CHAPTER 25

PISTONS, RINGS, AND CONNECTING RODS

OBJECTIVES

After studying Chapter 25, the reader will be able to:

1. Prepare for Engine Repair (A1) ASE certification test content area "C"(Engine Block Diagnosis and Repair).
2. Describe the purpose and function of pistons, rings, and connecting rods.
3. Explain how pistons and rods are constructed and what to look for during an inspection.
4. Discuss connecting rod reconditioning procedures.
5. Explain how piston rings operate and how to install them on a piston.

KEY TERMS

Back Clearance (p. 487)
Balancing Bosses (pads) (p. 492)
Bleed Hole (p. 492)
Blowby (p. 488)
Cam Ground (p. 481)
Compression Rings (p. 486)
Connecting Rod Bearing Journal (p. 478)
Crank Throw (p. 478)
Crankpin (p. 478)
Dish (p. 480)
Double-Knock (p. 484)
Ductile Iron (p. 487)
Eyebrows (p. 481)
Flat-Top Piston (p. 480)
Full Floating (p. 485)
Grooves (p. 486)
Gudgeon Pins (p. 482)
Heat Dams (p. 482)
Hypereutectic (p. 482)
Identification Marks (p. 494)
Inertia Forces (p. 479)
Interference Fit (p. 485)
Lands (p. 486)
Left-Hand Rule (p. 485)
Lock Rings (p. 485)
Major Thrust Surface (p. 483)
Notch (p. 494)
Oil Control Ring (p. 486)
Piloting Surfaces (p. 492)
Piston (p. 478)
Piston Pin (p. 478)
Piston Ring (p. 478)
Piston Ring Expanding Tool (p. 479)
Pop-Ups (p. 480)
Positive Twist (p. 488)
Recesses (p. 480)
Reverse Twist (p. 488)
Ring Gap (p. 488)
Scraper Ring (p. 488)
Side Clearance (p. 487)
Skirt (p. 486)
Slipper Skirt (p. 482)
Slots (p. 482)
Spit Hole (p. 492)
Struts (p. 482)
Taper Face Ring (p. 488)
Valve Pockets (p. 481)
Valve Reliefs (p. 481)
Wrist Pin (p. 478)

All engine power is developed by burning fuel in the presence of air in the combustion chamber. Heat from the combustion causes the burned gas to increase in pressure. The force of this pressure is converted into useful work through the piston, connecting rod, and crankshaft.

PURPOSE AND FUNCTION OF PISTONS, RINGS, AND CONNECTING RODS

The **piston** forms a movable bottom to the combustion chamber. It is attached to the connecting rod with a **piston pin** or **wrist pin.** See Figure 25-1. The piston pin is allowed to have a rocking movement because of a swivel joint at the piston end of the connecting rod. The connecting rod is connected to a part of the crankshaft called a **crank throw, crankpin,** or **connecting rod bearing journal.** This provides another swivel joint. The center of the crank throw is the amount by which the large end of the connecting rod is offset from the crankshaft main bearing centerline. This dimension of the crankshaft determines the stroke of the engine.

NOTE: The stroke is the distance from the center of the main bearing journal to the center of the connecting rod journal times two.

Piston rings seal the small space between the piston and cylinder wall, keeping the pressure above the piston. When the pressure builds up in the combustion chamber, it pushes on the piston. The piston, in turn, pushes on the piston pin and upper end of the connecting rod. The lower end of the connecting rod pushes on the crank throw. This provides the force to turn the crankshaft. As the crankshaft turns, it develops inertia. *Inertia is the force that causes the crankshaft to continue rotating.* This action will bring the piston back to its original position, where it will be ready for the next power stroke. While the engine is running, the combustion cycle keeps repeating as the piston reciprocates (moves up and down) and the crankshaft rotates.

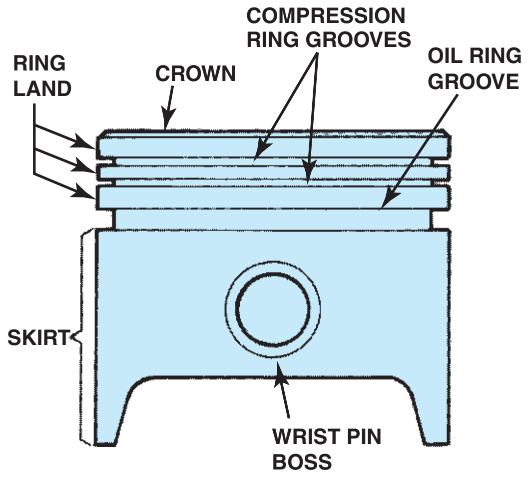


FIGURE 25-1 All pistons share these parts in common.

PISTON AND ROD REMOVAL

After the oil pan and cylinder head(s) have been removed, the piston and rod can be removed by the following steps:

Step 1 The rod and caps should be checked for markings that identify their location. *If the rod and caps are not marked, they should be marked before disassembly.* If number stamps are not available, punch marks, as shown in Figure 25-2, can be used.

CAUTION: Powdered metal connecting rods should only be marked with a permanent marker to avoid damage to the rod. See Figure 25-3.

Step 2 The crankshaft is turned until the piston is at the bottom of its stroke. This places the connecting rod nuts or cap screws where they are easily accessible. They are removed, and the rod cap is taken off. This may require light tapping on the connecting rod bolts with a soft-faced hammer.

Step 3 Protectors should be placed over the rod bolt threads to protect the threads and the surface of the crankshaft journal. The piston and rod assembly is pushed out, with care being taken to avoid hitting the bottom edge of the cylinder with the rod.

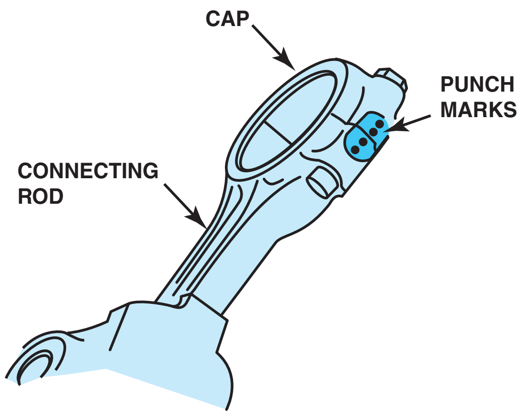


FIGURE 25-2 Punch marks on connecting rod and rod cap to identify their location in the engine. The cap and rod were machined together and must remain together.

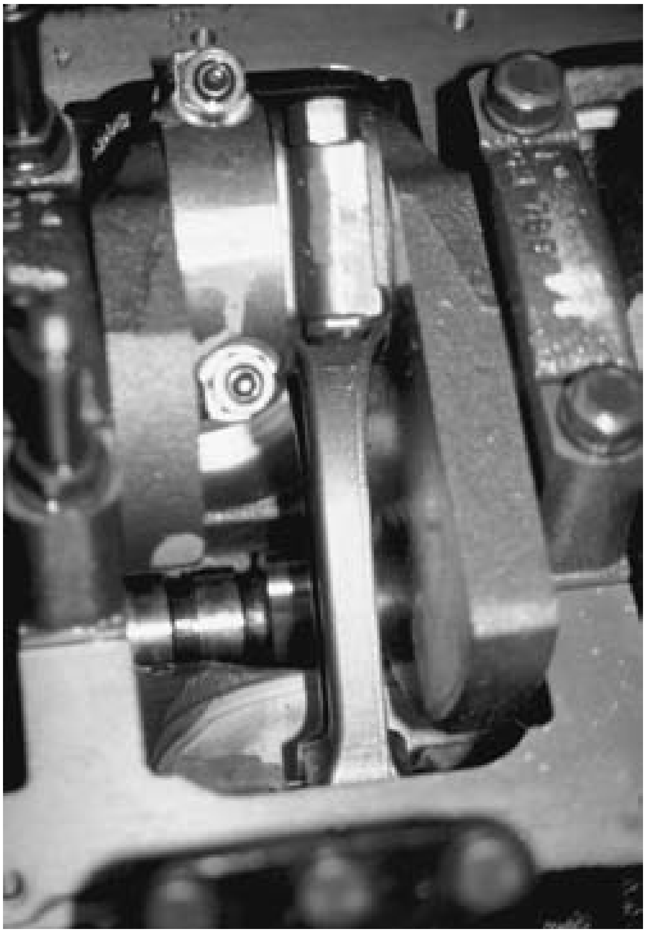


FIGURE 25-3 Powdered metal connecting rods can be identified by their smooth appearance.

The rod caps should be reattached to the rod after the assembly has been removed from the cylinder. The rod caps are not interchangeable between rods. The assembly must be handled carefully. It should be placed on a parts stand so that the piston and rod do not strike each other. The aluminum piston can be easily scratched or nicked.

The rings are carefully removed from the piston to avoid damage to either the piston or the ring. The best way to remove them is to use a **piston ring expanding tool.**

PISTON DESIGN

When the engine is running, the piston starts at the top of the cylinder. As it moves downward, it accelerates until it reaches a maximum velocity slightly before it is halfway down. The piston comes to a stop at the bottom of the cylinder at 180 degrees of crankshaft rotation. During the next 180 degrees of crankshaft rotation, the piston moves upward. It accelerates to reach a maximum velocity slightly above the halfway point and then comes to a stop at the top of the stroke. Thus, the piston starts, accelerates, and stops twice in each crankshaft revolution.

NOTE: A typical piston in an engine at 4000 RPM accelerates from 0 to 60 miles per hour (97 kilometers per hour) in about 0.004 second (4 milliseconds) as it descends about halfway down the cylinder.

This reciprocating action of the piston produces large **inertia forces.** Inertia is the force that causes a part that is stopped to stay stopped or a part that is in motion to stay in motion. The lighter the piston can be made, the less inertia force that is developed. Less inertia will allow higher engine operating speeds. For this reason, pistons are made to be as light as possible while still having the strength that is needed.

The piston operates with its head exposed to the hot combustion gases, whereas the skirt contacts the relatively cool cylinder wall. This results in a temperature difference of about 275°F (147°C) between the top and bottom of the piston.

TECH TIP

PISTON WEIGHT IS IMPORTANT!

All pistons in an engine should weigh the same to help ensure a balanced engine. Piston weight becomes a factor when changing pistons. Most aluminum pistons range in weight from 10 to 30 ounces (280 to 850 grams) (1 oz = 28.35 grams). *A typical paper clip weighs 1 gram.* If the cylinder has been bored, larger replacement pistons are obviously required. If the replacement pistons weigh more, this puts additional inertia loads on the rod bearings. Therefore, to help prevent rod bearing failure on an overhauled engine, the replacement pistons should not weigh more than the original pistons.

CAUTION: Some less-expensive replacement cast pistons or high-performance forged pistons are much heavier than the stock pistons, even in the stock bore size. This means that the crankshaft may need heavy metal added to the counterweights of the crankshaft for the engine to be balanced.

For the same reason, if one piston is being replaced, all pistons should be replaced or at least checked and corrected to ensure the same weight.

PISTON HEADS

Because the piston head forms a portion of the combustion chamber, its shape is very important to the combustion process. Generally, low-cost, low-performance engines have **flat-top pistons.** Some of these flat-top pistons come so close to the cylinder head that **recesses** are cut in the piston top for valve clearance. Pistons used in high-powered engines may have raised domes or **pop-ups** on the piston heads. These are used to increase the compression ratio. Pistons used in other engines may be provided with a depression or a **dish.** The varying depths of the dish provide different compression ratios required by different engine models. Several piston head shapes are shown in Figure 25-4.

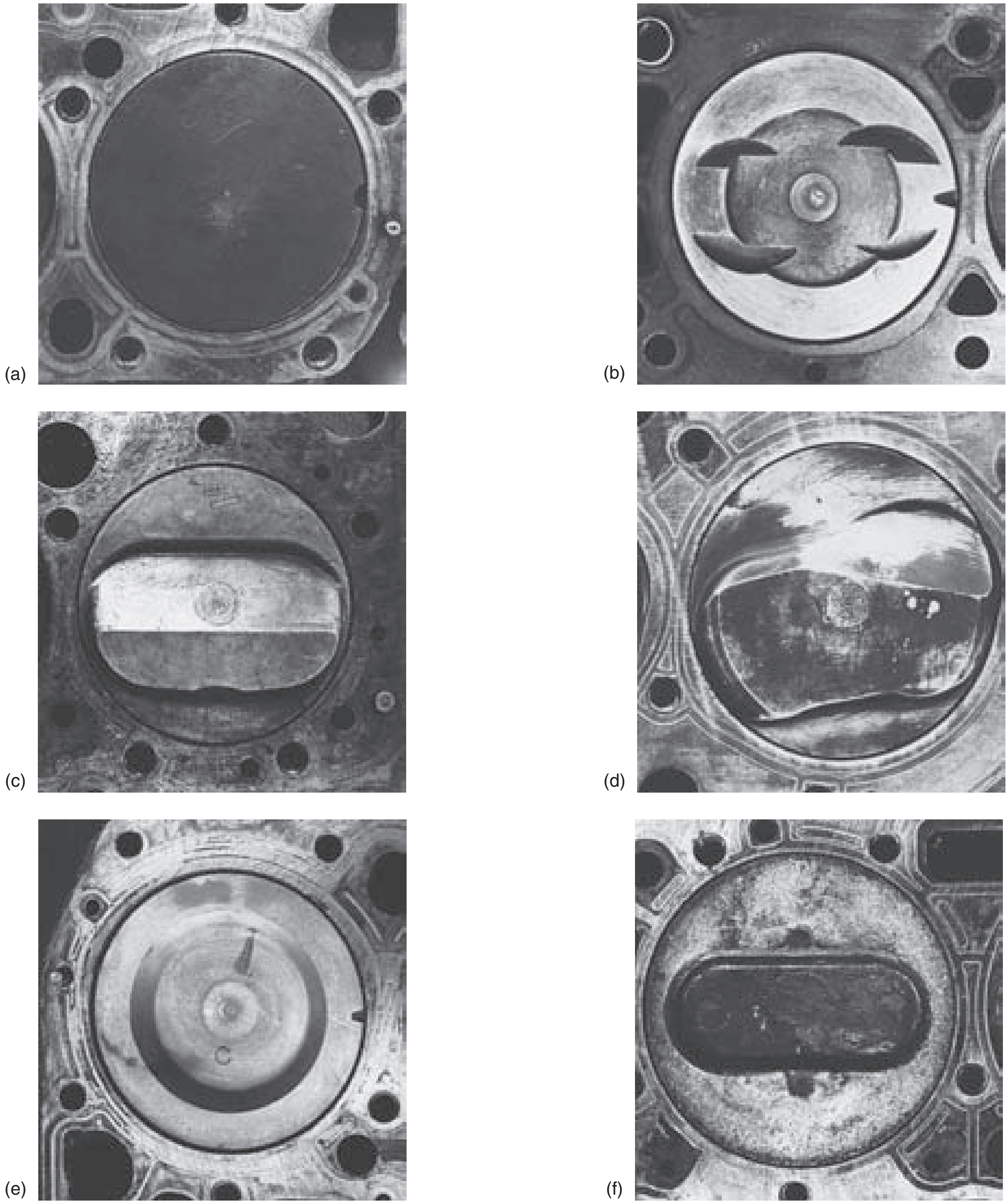


FIGURE 25-4 Piston head shapes: (a) flat (b) recessed, (c and d) pop-up, and (e and f) dished.

NOTE: Newer engines do not use valve reliefs because this requires that the thickness of the top of the piston be increased to provide the necessary strength. The thicker the top of the piston, the lower down from the top of the top piston ring. To reduce unburned hydrocarbon (HC) exhaust emissions, engineers attempt to place the top piston ring as close to the top of the piston as possible to prevent the unburned fuel from being trapped (and not burned) between the top of the piston and the top of the top piston ring.

Recesses machined or cast into the tops of the pistons for valve clearance are commonly called **eyebrows, valve reliefs,** or **valve pockets.** The depth of the eyebrows has a major effect on the compression ratio and is necessary to provide clearance for the valves if the timing belt of an overhead camshaft engine should break. Without the eyebrows, the pistons could hit the valves near TDC if the valves are not operating (closing) because of nonrotation of the camshaft. If an engine is designed not to have the pistons hitting the valves, the engine is called freewheeling.

CAM GROUND PISTONS

Aluminum pistons expand when they get hot. A method of expansion control was devised using a **cam ground** piston skirt. With this design, the piston thrust surfaces closely fit the cylinder, and the piston pin boss diameter is fitted loosely. As the cam ground piston is heated, it expands along the piston pin so that it becomes nearly round at its normal operating temperatures. A cam ground piston skirt is illustrated in Figure 25-5. See Figure 25-6 for an example of how to measure the diameter of a piston.

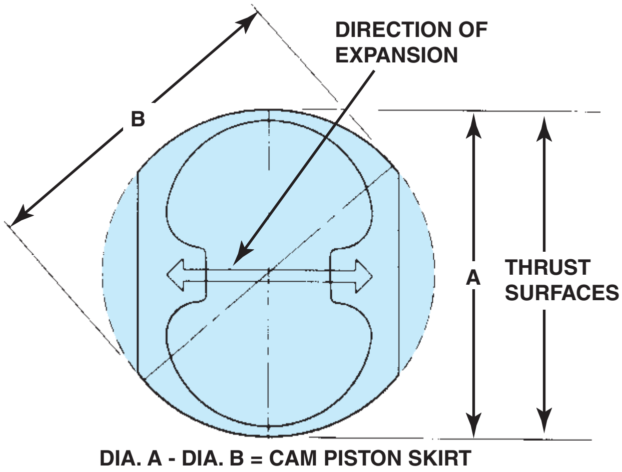


FIGURE 25-5 Piston cam shape. The largest diameter is across the thrust surfaces and perpendicular to the piston pin (lettered A).

PISTON FINISH

The finish on pistons varies with the manufacturer, but they all are designed to help reduce scuffing. Scuffing is a condition where the metal of the piston actually contacts the cylinder wall. When the piston stops at the top of the cylinder, welds or transfer of metal from one part to the other can take place. Scuffing can be reduced by coating the piston skirts with tin 0.0005 inch (0.0125 mm) thick or a moly graphite coating. See Figure 25-7.

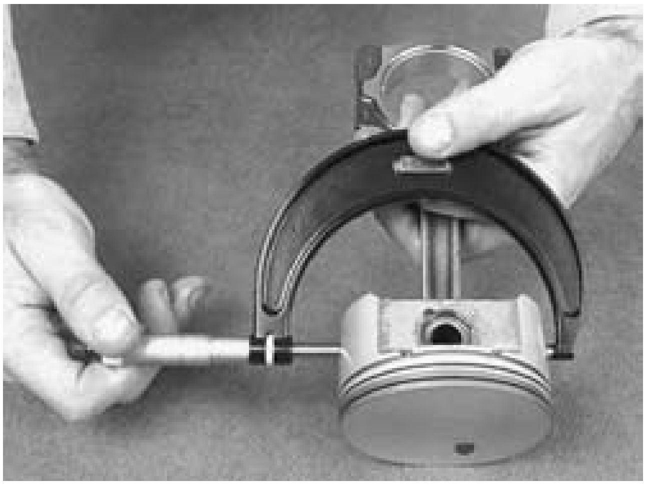
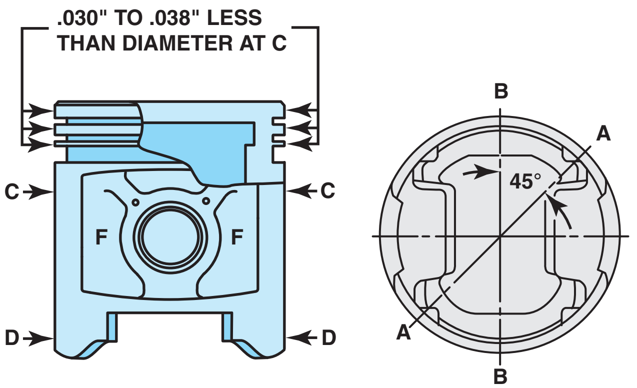


FIGURE 25-6 A piston diameter is measured across the thrust surfaces.

FIGURE 25-7 A moly graphite coating on the skirt of this piston from a General Motors 3800 V-6 engine helps prevent piston scuffing when the engine is cold.



DIAMETERS AT (C) AND (D) CAN BE EQUAL OR DIAMETER AT (D) CAN BE .0015" GREATER THAN (C).

THE ELLIPTICAL SHAPE OF THE PISTON SKIRT SHOULD BE .010" TO .012" LESS AT DIAMETER (A) THAN ACROSS THE THRUST FACES AT DIAMETER (B). MEASUREMENT IS MADE 1/8" BELOW LOWER RING GROOVE.

FIGURE 25-8 Piston skirt cam shape.

PISTON HEAD SIZE

The top or head of the piston is smaller in diameter than the rest of the piston. The top of the piston is exposed to the most heat and therefore tends to expand more than the rest of the piston. See Figure 25-8. Most pistons have horizontal separation **slots** that act as **heat dams.** These slots reduce heat transfer from the hot piston head to the lower skirt. This, in turn, keeps the skirt temperature lower so that there will be less skirt expansion. Because the slot is placed in the oil ring groove, it can be used for oil drainback and expansion control.

PISTON STRUT INSERTS

A major development in expansion control occurred when the piston aluminum was cast around two stiff steel **struts.** The struts are not chemically bonded to the aluminum, nor do they add any strength to the piston. There is only a mechanical bond between the steel and aluminum. The bimetallic action of this strut in the aluminum forces the piston to bow outward along the piston pin. This keeps the piston skirt thrust surfaces from expanding more than the cast-iron cylinder in which the piston operates. Pistons with steel strut inserts allow good piston-to-cylinder wall clearance at normal temperatures. At the same time, they allow the cold operating clearance to be as small as 0.0005 inch (one-half thousandth of an inch) (0.0127 millimeter). This small clearance will prevent cold piston slap and noise. A typical piston expansion control strut is visible in Figure 25-9.

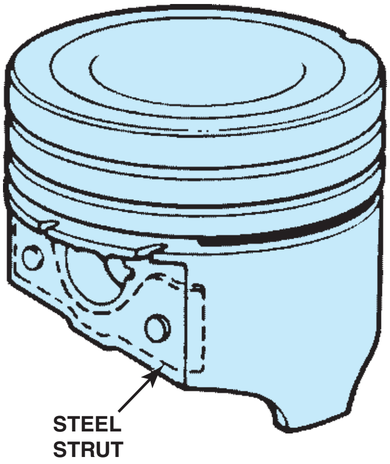


FIGURE 25-9 Steel struts cast inside pistons help control expansion.

With newer engines, the number and thickness of the piston rings have decreased and the cast-aluminum piston skirt has been reduced to a minimum by using an open-type **slipper skirt.** Examples of the slipper skirt piston are shown in Figure 25-10.

HYPEREUTECTIC PISTONS

A standard cast-aluminum piston contains about 9% to 12% silicon and is called a eutectic piston. To add strength, the silicon content is increased to about 16%, and the resulting piston is called a **hypereutectic** piston. Other advantages of a hypereutectic piston are its 25% weight reduction and lower expansion rate. The disadvantage of hypereutectic pistons is their higher cost, because they are more difficult to cast and machine.

Hypereutectic pistons are commonly used in the aftermarket and as original equipment in many turbocharged and supercharged engines.

FORGED PISTONS

High-performance engines need pistons with added strength. Forged pistons have a dense grain structure and are very strong. Forged pistons are often used in turbocharged or supercharged engines. Because forged pistons are less porous than cast pistons, they conduct heat more quickly. Forged pistons generally run about 20% cooler than cast pistons. See Figure 25-11. Figure 25-12 on page 484 is a forged heavy-duty truck aluminum piston, which shows the grain of the aluminum.

PISTON PINS

Piston pins are used to attach the piston to the connecting rod. Piston pins are also known as **gudgeon pins** (a British term).

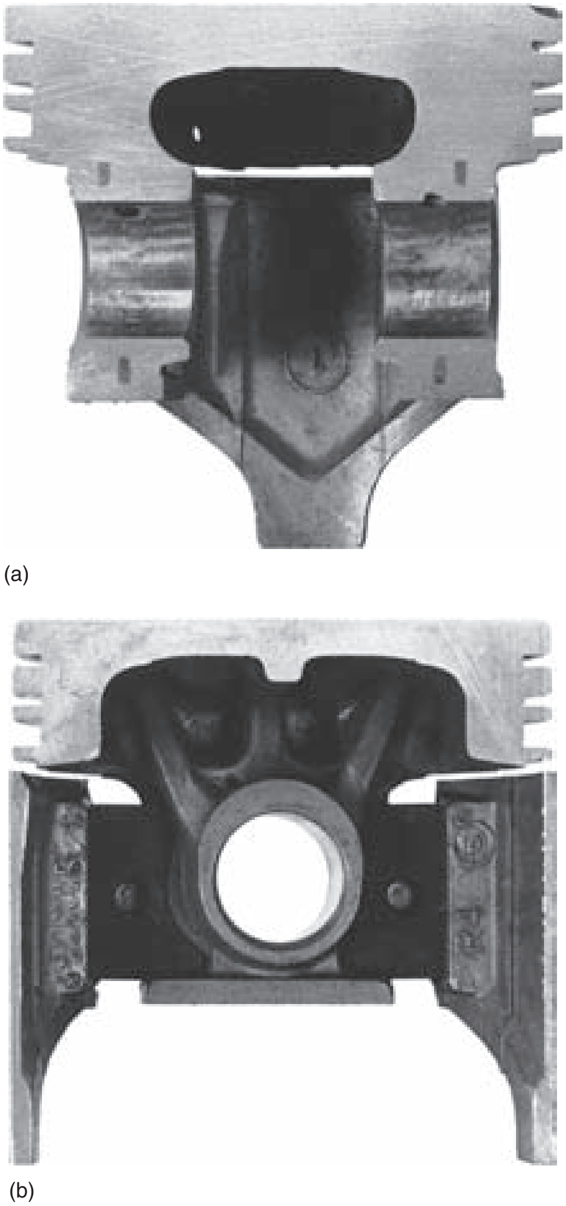


FIGURE 25-10 Two sectional views of a slipper-skirt-type piston that uses a steel expansion strut.

The piston pin transfers the force produced by combustion chamber pressures and piston inertia to the connecting rod. The piston pin is made from high-quality steel in the shape of a tube to make it both strong and light. Sometimes, the interior hole of the piston pin is tapered, so it is large at the ends and small in the middle of the pin. This gives the pin strength that is proportional to the location of the load placed on it. A double-taper hole such as this is more expensive to manufacture, so it is used only where its weight advantage merits the extra cost. See Figure 25-13.

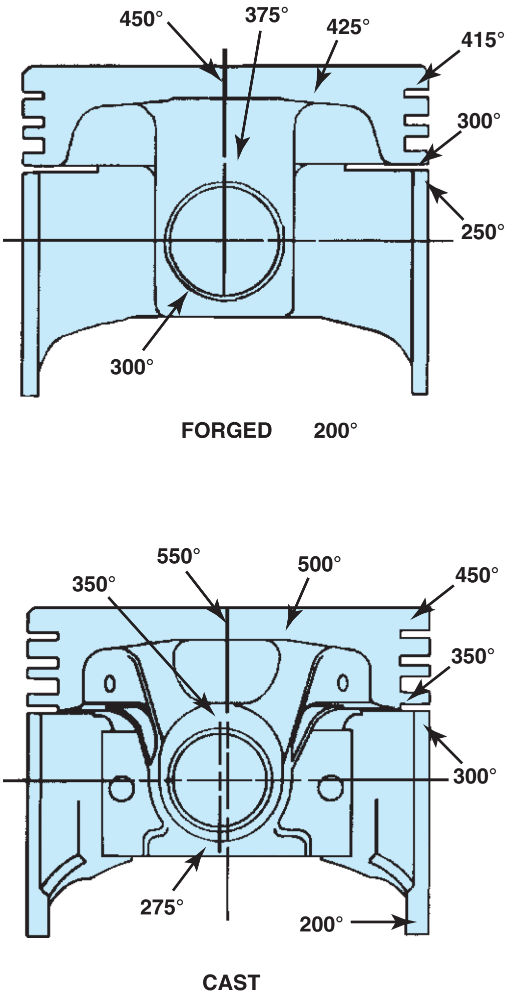


FIGURE 25-11 The critical crown temperature can be 100°F (38°C) cooler on a forged piston compared to a cast piston.

Piston Pin Offset

The piston pin holes are not centered in the piston. They are located toward the **major thrust surface,** approximately 0.062 inch (1.57 millimeters) from the piston centerline, as shown in Figure 25-14.

Pin offset is designed to reduce piston slap and the noise that can result as the large end of the connecting rod crosses over top dead center.

The minor thrust side of the piston head has a greater area than does the major side. This is caused by the pin offset. As the piston moves up in the cylinder on the compression stroke, it rides against the minor thrust surface. When compression pressure becomes high enough, the greater head area on the minor side causes the piston to cock slightly in the cylinder. This keeps the *top* of the minor thrust surface on the cylinder. It forces the *bottom* of the major thrust surface to contact the cylinder wall. As the piston approaches top center,

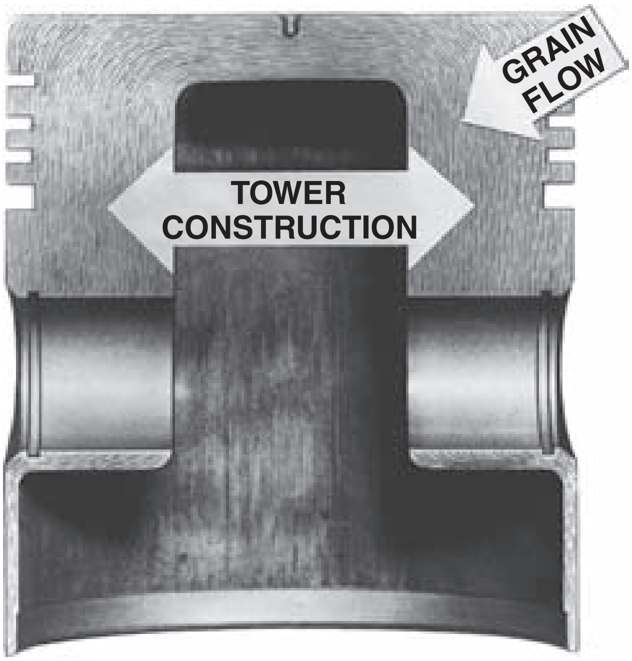


FIGURE 25-12 Grain flow lines can be seen in this forged aluminum piston with a trunk skirt.

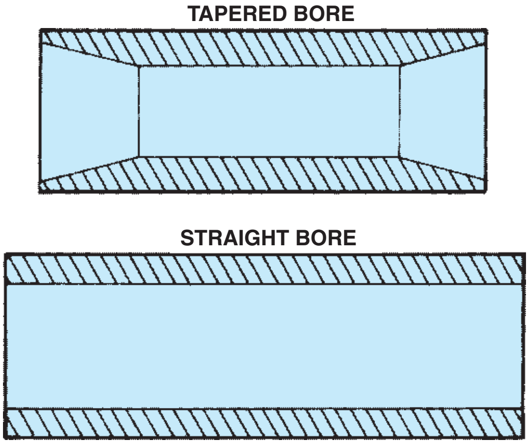


FIGURE 25-13 Most piston pins are hollow to reduce weight and have a straight bore. Some pins have a tapered bore to reinforce the pin.

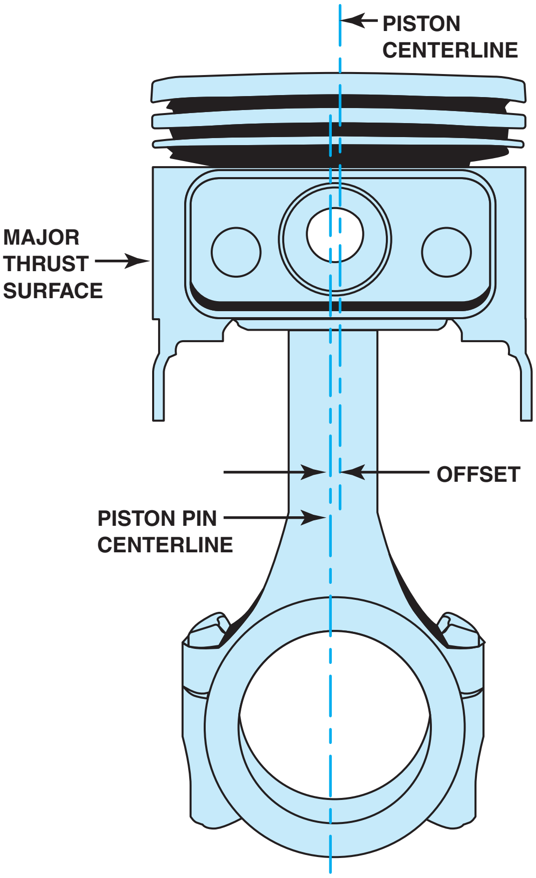


FIGURE 25-14 Piston pin offset toward the major thrust surface.

both thrust surfaces are in contact with the cylinder wall. When the crankshaft crosses over top center, the force on the connecting rod moves the entire piston toward the major thrust surface. The lower portion of the major thrust surface has already been in contact with the cylinder wall. The rest of the piston skirt slips into full contact just after the crossover point, thereby controlling piston slap. This action is illustrated in Figure 25-15.

Offsetting the piston toward the minor thrust surface would provide a better mechanical advantage. It also would cause less piston-to-cylinder friction. For these reasons, the offset is often placed toward the minor thrust surface in racing engines. Noise and durability are not as important in racing engines as is maximum performance.

NOTE: Not all piston pins are offset. In fact, many engines operate without the offset to help reduce friction and improve power and fuel economy.

Piston Pin Fit

The finish and size of piston pins are closely controlled. Piston pins have a smooth mirrorlike finish. Their size is held to tens of thousandths of an inch so that exact fits can be maintained. If the piston pin is loose in the piston or in the connecting rod, it will make a sound while the engine is running. This is often described as a **double-knock.** The noise is created when the piston stops at top dead center and occurs again as it starts to move downward, creating a double-knock sound, which is also described as a rattling sound. If the piston pin is too tight in the piston, it will restrict piston expansion along the pin diameter. This will lead to piston scuffing. Normal piston pin clearances range from 0.0005 to 0.0007 inch (0.0126 to 0.0180 millimeter).

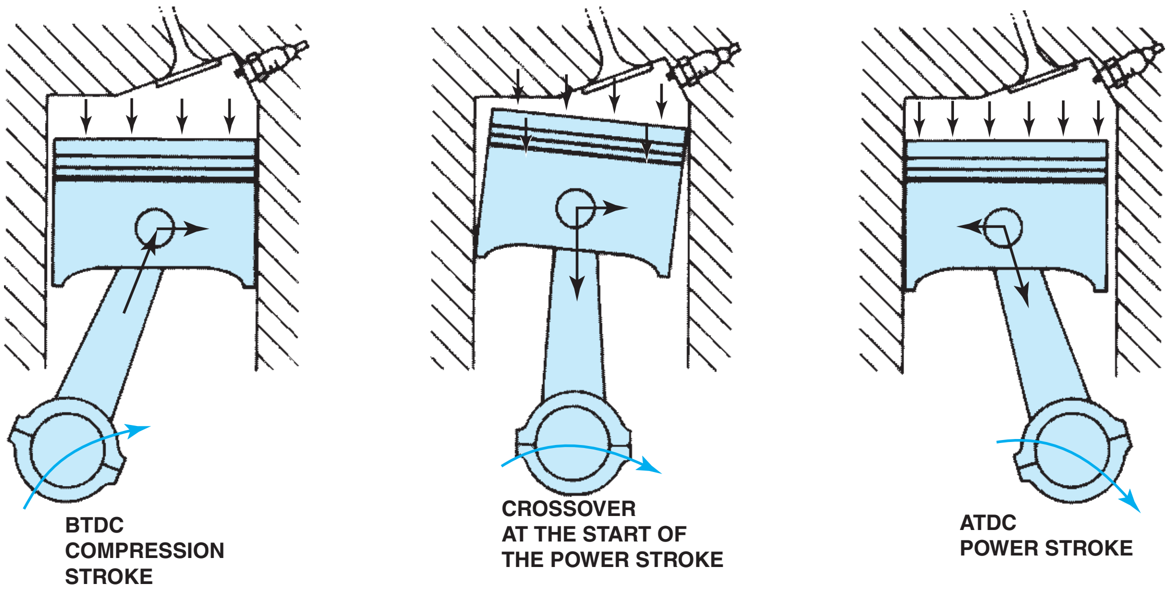


FIGURE 25-15 Engine rotation and rod angle during the power stroke causes the piston to press harder against one side of the cylinder, which is called the major thrust surface.

FREQUENTLY ASKED QUESTION

WHICH SIDE IS THE MAJOR THRUST SIDE?

The thrust side is the side the rod points to when the piston is on the power stroke. Any V-block engine (V-6 or V-8) that rotates clockwise is viewed from the front of the engine—the left bank piston thrust side faces the inside (center) of the engine. The right bank piston thrust side faces the outside of the block. This rule is called the **left-hand rule** and states:

- Stand at the rear of the engine and point toward the front of the engine.
- Raise your thumb straight up, indicating the top of the engine.
- Point your middle finger toward the right. This represents the major thrust side of the piston.

Always assemble the connecting rods onto the rods so that the notch or “F”on the piston is pointing toward the front of the engine and the oil squirt hole on the connecting rod is pointing toward the major thrust side with your left hand.

PISTON PIN RETAINING METHODS

Full Floating

It is necessary to retain or hold piston pins so that they stay centered in the piston. If piston pins are not retained, they will move endwise and groove the cylinder wall. The piston pin may be **full floating,** with some type of stop located at each end.

Full-floating piston pins in automotive engines are retained by **lock rings** located in grooves in the piston pin hole at the ends of the piston pin. See Figure 25-16. Some engines use aluminum or plastic plugs in both ends of the piston pin. These plugs touch the cylinder wall without scoring, to hold the piston pin centered in the piston.

Interference Fit

The modern method of retaining the piston pin in the connecting rod is to make the connecting rod hole slightly smaller than the piston pin. The pin is installed by heating the rod to expand the hole or by pressing the pin into the rod. This retaining method will securely hold the pin. See Figure 25-17. This press or shrink fit is called an **interference fit.** Care must be taken to have the correct hole sizes, and the pin must be centered in the connecting rod. The interference fit method is the least expensive to use. It is, therefore, used in the majority of engines.

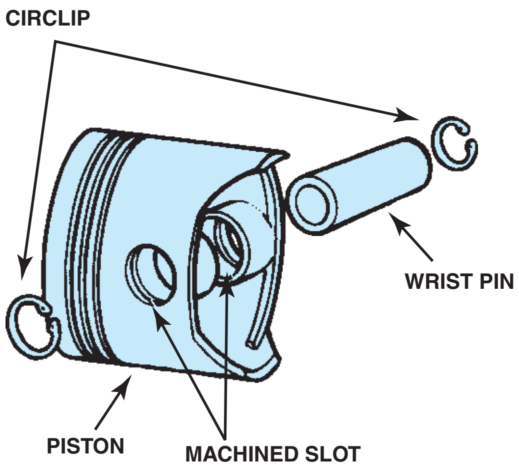


FIGURE 25-16 Circlips hold full-floating piston pins in place.

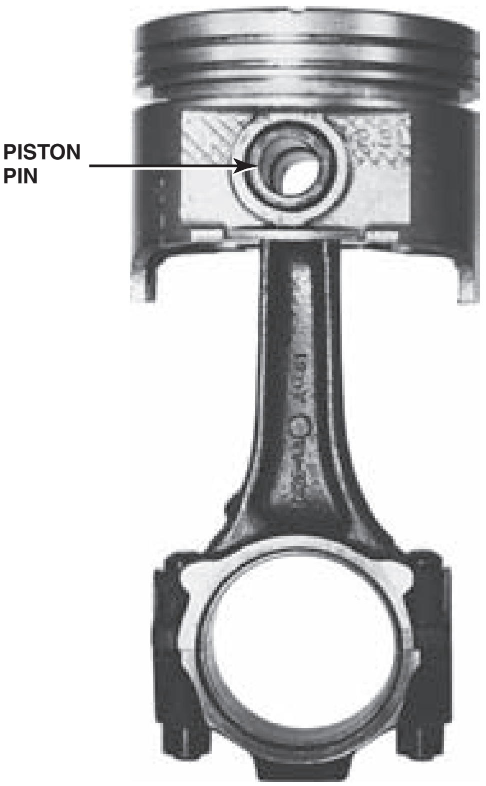


FIGURE 25-17 Interference fit type of piston pin.

PISTON RING GROOVES

Piston ring **grooves** are located between the piston head and skirt. The width of the grooves, the width of the **lands** between the ring grooves, and the number of rings are major factors in determining minimum piston height. The outside diameter of the lands is about 0.020 to 0.040 inch (0.5 to 1.0 millimeter) smaller than the **skirt** diameter.

REAL WORLD FIX

BIG PROBLEM, NO NOISE

Sometimes the piston pin can "walk"off the center of the piston and score the cylinder wall. This scoring is often not noticed because this type of wear does not create noise. Because the piston pin is below the piston rings, little combustion pressure is lost past the rings until the groove worn by the piston pin has worn the piston rings.

Troubleshooting the exact cause of the increased oil consumption is difficult because the damage done to the oil control rings by the groove usually affects only one cylinder.

Often, compression tests indicate good compression because the cylinder seals, especially at the top. More than one technician has been surprised to see the cylinder gouged by a piston pin when the cylinder head has been removed for service. In such a case, the cost of the engine repair immediately increases far beyond that of normal cylinder head service.

PISTON RINGS

Piston rings serve several major functions in engines.

- They form a sliding combustion chamber seal that prevents the high-pressure combustion gases from leaking past the piston.
- They keep engine oil from getting into the combustion chamber.
- The rings transfer some of the piston heat to the cylinder wall, where it is removed from the engine through the cooling system. See Figure 25-18.

Piston rings are classified into two types: two **compression rings,** located toward the top of the piston, and one **oil control ring,** located below the compression rings. See Figure 25-19.

NOTE: Some engines, such as the Honda high-fuel-economy engines, use pistons with only two rings: one compression ring and one oil control ring.

The first piston rings were made with a simple rectangular cross-section. This cross-section was modified with tapers, chamfers, counterbores, slots, rails, and expanders. Piston ring materials have also changed from plain cast iron to materials such as pearlitic and nodular iron, as well as steel. **Ductile iron,** which is very flexible and can be twisted without breaking, is also used as a piston ring material in some automotive engines.

COMPRESSION RINGS

A compression ring is designed to form a seal between the moving piston and the cylinder wall. This is necessary to get maximum power from the combustion pressure. At the same time, the compression ring must keep friction at a minimum. This is made possible by providing only enough static or built-in mechanical tension to hold the ring in contact with the cylinder wall during the intake stroke. Combustion chamber pressure during the compression, power, and exhaust strokes is applied to the top and back of the ring. This pressure will add the force on the ring that is required to seal the combustion chamber during these strokes. Figure 25-20 illustrates how the combustion chamber pressure adds force to the ring.

The space in the ring groove above the ring is called the **side clearance** and the space behind the ring is called the **back clearance.** See Figure 25-21.

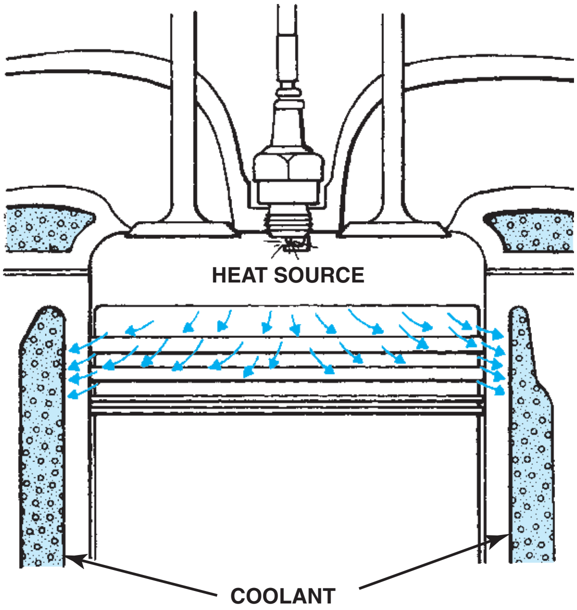


FIGURE 25-18 The rings conduct heat from the piston to the cylinder wall.

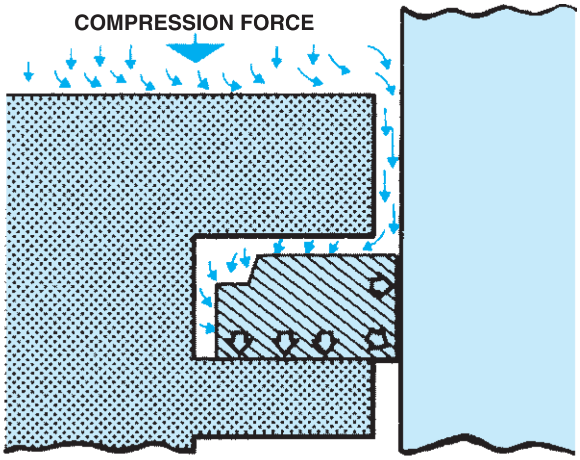


FIGURE 25-20 Combustion chamber pressure forces the ring against the cylinder wall and the bottom of the ring groove, effectively sealing the cylinder.

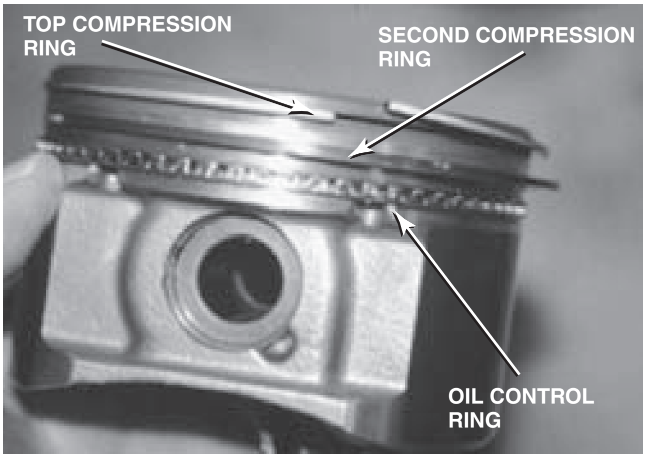


FIGURE 25-19 Most pistons use two compression rings and one oil control ring.

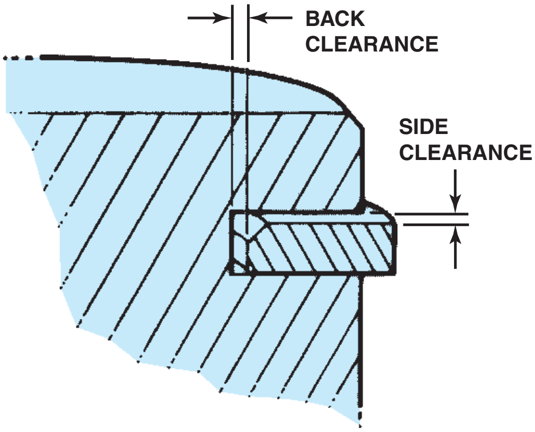


FIGURE 25-21 The side and back clearances must be correct for the compression rings to seal properly.

Ring Gap

The piston **ring gap** will allow some leakage past the top compression ring. This leakage is useful in providing pressure on the second ring to develop a dynamic sealing force. The amount of piston ring gap is critical. Too much gap will allow excessive **blowby.** Blowby is the leakage of combustion gases past the rings. Blowby will blow oil from the cylinder wall. This oil loss is followed by piston ring scuffing. Too little gap, however, will allow the piston ring ends to butt when the engine is hot. Ring end butting increases the mechanical force against the cylinder wall, causing excessive wear and possible engine failure.

A butt-type piston ring gap is the most common type used in automotive engines. Some low-speed industrial engines and some diesel engines use a more expensive tapered or seal-cut ring gap. These gaps are necessary to reduce losses of the high-pressure combustion gases. At low speeds, the gases have more time to leak through the gap. Typical ring gaps are illustrated in Figure 25-22.

Piston Ring Cross-Sections

As engine speeds have increased, inertia forces on the piston rings have also increased. As a result, engine manufacturers have found it desirable to reduce inertia forces on the rings by reducing their weight. This has been done by narrowing the piston ring from 1/4 inch (6 millimeters) to as little as 1/16 inch (1.6 millimeters).

A **taper face ring** will contact the cylinder wall at the lower edge of the piston ring. See Figure 25-23. When either a chamfer or counterbore relief is made on the *upper inside* corner of the piston ring, the ring cross-section is unbalanced. This will cause the ring to twist in the groove in a positive direction. **Positive twist** will give the same wall contact as the taper-faced ring. It will also provide a line contact seal on the bottom side of the groove. Sometimes, twist and a taper face are used on the same compression ring.

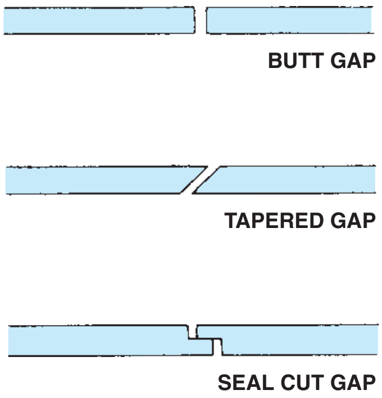


FIGURE 25-22 Typical ring gaps.

Some second rings are notched on the *outer lower* corner. This, too, provides a positive ring twist. The sharp lower outer corner becomes a scraper that helps in oil control, but this type of ring has less compression control than the preceding types.

By chamfering the ring's *lower inner* corner, a **reverse twist** is produced. This seals the lower outer section of the ring and piston ring groove, thus improving oil control. Reverse twist rings require a greater taper face or barrel face to maintain the desired ring face-to-cylinder wall contact. See Figure 25-24.

Another style of positive twist ring has a counterbore at the lower outside edge. See Figure 25-25. This ring is called a **scraper ring** because it does a good job of oil control and is usually recommended for use at the second compression ring.

Some rings replace the outer ring taper with a barrel face. The barrel is 0.0003 inch per 0.100 inch (0.0076 millimeter

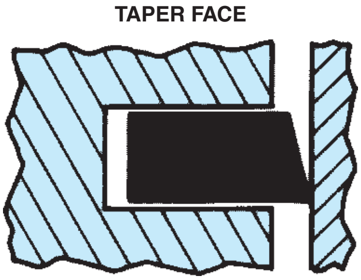


FIGURE 25-23 The taper face ring provides good oil control by scraping the cylinder wall. This style of ring must be installed right side up or the ring will not seal and oil will be drawn into the combustion chamber.

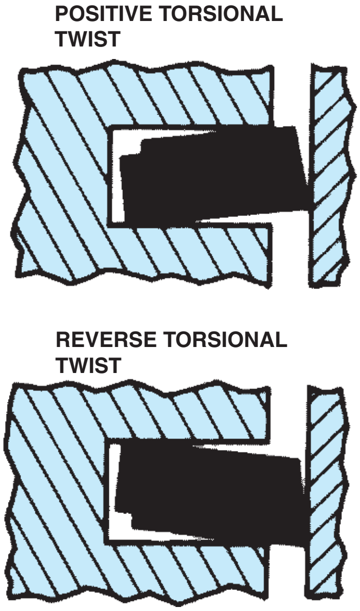


FIGURE 25-24 Torsional twist rings provide better compression sealing and oil control than regular taper face rings.

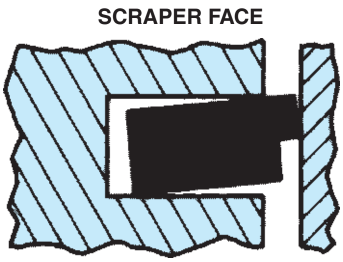


FIGURE 25-25 Scraper rings improve oil control.

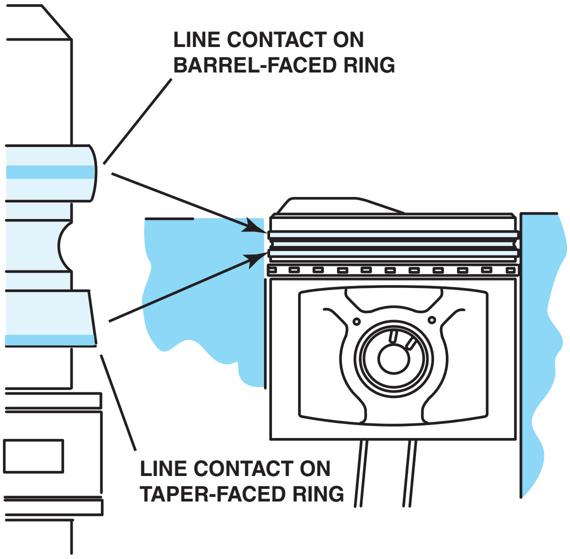


FIGURE 25-26 The piston rings are slightly used, so only the line contact shows. The upper, barrel-faced ring has line contact in the center. The second, taper-faced ring has line contact along the lower edge of the ring.

per 0.254 millimeter) of piston ring width. Barrel faces are found on rectangular rings and on torsionally twisted rings. See Figure 25-26.

Chromium Piston Rings

A chromium facing on cast-iron rings greatly increases piston ring life, especially where abrasive materials are present in the air. During manufacture, the chromium-plated ring is slightly chamfered at the outer corners. About 0.0004 inch (0.010 millimeter) of chrome is then plated on the ring face. Chromium-faced rings are then prelapped or honed before they are packaged and shipped to the customer. The finished chromium facing is shown in a sectional view in Figure 25-27.

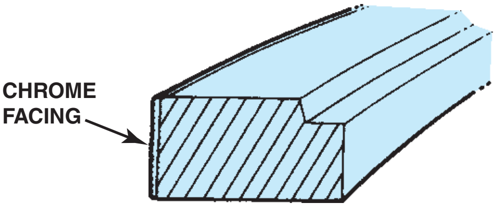


FIGURE 25-27 The chrome facing on this compression ring is about 0.004-inch (0.10-mm) thick.

Molybdenum Piston Rings

Early in the 1960s, molybdenum piston ring faces were introduced. These rings proved to have good service life, especially under scuffing conditions. The plasma method is a spray method used to deposit molybdenum on cast iron to produce a long-wearing and low-friction piston ring. The plasma method involves an electric arc plasma (ionized gas) that generates an extremely high temperature to melt the molybdenum and spray-deposit a molten powder of it onto a piston ring. Therefore, plasma rings are molybdenum (moly) rings that have the moly coating applied by the plasma method. Most molybdenum-faced piston rings have a groove that is 0.004- to 0.008-inch (0.1- to 0.2-millimeter) deep cut into the ring face. This groove is filled with molybdenum, using a metallic (or plasma) spray method, so that there is a cast-iron edge above and below the molybdenum. This edge may be chamfered in some applications. A sectional view of a molybdenum-faced ring is shown in Figure 25-28.

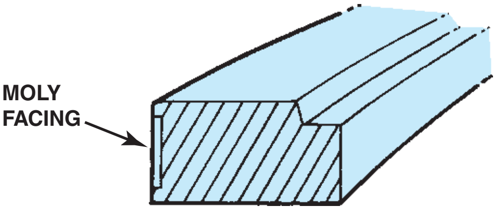


FIGURE 25-28 The moly facing on this compression ring is about 0.005-inch (0.13-mm) thick.

Molybdenum-faced piston rings will survive under high-temperature and scuffing conditions better than chromium-faced rings. Under abrasive wear conditions, chromium-faced rings will have a better service life. There is little measurable difference between these two facing materials with respect to blowby, oil control, break-in, and horsepower. Piston rings with either of these two types of facings are far better than plain cast-iron rings with phosphorus coatings. A molybdenum-faced ring, when used, will be found in the top groove, and a plain cast-iron or chromium-faced ring will be found in the second groove.

Moly-Chrome-Carbide Rings

Rings with moly-chrome-carbide coating are also used in some original equipment (OE) and replacement applications. The coating has properties that include the hardness of the chrome and carbide combined with the heat resistance of molybdenum. Ceramic-coated rings are also being used where additional heat resistance is needed, such as in some heavy-duty, turbocharged, or supercharged engines.

Oil Control Rings

The scraping action of the oil control ring allows oil to return through the ring and openings in the piston. Figure 25-29 shows how the scraping action of the oil control ring can be used to lubricate the piston pin. Steel spring expanders were placed in the ring groove behind the ring to improve static radial tension. They forced the ring to conform to the cylinder wall. Many expander designs are used. On the three-piece ring, a spacer-expander lies between the top and bottom rails. The spacer-expander keeps the rails separated and pushes them out against the cylinder wall. See Figure 25-30.

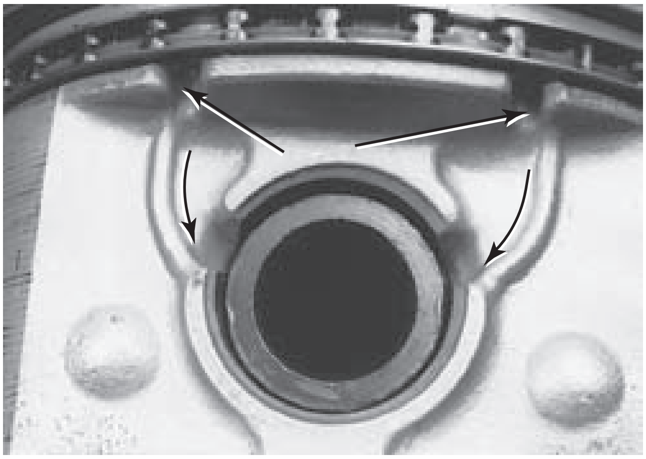


FIGURE 25-29 The oil scraped from the cylinder walls by the oil control ring is directed to lubricate the piston pin in this design.

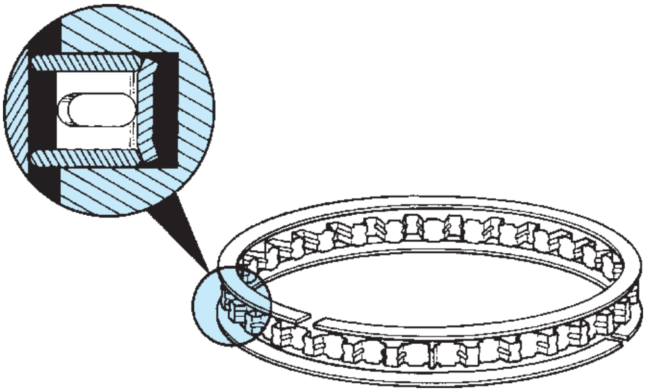


FIGURE 25-30 This typical three-piece oil control ring uses a hump-type stainless steel spacer-expander. The expander separates the two steel rails and presses them against the cylinder wall.

PISTON SERVICE

The pistons are removed from the rods using a special fixture shown in Figure 25-31. After cleaning, the skirts of the used industrial pistons should be resized, and a spacer is placed in the top of the upper ring grooves.

As the piston goes rapidly up and down in the cylinder, it tosses the rings to the top and to the bottom of the ring grooves. The pounding of each ring in its groove gradually increases the piston ring side clearance. Material is worn from both the ring and the groove. See Figure 25-32. Replace the piston if the ring groove is larger than factory specifications.

CONNECTING RODS

The connecting rod transfers the force and reciprocating motion of the piston to the crankshaft. The small end of the connecting rod reciprocates with the piston. The large end rotates with the crankpin. See Figure 25-32. These dynamic motions make it desirable to keep the connecting rod as light as possible while still having a rigid beam section. See Figure 25-33.

Connecting rods are manufactured by casting, forging, and powdered (sintered) metal processes.

Cast Connecting Rods

Casting materials and processes have been improved so that they are used in most vehicle engines with high production standards. Cast connecting rods can be identified by their

FIGURE 25-31 A press used to remove the connecting rod from the piston.

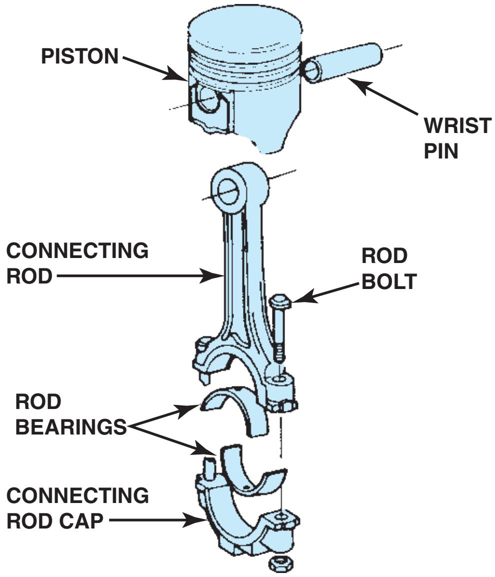


FIGURE 25-32 The connecting rod is the most highly stressed part of any engine because combustion pressure tries to compress it and piston inertia tries to pull it apart.

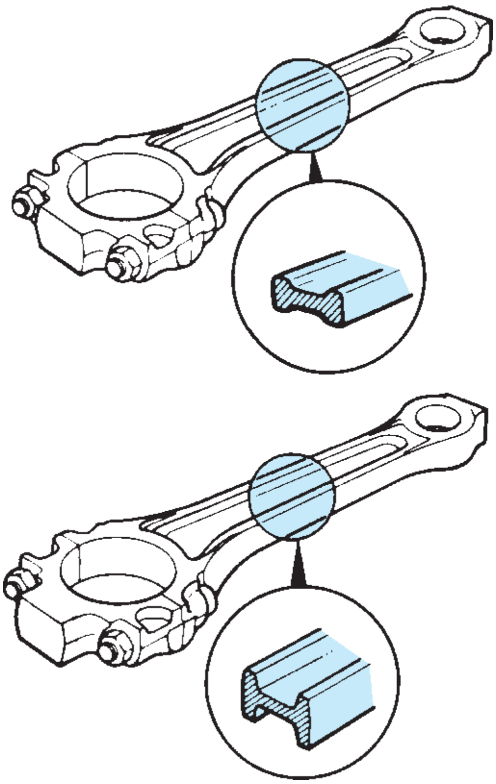


FIGURE 25-33 Even though different rods may have different cross-sections, most are I-beam shaped.

narrow parting line. A typical rough connecting rod casting is shown in Figure 25-34.

Forged Connecting Rods

Forged connecting rods have been used for years. They are generally used in heavy-duty and high-performance engines. Generally, the forging method produces lighter weight and stronger, but more expensive, connecting rods. Forged connecting rods can be identified by their *wide parting line.* Many high-performance connecting rods use a bronze bushing in the small end of the rod as shown in Figure 25-35.

FIGURE 25-34 Rough casting for a connecting rod.

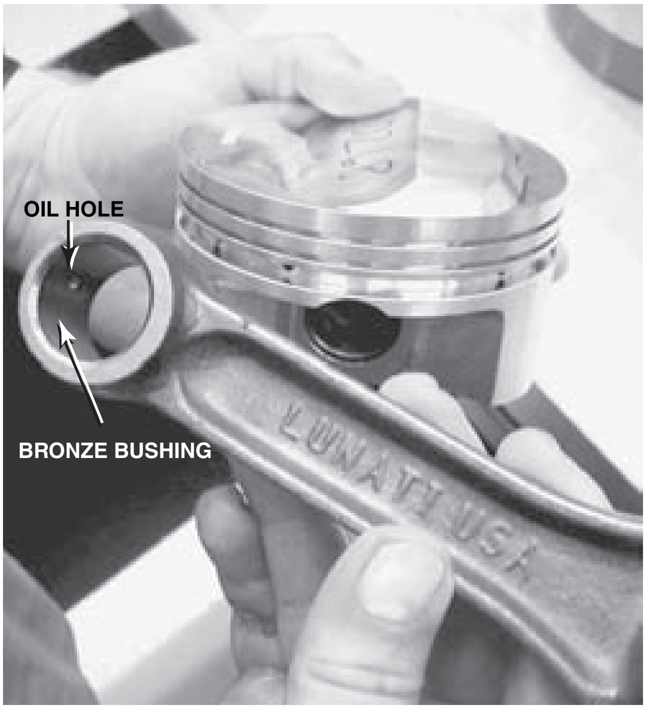


FIGURE 25-35 This high-performance connecting rod uses a bronze bushing in the small end of the rod and oil hole to allow oil to reach the full-floating piston pin.

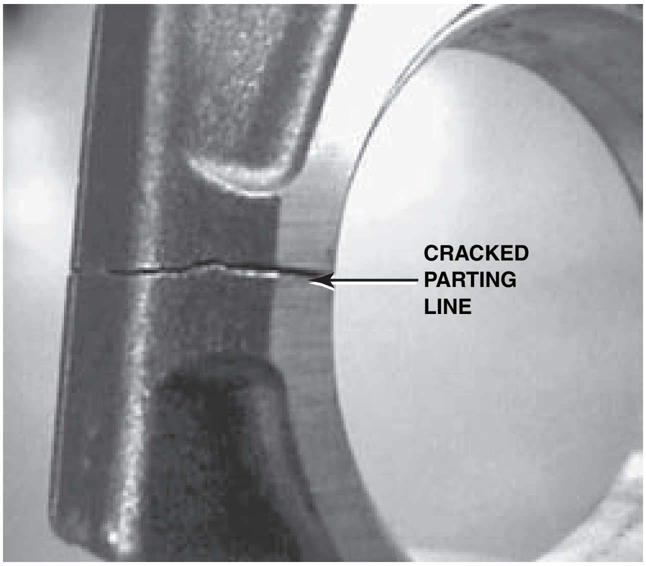


FIGURE 25-36 Powdered metal connecting rods feature a fractured parting line at the big end of the rod.

Powdered Metal Connecting Rods

Most new production engines, such as the General Motors Northstar and Chrysler Hemi, use powdered metal (PM) rods.

Powdered metal connecting rods have many advantages over conventional cast or forged rods including precise weight control. Each rod is created using a measured amount of material so that rod balancing, and therefore engine balancing, is now achieved without extra weighting and machining operations.

Powdered metal connecting rods start as powdered metal, which includes iron, copper, carbon, and other alloying agents. This powder is then placed in a die and compacted (forged) under a pressure of 30 to 50 tons per square inch. After the part is shaped in the die, it is taken through a sintering operation where the part is heated, without melting, to about 2,000°F. During the sintering process, the ingredients are transformed into metallurgical bonds, giving the part strength. Machining is very limited and includes boring the small and big ends and drilling the holes for the rod bearing cap retaining bolts. The big end is then fractured using a large press. The uneven parting line helps ensure a perfect match when the pieces are assembled. See Figure 25-36.

CONNECTING ROD DESIGN

The big end of the connecting rod must be a perfect circle. Therefore, the rod caps must not be interchanged. Assembly bolt holes are closely reamed in both the cap and connecting rod to ensure alignment. The connecting rod bolts have **piloting surfaces** that closely fit these reamed holes. The fit of the connecting rod bolts is so tight that a press must be used to remove the bolts when they are to be replaced, as shown in Figure 25-37.

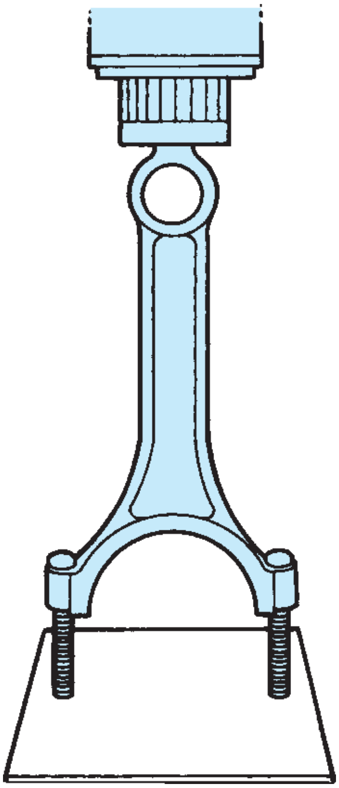


FIGURE 25-37 Rod bolts are quickly removed by using a press.

In some engines, offset connecting rods provide the most economical distribution of main bearing space and crankshaft cheek clearance.

Connecting rods are made with **balancing bosses (pads)** so that their weight can be adjusted to specifications. Some have balancing bosses only on the rod cap. Others also have a balancing boss above the piston. Some manufacturers put balancing bosses on the side of the rod, near the center of gravity of the connecting rod. Typical balancing bosses can be seen in Figure 25-38. Balancing is done on automatic balancing machines as the final machining operation before the rod is installed in an engine.

Most connecting rods have a **spit hole** that bleeds some of the oil from the connecting rod journal. See Figure 25-39. On inline engines, oil is thrown up from the spit hole into the cylinder in which the rod is located. On V-type engines, it is often thrown into a cylinder in the opposite bank. The oil that is spit from the rod is aimed so that it will splash into the interior of the piston. This helps to lubricate the piston pin. A hole similar to the spit holes may be used. It is called a **bleed hole.** Its only purpose is to control the oil flow through the bearing.

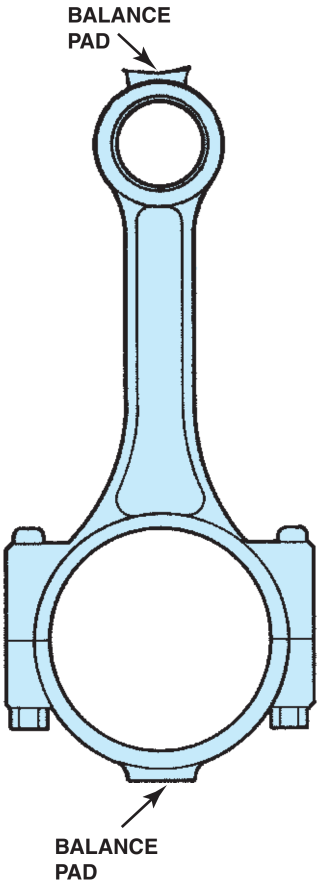


FIGURE 25-38 Some rods have balance pads on each end of the connecting rod.

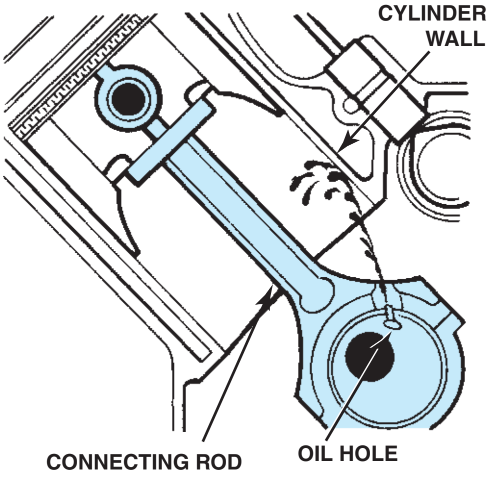


FIGURE 25-39 Some connecting rods have spit holes to help lubricate the cylinder walls or piston pins.

ROD TWIST

During connecting rod reconditioning, the rod should be checked for twist. See Figure 25-40. In other words, the hole at the small end and the hole at the big end of the connecting rod should be parallel. No more than 0.002-inch (0.05-millimeter) twist is acceptable. See Figure 25-41 for the fixture used to check connecting rods for twist. If measured rod twist is excessive, some specialty shops can remove the twist by bending the rod cold. Both cast and forged rods can be straightened. However, many engine builders replace the connecting rod if it is twisted.

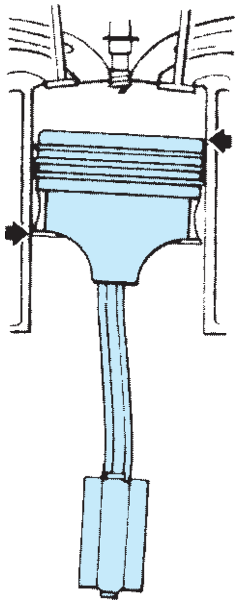


FIGURE 25-40 If the rod is twisted, it will cause diagonal-type wear on the piston skirt.

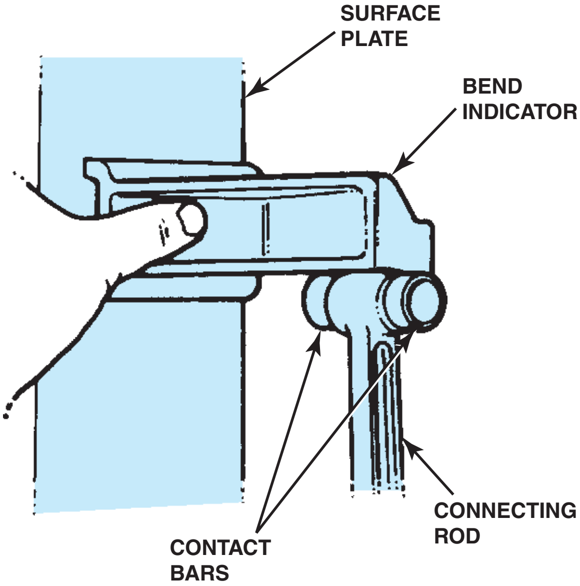


FIGURE 25-41 A rod alignment fixture being used to check a connecting rod to see if it is bent or twisted.

CONNECTING ROD SERVICE

As an engine operates, the forces go through the large end of the connecting rod. This causes the crankshaft end opening of the rod (eye) to gradually deform. See Figure 25-42. The large eye of the connecting rod is resized during precision engine service.

Step 1 The parting surfaces of the rod and cap are smoothed to remove all high spots before resizing. A couple of thousandths of an inch of metal is removed from the rod cap parting surface. This is done using the same grinder that is used to remove a slight amount of metal from the parting surface of main bearing caps. The amount removed from the rod and rodcap only reduces the bore size 0.003 to 0.006 inch (0.08 to 0.15 millimeter).

NOTE: Powdered metal connecting rods cannot be reconditioned using this method. Most manufacturers recommend replacing worn powdered metal connecting rods.

Step 2 The cap is installed on the rod, and the nuts or cap screws are properly torqued. The hole is then bored or honed to be perfectly round and of the size and finish required to give the correct connecting rod bearing crush. Figure 25-43 shows the setup for resizing the rod on a typical hone used in engine reconditioning.

Even though material is being removed at the big end of the rod, the compression ratio is changed very little. The inside of the bore at the big end should have a 60- to 90-microinch finish for proper bearing contact and heat transfer.

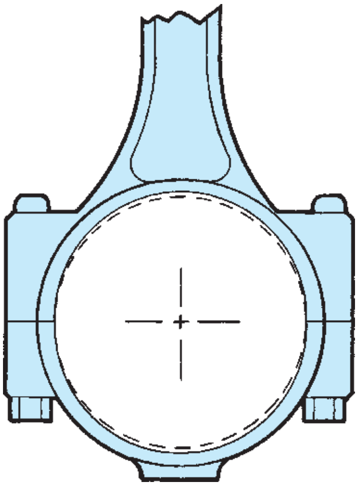


FIGURE 25-42 Rod bearing bores normally stretch from the top to the bottom, with most wear concentrated on the cap.

PISTON AND ROD ASSEMBLY

To assemble the piston and rod, the piston pin is put in one side of the piston. The small end of the connecting rod should be checked for proper size. The small eye of the connecting rod is heated before the pin is installed. See Figure 25-44. This causes the rod eye to expand so that the pin can be pushed into place with little force. The pin must be rapidly pushed into the correct center position. There is only one chance to get it in the right place because the rod will quickly seize on the pin as the rod eye is cooled by the pin.

Full-floating piston pins operate in a bushing in the small eye of the connecting rod. The bushing can be replaced. The bushing and the piston are honed to the same diameter. This allows the piston pin to slide freely through both. The full-floating piston pin is held in place with a lock ring at each end of the piston pin. The lock ring expands into a small groove in the pin hole of the piston.

NOTE: The lock rings should always be replaced with new rings.

Care must be taken to ensure that the pistons and rods are in the correct cylinder. They must face in the correct direction. There is usually a **notch** on the piston head indicating the *front.* Using this will correctly position the piston pin offset toward the right side of the engine. The connecting rod **identification marks** on pushrod inline engines are normally placed on the camshaft side.

NOTE: The camshaft side of an inline OHV engine is also the oil filter side of most engines.

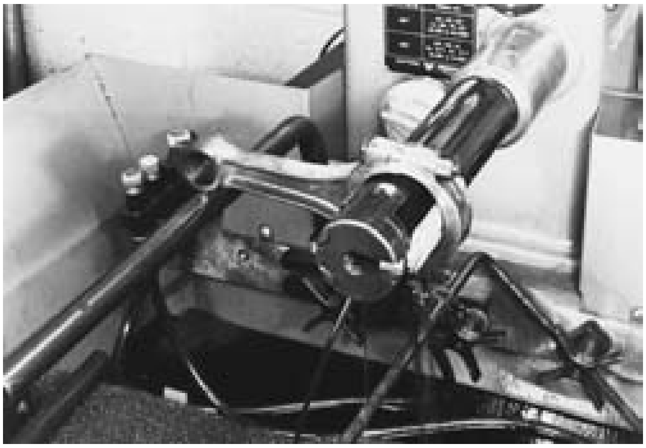


FIGURE 25-43 Resizing the big end of the connection rod with a hone. To help ensure a more accurate and straighter job, hone two connecting rods at a time.

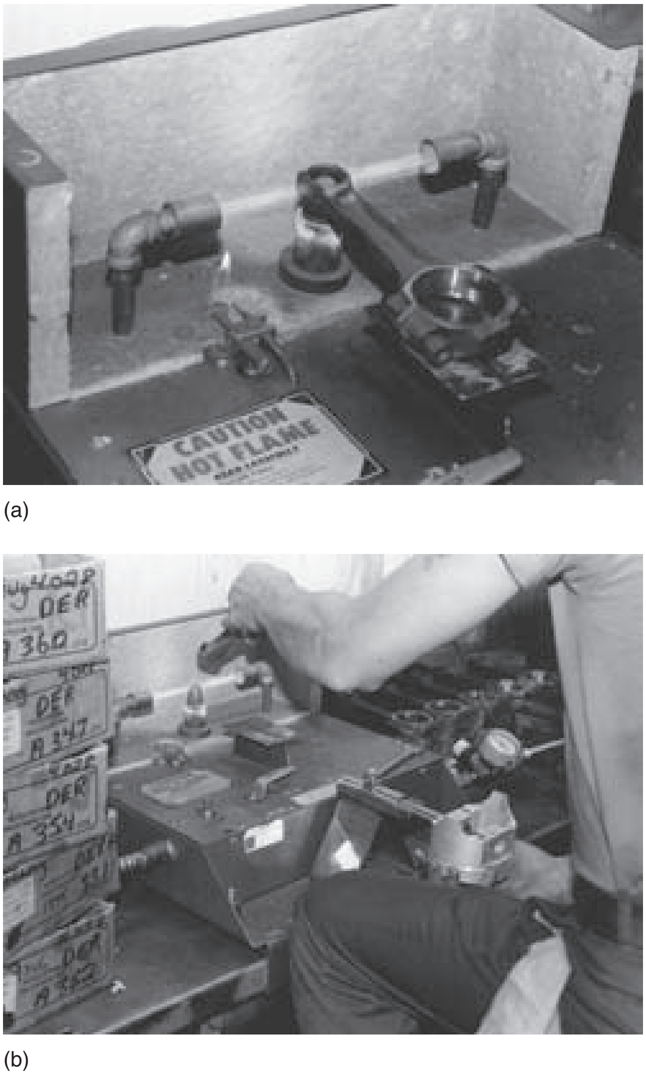


FIGURE 25-44 (a) Flame-type connecting rod heater, the type most often used by remanufacturers because of the rapid heating. The rod should not be heated to more than 700°F (370°C). (If the rod turns blue, it is too hot.) (b) An operator removing the heated connecting rod and preparing to install it on the piston. Note the fixture used to hold the piston pin, and the dial indicator (gauge) used to ensure proper positioning.

The notch and numbers on a piston and rod assembly can be seen in Figure 25-45. On V-type engines, the connecting rod cylinder identification marks are on the side of the rods that can be seen from the bottom of the engine when the piston and rod assemblies are installed in the engine. The service manual should be checked for any special piston and rod assembly instructions.

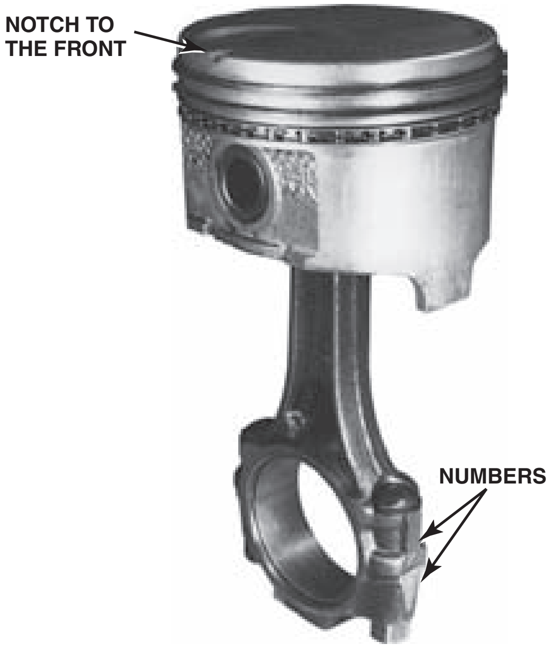


FIGURE 25-45 Position of the notch at the front of the piston, and the connecting rod numbers.

FIGURE 25-46 The side clearance of the piston ring is checked with a thickness (feeler) gauge.

PISTON RING SERVICE

Each piston ring, one at a time, should be placed backward in the groove in which it is to be run. Its side clearance in the groove should be checked with a feeler gauge, as shown in Figure 25-46. If a ring is tight at any spot, check for deposits or burrs in the ring groove. Each piston ring, one at a time, is then placed in the cylinder in which it is to operate.

After the block and cylinder bores have been reconditioned, invert the piston and push each ring into the lower quarter of the cylinder; then measure the ring gap. See Figure 25-47. It should be approximately 0.004 inch for each inch of bore diameter (0.004 millimeter for each centimeter of bore diameter). If necessary, use a file or hand-operated piston ring grinder to achieve the necessary ring gap. See Figure 25-48.

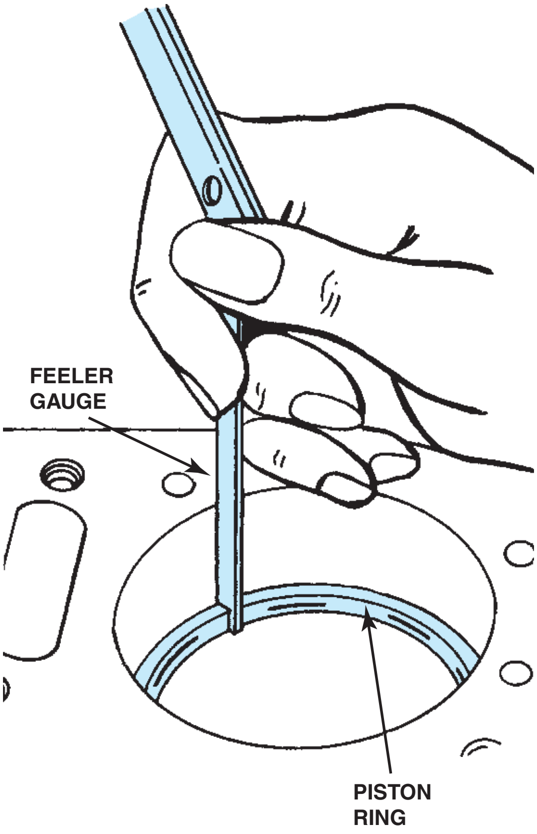


FIGURE 25-47 The ring gap is measured with a feeler gauge.

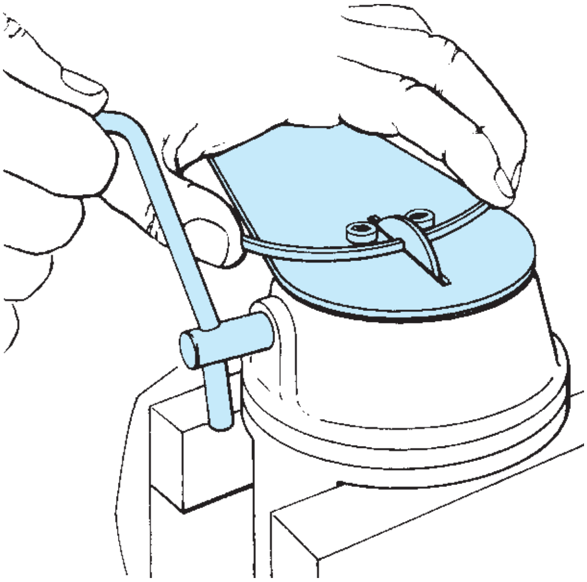


FIGURE 25-48 A hand-operated piston ring end gap grinder being used to increase the end gap of a piston ring in order to bring it to within factory specifications before installation on the piston.

The oil rings are installed first. The expander-spacer of the oil ring is placed in the lower ring groove. One oil ring rail is carefully placed above the expander-spacer by winding it into the groove. The other rail is placed below the expander-spacer. The ring should be rotated in the groove to ensure that the expander-spacer ends have not overlapped. If they have, the ring must be removed and reassembled correctly.

Installing the compression rings requires the use of a piston ring expander tool that will only open the ring gap enough to slip the ring on the piston. See Figure 25-49. Be careful to install the ring with the correct side up. The top of the compression ring is marked with a dot, the letter *T*, or the word *top*. See Figure 25-50. After the rings are installed, they should be rotated in the groove to ensure that they move freely, and checked to ensure that they will go fully into the groove so that the ring face is flush with the surface of the piston ring lands. Usually, the rings are placed on all pistons before any pistons are installed in the cylinders.

FIGURE 25-49 A typical ring expander being used to install a piston ring.

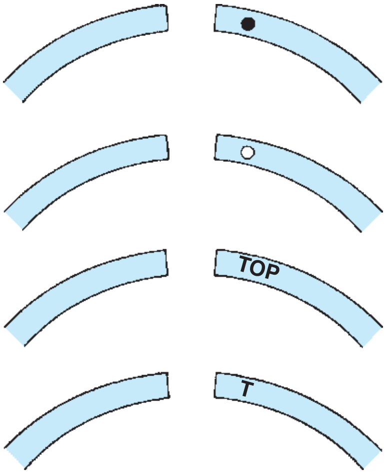


FIGURE 25-50 Identification marks used to indicate the side of the piston ring to be placed toward the head.

SUMMARY

1. The connecting rods should be marked before disassembly.
2. Pistons are cam ground so that when operating temperature is reached, the piston will have expanded enough across the piston pin area to become round.
3. Replacement pistons should weigh the same as the original pistons to maintain proper engine balance.
4. Some engines use an offset piston pin to help reduce piston slap when the engine is cold.
5. Piston rings usually include two compression rings at the top of the piston and an oil control ring below the compression rings.
6. If the ring end gap is excessive, blowby gases can travel past the rings and into the crankcase.
7. Many piston rings are made of coated cast iron to provide proper sealing.
8. If the connecting rod is twisted, diagonal wear will be noticed on the piston skirt.
9. Powdered metal connecting rods are usually broken at the big end parting line. Because of this rough junction, powdered metal connecting rods cannot be reconditioned—they must be replaced if damaged or worn.
10. The piston and the connecting rod must be correctly assembled according to identifying notches or marks.

REVIEW QUESTIONS

1. Describe the procedure for correctly removing the piston and rod assembly from the engine.
2. What methods are used to control piston heat expansion?
3. Why are some piston skirts tin plated?
4. Describe the effect of the piston pin offset as it controls piston slap.
5. Why is it important to keep the connecting rod cap with the rod on which it was originally used, and to install it in the correct way?
6. What causes the piston ring groove clearance to widen in service?
7. Describe how connecting rods are reconditioned.
8. How is the piston pin installed in the piston and rod assembly?

CHAPTER QUIZ

1. Connecting rod caps should be marked (if they were not marked at the factory) before the piston and connecting rod assembly is removed from the engine _____.
   - **a.** Because they are balanced together
   - **b.** Because they are machined together
   - **c.** To make certain that the heavier rod is matched to the heavier piston
   - **d.** To make certain that the lighter rod is matched to the lighter piston
2. Many aluminum piston skirts are plated with _____.
   - **a.** Tin
   - **b.** Lead
   - **c.** Antimony
   - **d.** Terneplate
3. A hypereutectic piston has _____.
   - **a.** A higher weight than a eutectic piston
   - **b.** A higher silicon content
   - **c.** A higher tin content
   - **d.** A higher nickel content
4. The purpose of casting steel struts into an aluminum piston is to _____.
   - **a.** Provide increased strength
   - **b.** Provide increased weight at the top part of the piston where it is needed for stability
   - **c.** Provide increased heat transfer from the piston head to the piston pin
   - **d.** Control thermal expansion

5. Full-floating piston pins are retained by _____.

a. Lock rings

b. A drilled hole with roll pin

c. An interference fit between rod and piston pin

d. An interference fit between piston and piston pin

6. The space behind the ring is called _____.

a. side clearance

b. forward clearance

c. back clearance

d. piston ring clearance

7. A misaligned connecting rod causes what type of engine wear?

a. Cylinder taper

b. Barrel-shaped cylinders

c. Ridge wear

d. Angle wear on the piston skirt

8. Side clearance is a measure taken between the _____ and the _____.

a. Piston (side skirt); cylinder wall

b. Piston pin; piston pin retainer (clip)

c. Piston ring; piston ring groove

d. Compression ring; oil control ring

9. Piston ring gap should only be measured _____.

a. After all cylinder work has been performed

b. After installing the piston in the cylinder

c. After installing the rings on the piston

d. Both a and c

10. Which type of connecting rod needs to be heated to be installed?

a. forged

b. interference fit

c. floating

d. PM rods