve guide in Figure 22-32. The expanded part of the ball should be placed crosswise to the engine where the greatest amount of valve guide wear exists. The dimension of the valve stem diameter is subtracted from the dimension of the valve guide diameter. If the clearance exceeds the specified clearance, then the valve guide will have to be reconditioned.

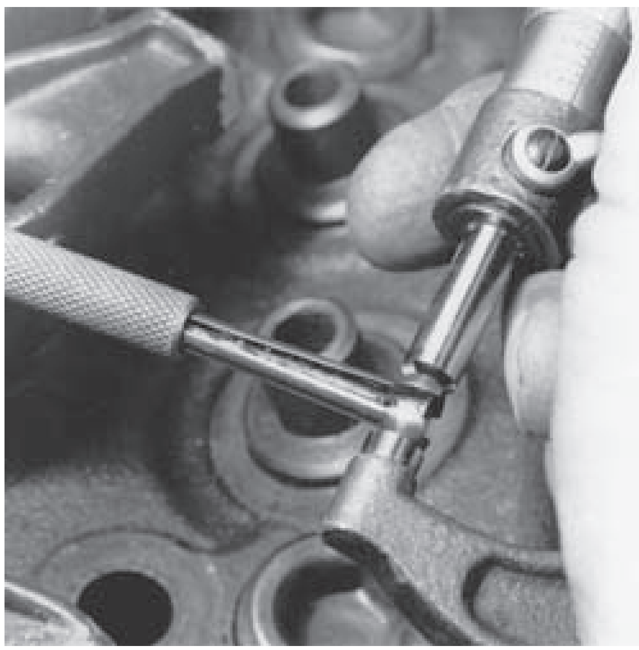
Valve stem-to-guide clearance can also be checked using a dial indicator (gauge) to measure the amount of movement of the valve when lifted off the valve seat. See Figure 22-33. The valve stem should also be measured as shown in Figure 22-34.

OVERSIZE STEM VALVES

Most domestic automobile manufacturers that have integral valve guides in their engines recommend reaming worn valve guides and installing new valves with **oversize (OS) stems.** When a valve guide is worn, the valve stem is also likely to be worn. In this case, new valves are required. If new valves are used, they can just as well have oversize stems as standard stems. Typically, available sizes include 0.003, 0.005, 0.015, and 0.030 inch OS. The valve guide is reamed or honed to the correct size to fit the oversize stem of the new valve. Figure 22-35 shows a reamer in a valve guide. The resulting clearance of the valve stem in the guide is the same as the original clearance. The oil clearance and the heat transfer properties of the original valve and guide are not changed when new valves with oversize stems are installed.



(a) (b) (c)



(d)

FIGURE 22-32 (a), (b), and (c) A cutaway head is used to show how a small-hole gauge is used to measure the taper and wear of a valve guide. (d) After it is adjusted to the valve guide size, the small-hole gauge is measured with an outside micrometer.

TECH TIP

TIGHT IS NOT ALWAYS RIGHT

Many engine manufacturers specify a valve stem-to-valve guide clearance of 0.001 to 0.003 inch (0.025 to 0.076 millimeter). However, some vehicles, especially those equipped with aluminum cylinder heads, may specify a much greater clearance. For example, many Chrysler 2.2-liter and 2.5-liter engines have a specified valve stem-to-valve guide clearance of 0.003 to 0.005 inch (0.076 to 0.127 millimeter). This amount of clearance feels loose to those technicians accustomed to normal valve stem clearance specifications. While this large amount of clearance may seem excessive, remember that the valve stem increases in diameter as the engine warms up. Therefore, the *operating* clearance is smaller than the clearance measured at room temperature. Always double-check factory specifications before replacing a valve guide for excessive wear.

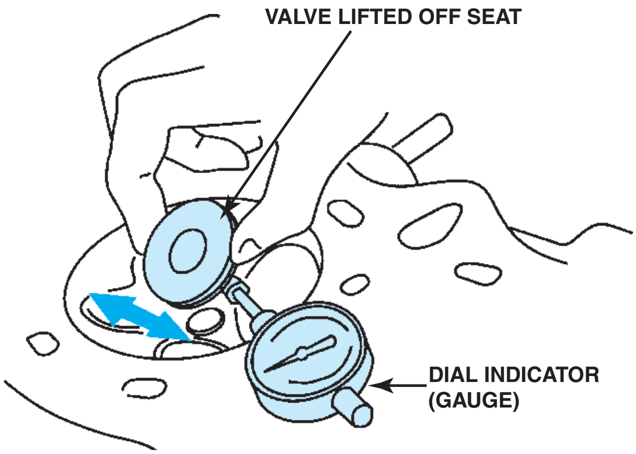


FIGURE 22-33 Measuring valve guide-to-stem clearance with a dial indicator while rocking the stem in the direction of normal thrust. The reading on the dial indicator should be compared with specifications, because it does not give the guide-to-stem clearance directly. The usual conversion factor is to record the reading on the dial indicator and divide by 2 to obtain the valve guide clearance. The valve is usually lifted off its seat to its maximum operating lift.

NOTE: **Many remanufacturers of cylinder heads use oversize valve stems to simplify production.**

FIGURE 22-34 Using a vernier dial caliper to measure the valve stem diameter of a valve. Subtract the diameter of the valve stem from the inside diameter of the valve guide to determine the valve guide clearance.

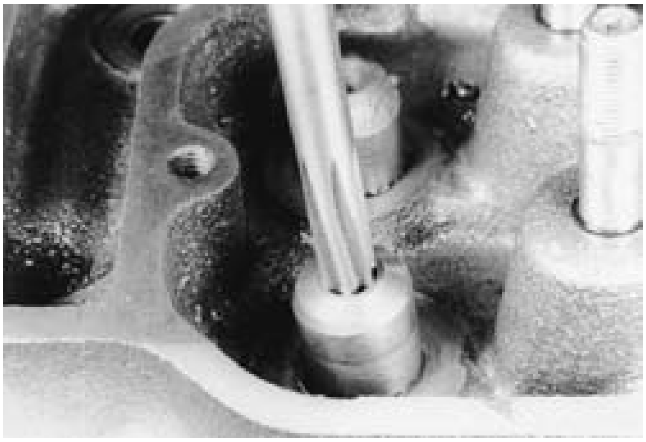


FIGURE 22-35 Reaming a valve guide to be oversize. This permits the use of new valves with oversize stem diameters. Many remanufacturers use this method to save the money and time involved in replacing or knurling valve guides and grinding old valves.

VALVE GUIDE KNURLING

In the process known as **valve guide knurling,** a tool is rotated as it is driven into the guide. The tool *displaces* the metal to reduce the hole diameter of the guide. Knurling is ideally suited to engines with integral valve guides (guides that are part of the cylinder head and are nonremovable). It is recommended that knurling not be used to correct wear exceeding

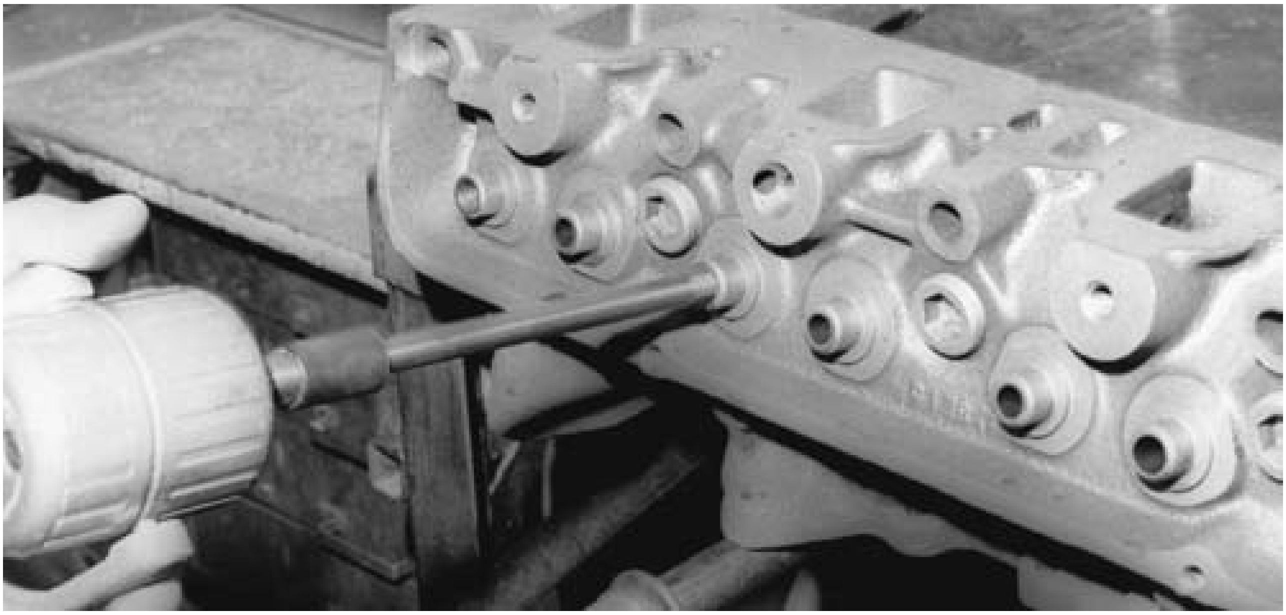


FIGURE 22-36 Knurling tool being used in a valve guide. After the knurling tool displaces the metal inside the guide, a reamer is run through the guide to produce a restored, serviceable valve guide.

0.006 inch (0.15 millimeter). In the displacing process, the knurling tool pushes a small tapered wheel or dull threading tool into the wall of the guide hole. This makes a groove in the wall of the guide without removing any metal, as pictured in Figures 22-36 and 22-37. The metal piles up along the edge of the groove just as dirt would pile up along the edge of a tire track as the tire rolled through soft dirt. (The dirt would be displaced from under the wheel to form a small ridge alongside the tire track.)

The knurling tool is driven by an electric drill and an attached speed reducer that slows the rotating speed of the knurling tool. The reamers that accompany the knurling set will ream just enough to provide the correct valve stem clearance for commercial reconditioning standards. The valve guides are honed to size in the precision shop when precise fits are desired. Clearances of knurled valve guides are usually one-half of the new valve guide clearances. Such small clearance can be used because knurling leaves so many small oil rings down the length of the guide for lubrication.

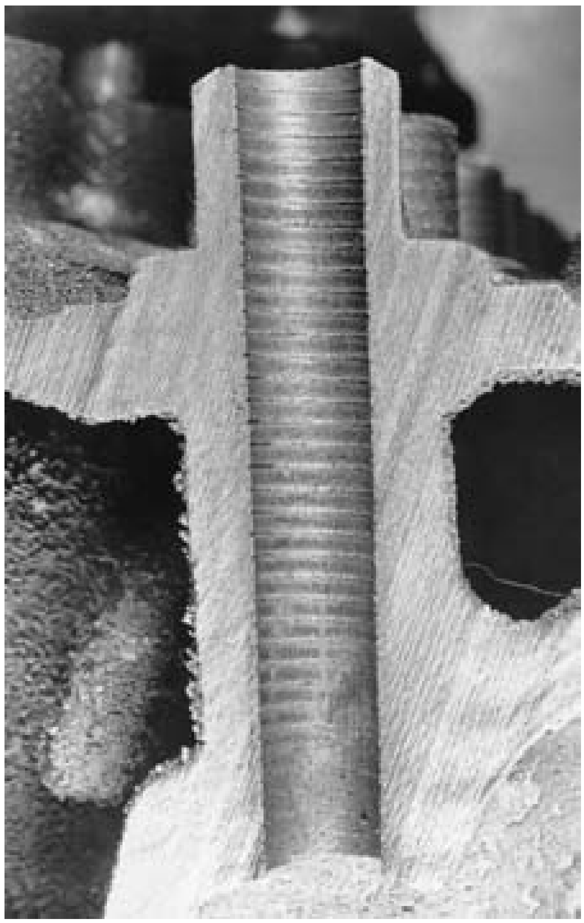


FIGURE 22-37 Sectional view of a knurled valve guide.

VALVE GUIDE REPLACEMENT

When an engine is designed with replaceable valve guides, their replacement is always recommended when the valve assembly is being reconditioned. The original valve guide height should be measured before the guide is removed so that the new guide can be properly positioned.

After the valve guide height is measured, the worn guide is pressed from the head with a properly fitting *driver.* Figure 22-38 shows how the driver is used to remove and

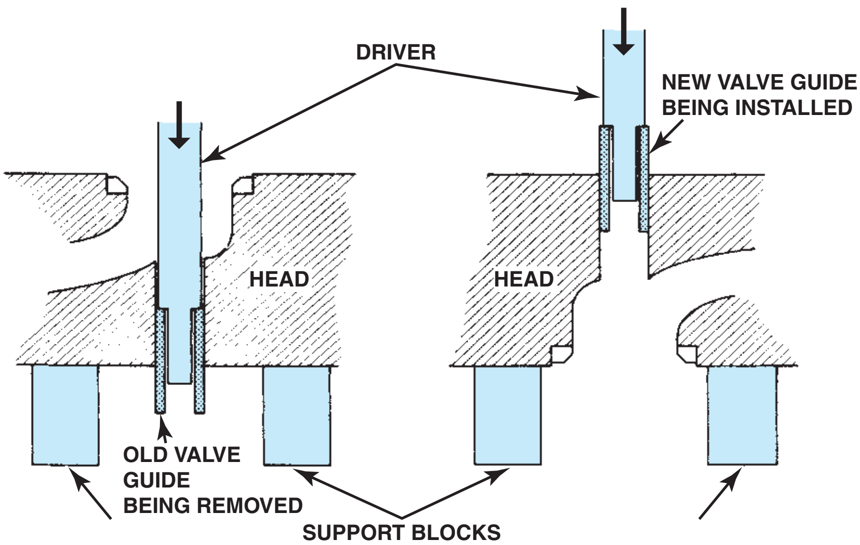


FIGURE 22-38 Valve guide replacement procedure.

TECH TIP

RIGHT SIDE UP

When replacing valve guides, it is important that the recommended procedures be followed. Most manufacturers specify that replaceable guides be driven from the combustion chamber side toward the rocker arm side. For example, big block Chevrolet V-8 heads (396, 402, 427, and 454 cubic inches) have a 0.004-inch (0.05-millimeter) taper (small end toward the combustion chamber).

Other manufacturers, however, may recommend driving the old guide from the rocker arm side to prevent any carbon buildup on the guide from damaging the guide bore. Always consult the manufacturer's recommended procedures before attempting to replace a valve guide.

replace valve guides. The driver has a stem to fit the guide opening and a shoulder that pushes on the end of the guide. If the guide has a flange, care should be taken to make sure that the guide is pushed out from the correct end, usually from the port side and toward the rocker arm side. The new guide is pressed into the guide bore using the same driver. Make sure that the guide is pressed to the correct depth. After the guides are replaced, they are reamed or honed to the proper inside diameter.

Replacement valve guides can also be installed to repair worn integral guides. Both **cast-iron** and **bronze guides** are available. See Figure 22-39. Three common valve guide sizes are as follows:

5/16 or 0.313 inches
11/32 or 0.343 inches
3/8 or 0.375 inches

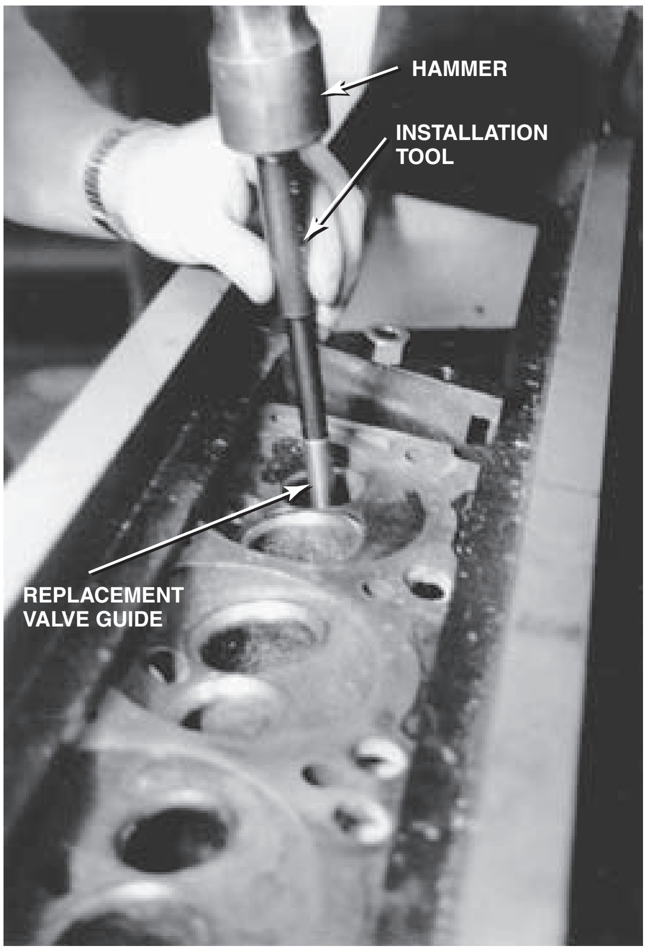
VALVE GUIDE INSERTS

When the integral valve guide is badly worn, it can be reconditioned using an insert. This repair method is usually preferred in heavy-duty and high-speed engines. Two types of guide inserts are commonly used for guide repair: a **thin-walled bronze alloy sleeve bushing** and a **spiral bronze alloy bushing.** The thin-walled bronze sleeve bushings are also called **bronze guide liners.** The valve guide rebuilding kit used to install each of these bushings includes all of the reamers, installing sleeves, broaches, burnishing tools, and cutoff tools that are needed to install and properly size the bushings.

The valve guide must be bored to a large enough size to accept the thin-walled insert sleeve. The boring tool is held in alignment by a rugged fixture. One type is shown in Figure 22-40 on page 393. Depending on the make of the equipment, the boring fixture is aligned with the valve guide hole, the valve seat, or the head gasket surface. First, the boring fixture is properly aligned. The guide is then bored, making a hole somewhat smaller than the insert sleeve that will be used. The bored hole is reamed to make a precise smooth hole that is still slightly smaller than the insert sleeve. The insert sleeve is installed with a press fit that holds it in the guide. The press fit also helps to maintain normal heat transfer from the valve to the head. The thin-walled insert sleeve is held in an installing sleeve. A driver is used to press the insert from the installing sleeve into the

(a)

(b)



(c)

FIGURE 22-39 (a) Drilling out old valve guide in preparation for replacing the guide. (b) Reaming the hole after drilling. (c) Replacement guide being driven into the cylinder head.

guide. A broach is then pressed through the insert sleeve to firmly seat it in the guide. The broach is designed to put a knurl in the guide to aid in lubrication. The insert sleeve is then trimmed to the valve guide length. Finally, the insert sleeve is reamed or honed to provide the required valve stem clearance. A very close clearance of 0.0005 inch (one-half of one thousandth of an inch) (0.013 millimeter) is usually used with the bronze thin-walled insert sleeve. See Figure 22-41.

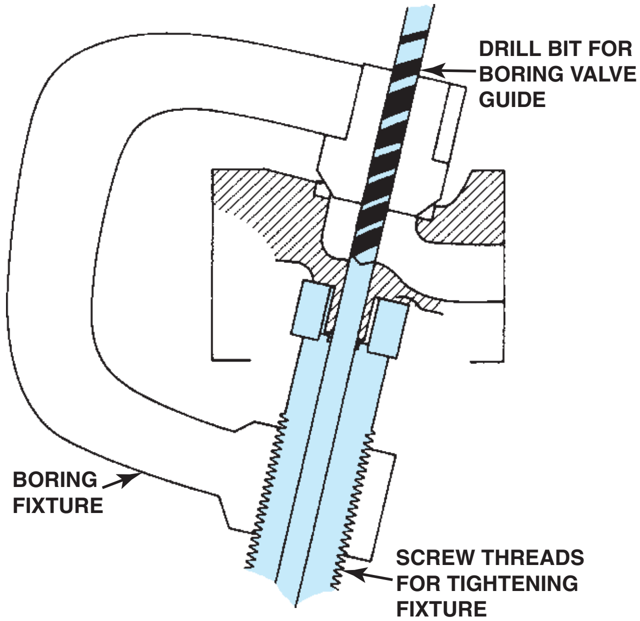
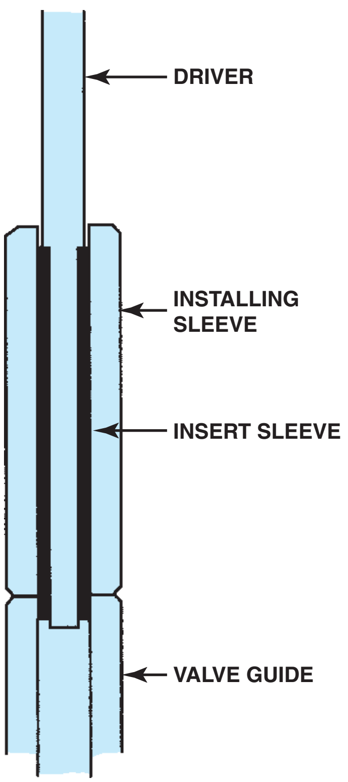
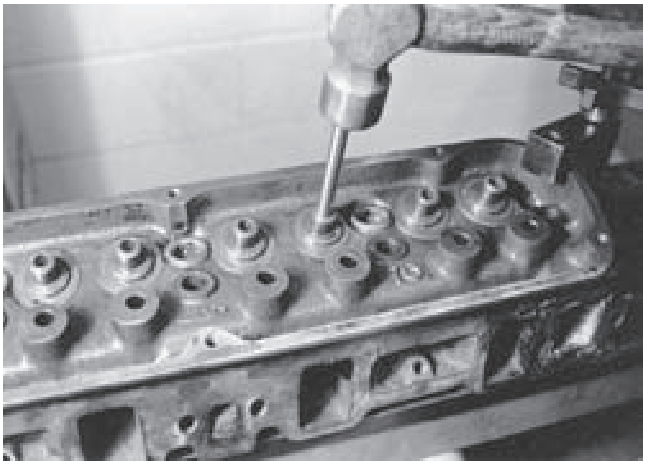


FIGURE 22-40 Type of fixture required to bore the valve guide to be oversize to accept a thin-walled insert sleeve.



(a)



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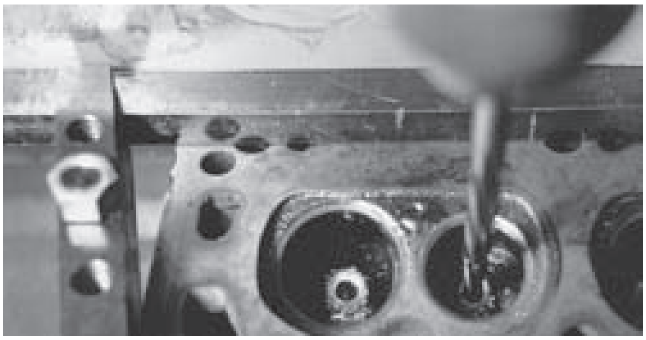
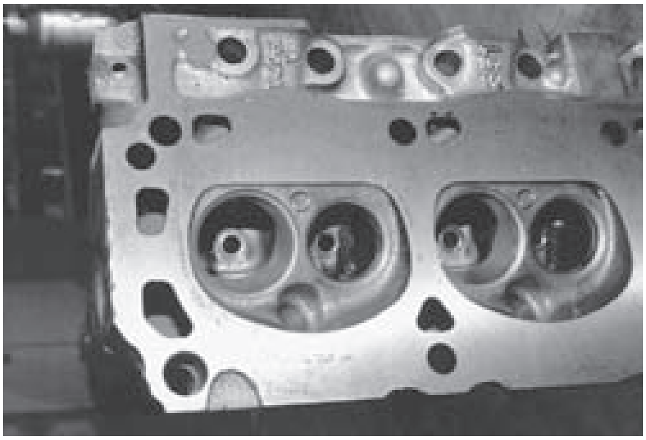


(c)



(d)

FIGURE 22-41 (a) The valve guide thin-walled insert being pushed into the valve guide from the installing sleeve. (b) Burnishing a thin-walled bronze liner. (c) Reaming a bronze guide liner (thin-walled bronze sleeve). (d) Finished installation. Bronze guides wear many times longer than cast-iron guides.

SPIRAL BRONZE INSERT BUSHINGS

The spiral bronze alloy insert bushing is screwed into a thread that is put in the valve guide. The tap used to put cut threads in the valve guide has a long pilot ahead of the thread-cutting portion of the tap. This aids in restoring the original guide alignment. The long pilot is placed in the guide from the valve seat end. A power driver is attached to the end of the pilot that extends from the spring end of the valve guide. The threads are cut in the guide from the seat end toward the spring end as the power driver turns the tap, pulling it toward the driver. The tap is stopped before it comes out of the guide, and the power driver is removed. The thread is carefully completed by hand to avoid breaking either the end of the guide or the tap. An installed spiral bronze insert bushing can be seen in Figure 22-42.

The spiral bronze bushing is tightened on an inserting tool. This holds it securely in the wound-up position so that it can be screwed into the spring end of the guide. It is screwed in until the bottom of the bushing is flush with the seat end of the guide. The holding tool is removed, and the bushing material is trimmed to one coil *above* the spring end of the guide. The end of the bushing is temporarily secured with a plastic serrated bushing retainer and a worm gear clamp. This holds the bushing in place as a broach is driven through the bushing to firmly seat it in the threads. The bushing is reamed or honed to size before the temporary bushing retainer is removed. The final step is to trim the end of the bushing with a special cut-off tool that is included in the bushing installation tool set. This type of spiral bronze bushing can be removed by using a pick to free the end of the bushing. It can then be stripped out and a new bushing inserted in the original threads in the guide hole. New threads do not have to be put in the guide. The spiral bushing design has natural spiral grooves to hold oil for lubrication. The valve stem clearances are the same as those used for knurling and for the thin-walled insert (about one-half of the standard recommended clearance).

FIGURE 22-42 Installed spiral bronze insert bushing.

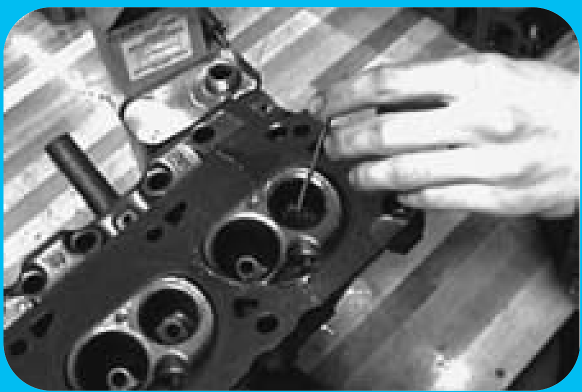
INSTALLING REPLACEMENT VALVE GUIDES Step-by-Step

STEP 1 The first step when replacing valve guides is to square the cylinder head and secure it on the holding fixture.

STEP 2 After the cylinder head has been installed, level the head using a bubble level inserted in the valve guide.

STEP 3 The first step is to drill and ream out the original integral valve guide. Here a combination drill and reamer is doing this in one operation and should be performed dry without using any lubricant.

STEP 4 A close-up view of the drill/reamer used to prepare the valve guide before installing the thin-wall bronze guides.



STEP 5 Before installing the thin-wall bronze guide, lubricate the guides with bronze guide lubricant.

STEP 6 Here the edge of a tapered punch is being used to taper the opening to the guide slightly so that the bronze thin-wall guide can be easily inserted.

(continued)

INSTALLING REPLACEMENT VALVE GUIDES continued

STEP 7 Installing the thin-wall bronze guide insert.

STEP 8 Using an installer to force the thin-wall bronze guide fully into the guide from the combustion chamber side of the head.

STEP 9 The thin-wall bronze guide insert is longer than the guide and protrudes out of the top of the original guide.

STEP 10 The top of the thin-wall bronze guide insert is then trimmed to the same level as the original integral guide.

SUMMARY

1. The most commonly used combustion chamber types include hemispherical, wedge, and pentroof.
2. Coolant and lubricating openings and passages are located throughout most cylinder heads.
3. Cylinder head reconditioning should start with cleaning and repairing, if needed, followed by resurfacing of valves and, finally, grinding of valves and seats.
4. Cylinder head resurfacing machines include grinders and milling machines.
5. Valve guides should be checked for wear using a ball gauge or a dial indicator. Typical valve stem-to-guide clearance is 0.001 to 0.003 inch for intake valves and 0.002 to 0.004 inch for exhaust valves.
6. Valve guide repair options include use of oversize stem valves, replacement valve guides, valve guide inserts, and knurling of the original valve guide.

REVIEW QUESTIONS

1. What are the advantages of a hemispherical combustion chamber?
2. What are the advantages of a wedge combustion chamber?
3. What is meant by the term *cross flow head?*
4. What is a Siamese port?
5. What is the recommended cylinder head reconditioning sequence?
6. What are the advantages of using four valves per cylinder?

CHAPTER QUIZ

1. The reason why cylinder heads with four valves flow more air than two-valve heads is because _____.
   a. They have a greater open area
   b. Use a higher lift camshaft
   c. Increases the velocity of the air
   d. Use a camshaft with a greater duration
2. Two technicians are discussing a Hemi engine. Technician A says that Hemi means an engine with a hemispherical-shaped combustion chamber. Technician B says that all Hemi engines use four valves per cylinder. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technician A and B
   d. Neither Technician A nor B
3. Technician A says that Audi five valve engines use three intake valves and two exhaust valves. Technician B says that the engines use two intake valves and three exhaust valves. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technician A and B
   d. Neither Technician A nor B
4. The gasket surface of a cylinder head, as measured with a straightedge, should have a maximum variation of _____.
   a. 0.002 inch in any 6-inch length or 0.004 inch overall
   b. 0.001 inch in any 6-inch length or 0.004 inch overall
   c. 0.020 inch in any 10-inch length or 0.020 inch overall
   d. 0.004 inch in any 10-inch length or 0.008 inch overall
5. A warped aluminum cylinder head can be restored to useful service by _____.
   a. Grinding the gasket surface and then align honing the camshaft bore
   b. Heating it in an oven at 500°F with shims under each end, allowing it to cool, and then machining it
   c. Heating it to 500°F for 5 hours and cooling it rapidly before final machining
   d. Machining the gasket surface to one-half of the warped amount and then heating the head in an oven and allowing it to cool slowly
6. Most vehicle manufacturers recommend repairing integral guides using _____.
   a. OS stem valves
   b. Knurling
   c. Replacement valve guides
   d. Valve guide inserts

7. Typical valve stem-to-valve guide clearance is _____.
   a. 0.030 to 0.045 inch (0.8 to 1.0 millimeter)
   b. 0.015 to 0.020 inch (0.4 to 0.5 millimeter)
   c. 0.005 to 0.010 inch (0.13 to 0.25 millimeter)
   d. 0.001 to 0.004 inch (0.03 to 0.05 millimeter)
8. What other engine component may have to be machined if the cylinder heads are machined on a V-type engine?
   a. Exhaust manifold
   b. Intake manifold
   c. Block deck
   d. Distributor mount (if the vehicle is so equipped)
9. Which operation should be performed first?
   a. Resurfacing the head
   b. Installing replacement guides
10. Which statement is true about surface finish?
    a. Cast-iron surfaces should be smoother than aluminum surfaces.
    b. The rougher the surface, the higher the microinch finish measurement.
    c. The smoother the surface, the higher the microinch finish measurement.
    d. A cylinder head should be a lot smoother than a crankshaft journal.