CHAPTER 27

CRANKSHAFTS AND BEARINGS

OBJECTIVES

After studying Chapter 27, 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 a crankshaft.
3. Explain how crankshafts are machined and polished.
4. Discuss engine bearing construction and installation procedures.

KEY TERMS

Aluminum Bearing (p. 539)
Amplitude (p. 530)
Babbitt (p. 537)
Bank (p. 527)
Bearing Crown (p. 535)
Case Hardening (p. 526)
Conformability (p. 536)
Copper-Lead Alloy (p. 537)
Corrosion Resistance (p. 537)
Counterweights (p. 528)
Crankpins (p. 525)
Crankshaft Centerline (p. 524)
Crush (p. 539)
Elastomer (p. 530)
Electroplating (p. 538)
Embedability (p. 537)
Fatigue Life (p. 536)
Flying Web (p. 528)
Frequency (p. 529)
Full Round Bearing (p. 541)
Fully Counterweighted (p. 528)
Half-Shell Bearing (p. 539)
Hub (p. 530)
Inertia Ring (p. 530)
Nitriding (p. 526)
Overlay (p. 538)
Plain Bearing (p. 535)
Precision Insert-Type Bearing Shells (p. 539)
Resonate (p. 529)
Score Resistance (p. 537)
Sleeve Bearing (p. 535)
Splay Angle (p. 528)
Split-Type (Half-Shell) Bearing (p. 541)
Spread (p. 539)
Spun Bearing (p. 540)
Surface Finish (p. 526)
Thrust Bearing (p. 525)
Tuftriding (p. 526)
Work Hardened (p. 536)

CRANKSHAFT

Purpose and Function

Power from expanding gases in the combustion chamber is delivered to the crankshaft through the piston, piston pin, and connecting rod. The connecting rods and their bearings are attached to a bearing journal on the crank throw. The crank throw is offset from the **crankshaft centerline.** The combustion force is applied to the crank throw after the crankshaft has moved past top center. This produces the turning effort or torque, which rotates the crankshaft. The crankshaft rotates on the main bearings. These bearings are split in half so that they can be assembled around the crankshaft main bearing journals. The crankshaft includes the following parts:

- Main bearing journals
- Rod bearing journals
- Crankshaft throws
- Counterweights
- Keyways
- Oil passages

See Figure 27-1.

Main Bearing Journals

The crankshaft rotates in the cylinder block on main bearings. See Figure 27-2.

The bearings support the crankshaft and allow it to rotate easily without excessive wear. The number of cylinders usually determines the number of main bearings.

- Four-cylinder engines and V-8 engines usually have five main bearings.
- Inline 6-cylinder engines usually have seven main bearings.
- V-6 engines normally have only four main bearings.

See Figure 27-3.

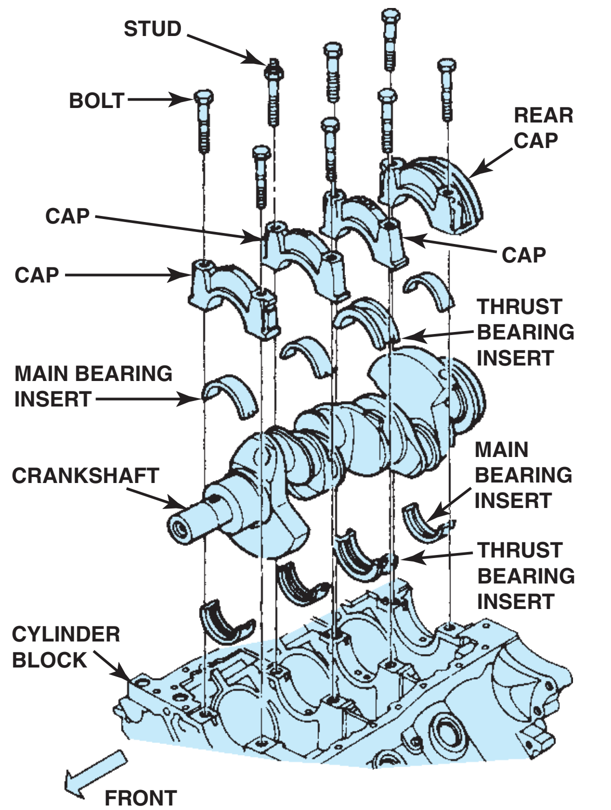


FIGURE 27-2 The crankshaft rotates on main bearings. Longitudinal (end-to-end) movement is controlled by the thrust bearing.

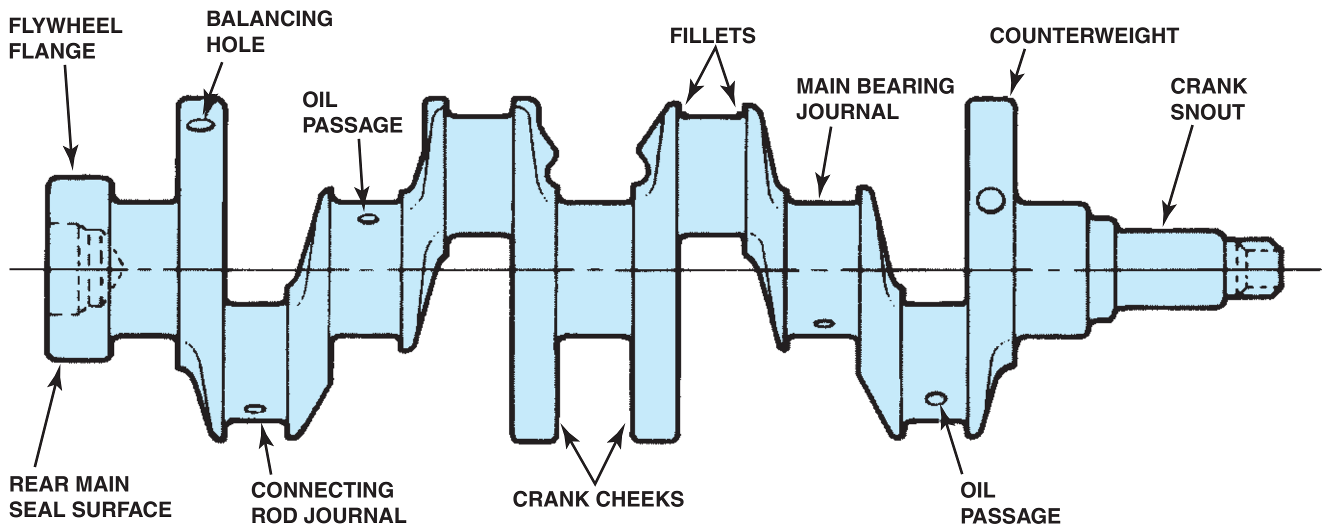


FIGURE 27-1 Typical crankshaft with main journals that are supported by main bearings in the block. Rod journals are offset from the crankshaft centerline.

The crankshaft also has to be able to absorb thrust loads from the clutch on a manual transmission vehicle or the torque converter on a vehicle equipped with an automatic transmission. Thrust loads are forces that push and pull the crankshaft forward and rearward in the engine block. A **thrust bearing** supports these loads and maintains the front-to-rear position of the crankshaft in the block. See Figure 27-4.

The thrust surface is usually located at the middle on one of the end main bearings. On most engines, the bearing insert for the main bearing is equipped with thrust bearing flanges that ride against the thrust surface.

Rod Bearing Journals

The rod bearing journals, also called **crankpins,** are offset from the centerline of the crank. Insert-type bearings fit between the big end of the connecting rod and the crankpin of the crankshaft.

The amount of offset of the rod bearing journal determines the stroke of the engine. The crankshaft with throws that measure one-half of the stroke has a direct relationship to the displacement of the engine. See Figure 27-5.

FIGURE 27-4 A ground surface on one of the crankshaft cheeks next to a main bearing supports thrust loads on the crank.

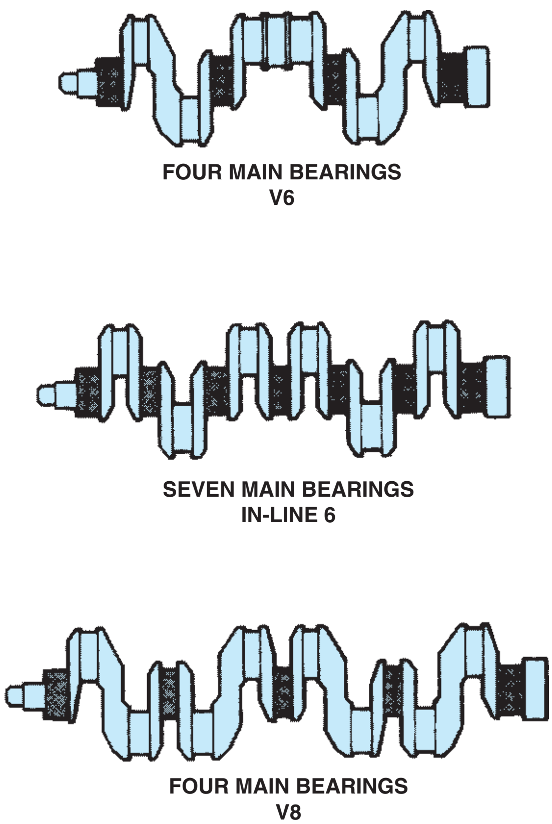


FIGURE 27-3 The longer the crankshaft, the more main bearing journals are needed.

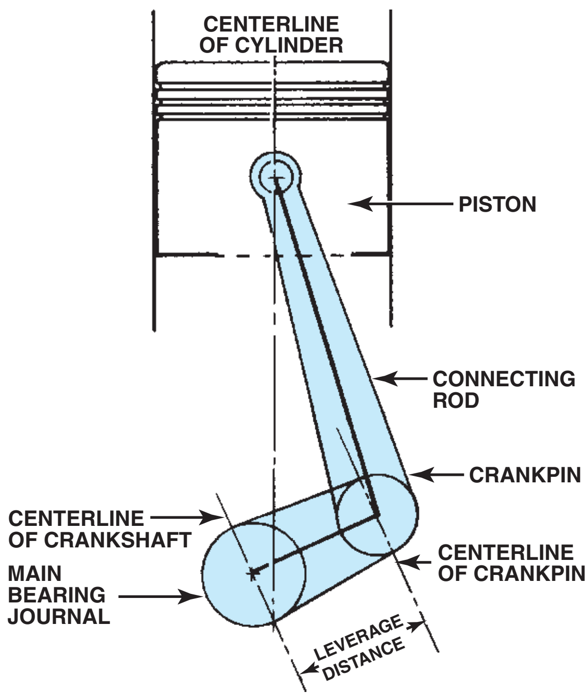


FIGURE 27-5 The distance from the crankpin centerline to the centerline of the crankshaft determines the stroke, which is the leverage available to turn the crankshaft.

Surface Finish

All crankshaft journals are ground to a very smooth finish. **Surface finish** is measured in micro-inches and the smaller the number, the smoother the surface. Where the surface finish of a machined block deck or cylinder head may range from 60 to 100 RA (roughness average), the typical specification for main and rod crankshaft journals is between 10 and 20 RA. This very smooth surface finish is achieved by polishing the crank journals after the grinding operation.

Journal Hardness

To improve wear resistance, some manufacturers harden the crankshaft journals. One method used is called **case hardening,** where only the outer portion of the surface is hardened. Case hardening involves heating the crankshaft and adding carbon to the journals where it causes the outer surface to become harder than the rest of the crankshaft. If the entire crankshaft was hardened, it would become too brittle to be able to absorb the torsional stresses of normal engine operation.

Another form of case hardening is called **nitriding.** The crankshaft is heated to about 1,000°F (540°C) in a furnace filled with ammonia gas, and then allowed to cool. The process adds nitrogen (from the ammonia) into the surface of the metal—forming hard nitrides in the surface of the crankshaft to a depth of about 0.007 inch (0.8 mm).

Another variation of this process involves heating the crankshaft in a molten cyanide salt bath. General Motors Corporation uses this process referred to by the trade name **Tuftriding.**

CRANKSHAFT CONSTRUCTION

Forged

Crankshafts used in high-production automotive engines may be either forged or cast. Forged crankshafts are stronger than the cast crankshaft, but they are more expensive. Forged crankshafts have a wide separation line, as seen in Figure 27-6.

Most high-performance forged crankshafts are made from SAE 4340 or a similar type of steel. The crankshaft is formed from a hot steel billet through the use of a series of forging dies. Each die changes the shape of the billet slightly. The crankshaft blank is finally formed with the last die. The blanks are then machined to finish the crankshaft. Forging makes a very dense, tough crankshaft with the metal's grain structure running parallel to the principal direction of stress.

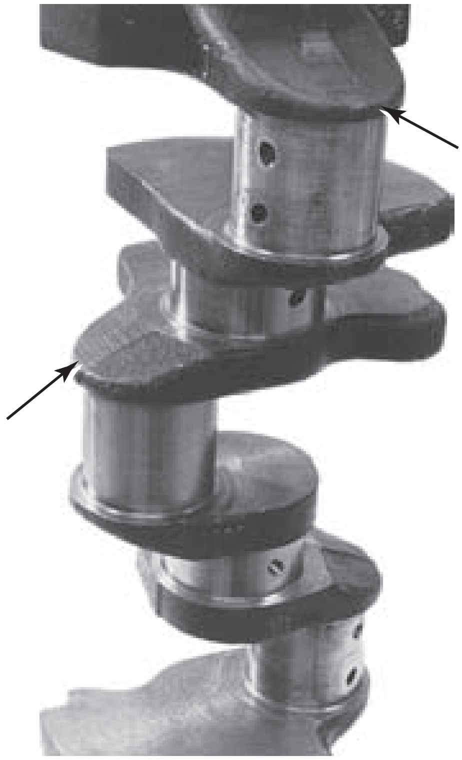


FIGURE 27-6 Wide separation lines where the flashings have been removed from this forged crankshaft show that it has been twisted to index the crank throws. Most newer forged crankshafts are not twisted.

Two methods are used to forge crankshafts.

- One method is to forge the crankshaft *in place*. This is followed by straightening. The forging in place method is primarily used with forged 4- and 6-cylinder crankshafts.
- A second method is to forge the crankshaft in a *single plane*. It is then twisted in the main bearing journal to index the throws at the desired angles.

Cast Crankshafts

Casting materials and techniques have improved cast crankshaft quality so that cast crankshafts are used in most production automotive engines. Automotive crankshafts may be cast in steel, nodular iron, or malleable iron. The major advantage of the casting process is that crankshaft material and machining costs are less than they are with forging. The reason is that the crankshaft can be made close to the required shape and size, including all complicated counterweights. The only machining required on a carefully designed cast crankshaft is the grinding of bearing journal surfaces and the finishing of front and rear drive ends. Metal grain structure in the cast crankshaft is uniform and random throughout; thus, the shaft is able to handle loads from all directions. Counterweights on cast crankshafts are slightly larger than counterweights on a forged crankshaft, because the cast shaft metal is less dense

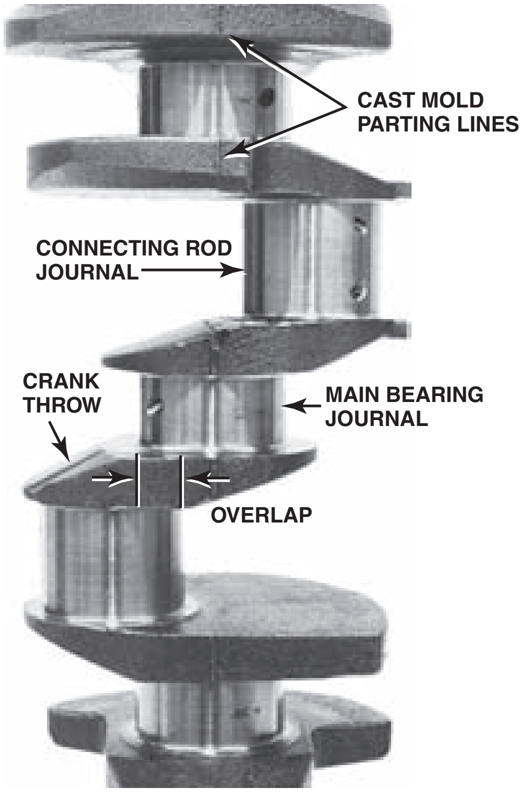


FIGURE 27-7 Cast crankshaft showing the bearing journal overlap and a straight, narrow cast mold parting line.

and therefore somewhat lighter. The narrow mold parting surface lines can be seen on the cast crankshaft pictured in Figure 27-7.

V-8 ENGINE CRANKSHAFTS

The V-8 engine has four inline cylinders in each of the two blocks that are placed at a 90-degree angle to each other. Each group of four inline cylinders is called a **bank.** The crankshaft for the V-8 engine has four throws. The connecting rods from two cylinders are connected to each throw, one from each bank. This arrangement results in a condition of being only minimally unbalanced. The V-8 engine crankshaft has two planes, so there is one throw every 90 degrees. A plane is a flat surface that cuts through the part. These planes could be seen if the crankshaft were cut lengthwise through the center of the main bearing and crankpin journals. Looking at the front of the crankshaft with the first throw at 360 degrees (up), the second throw is at 90 degrees (to the right), the third throw is at 270 degrees (to the left), and the fourth throw is at 180 degrees (down). In operation with this arrangement, one piston reaches top center at each 90 degrees of crankshaft rotation so that the engine operates smoothly with even firing at each 90 degrees of crankshaft rotation.

FOUR-CYLINDER ENGINE CRANKSHAFTS

The crankshaft used on 4-cylinder inline engines has four throws on a single plane. There is usually a main bearing journal between each throw, making it a five-main bearing crankshaft. Pistons also move as pairs in this engine. Pistons in #1 and #4 cylinders move together, and pistons #2 and #3 move together. Each piston in a pair is 360 degrees out-of-phase with the other piston in the 720-degree four-stroke cycle. With this arrangement, the 4-cylinder inline engine fires one cylinder at each 180 degrees of crankshaft rotation.

A 4-cylinder opposed engine and a 90-degree V-4 engine have crankshafts that look like that of the 4-cylinder inline engine.

FIVE-CYLINDER ENGINE CRANKSHAFTS

The inline 5-cylinder engine has a five-throw crankshaft with one throw at each 72 degrees. Six main bearings are used on this crankshaft. The piston in one cylinder reaches top center at each 144 degrees of crankshaft rotation. The throws are arranged to give a firing order of 1-2-4-5-3. Dynamic balancing has been one of the major problems with this engine design, yet the vibration was satisfactorily dampened and isolated on both the Audi and Acura 5-cylinder engines.

THREE-CYLINDER ENGINE CRANKSHAFTS

A 3-cylinder engine uses a 120-degree three-throw crankshaft with four main bearings. This engine requires a balancing shaft that turns at crankshaft speed, but in the opposite direction, to reduce the vibration to an acceptable level.

ODD-FIRING 90-DEGREE V-6 ENGINE CRANKSHAFTS

The 90-degree V-6 engine uses a three-throw crankshaft with four main bearings. The throws are 120 degrees apart. As in typical V-type engines, each crank throw has two connecting rods attached, one from each bank. This V-6 engine design does not have even-firing impulses, because the pistons, connected to the 120-degree crankpins, do not reach top center at even intervals. The engine has a firing pattern of 150°-90°-150°-90°-150°-90°, as illustrated in Figure 27-8.

This firing pattern produces unequal pulses that have to be isolated with engine mounts that have been carefully designed.

REAL WORLD FIX

THE MYSTERIOUS ENGINE VIBRATION

A Buick-built, 3.8-liter V-6 engine vibrated the whole car after a new short block had been installed. The technician who had installed the replacement engine did all of the following:

1. Checked the spark plugs
2. Checked the spark plug wires
3. Disconnected the torque converter from the flex plate (drive plate) to eliminate the possibility of a torque converter or automatic transmission pump problem
4. Removed all accessory drive belts one at a time

Yet the vibration still existed.

Another technician checked the engine mounts and found that the left (driver's side) engine mount was out of location, ripped, and cocked. The transmission mount was also defective. After the technician replaced both mounts and made certain that all mounts were properly set, the vibration was eliminated. The design and location of the engine mounts are critical to the elimination of vibration, especially on 90-degree V-6 engines.

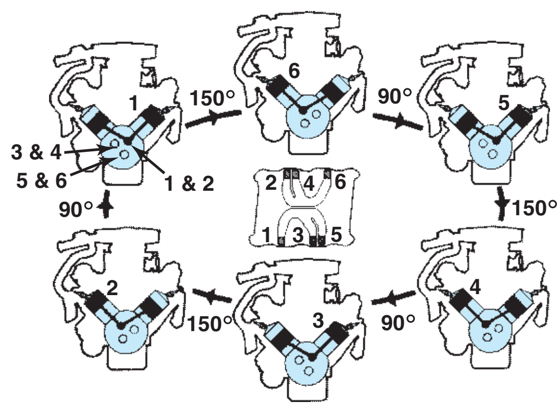


FIGURE 27-8 The firing impulses of this odd-fire V-6 are unequally spaced because two cylinders share a common crankpin.

EVEN-FIRING 90-DEGREE V-6 ENGINE CRANKSHAFTS

The crank throws for an even-firing V-6 engine are split, making separate crankpins for each cylinder. The split throw can be seen in Figure 27-9.

This angle between the crankpins on the crankshaft throws is called a **splay angle.** A flange was left between the split crankpin journals. This provides a continuous fillet or edge for machining and grinding operations. It also provides a normal flange for the rod and bearing. This flange between the splayed crankpin journals is sometimes called a **flying web.**

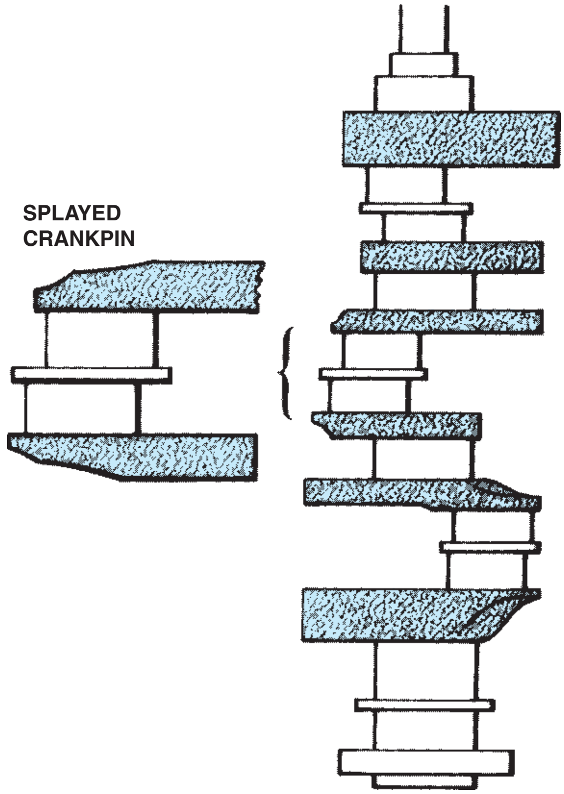


FIGURE 27-9 A splayed crankshaft design is used to create an even-firing 90-degree V-6.

SIXTY-DEGREE V-6 ENGINE CRANKSHAFTS

The 60-degree V-6 engine is similar to the even-firing 90-degree V-6 engine. The adjacent pairs of crankpins on the crankshaft used in the 60-degree V-6 engine have a splay angle of 60 degrees.

With this large 60-degree splay angle, the flange or flying web between the splayed crankpins is made heavier than on crankshafts with smaller splay angles. This is necessary to give strength to the crankshaft. The crankshaft of the 60-degree V-6 engine also uses four main bearings.

COUNTERWEIGHTS

Crankshafts are balanced by **counterweights,** which are cast or forged as part of the crankshaft. A crankshaft that has counterweights on both sides of each connecting rod journal is called **fully counterweighted.** See Figure 27-10.

A fully counterweighted crankshaft is the smoothest running and most durable design, but it is also the heaviest and most expensive to manufacture. Most vehicle manufacturers do not use fully counterweighted crankshafts in an effort to lighten the rotating mass of the engine. An engine with a light crankshaft allows the engine to accelerate quicker.

Vibration Damage

Each time combustion occurs, the force deflects the crankshaft as it transfers torque to the output shaft. This deflection occurs in two ways, to bend the shaft sideways and to twist the shaft in torsion. The crankshaft must be rigid enough to keep the deflection forces to a minimum.

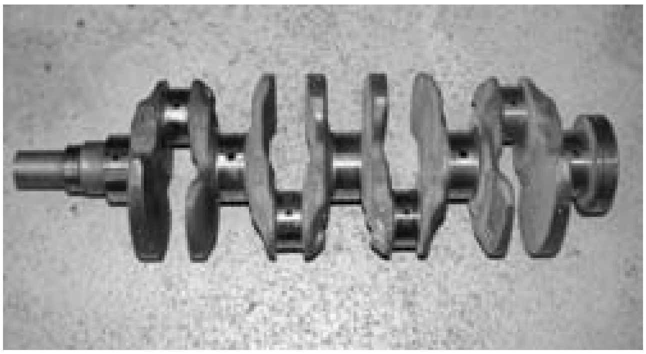


FIGURE 27-10 A fully counterweighted 4-cylinder crankshaft.

FREQUENTLY ASKED QUESTION

WHAT IS AN OFFSET CRANKSHAFT?

To reduce side loads, some vehicle manufacturers offset the crankshaft from center. For example, if an engine rotates clockwise as viewed from the front, the crankshaft may be offset to the left to reduce the angle of the connecting rod during the power stroke. See Figure 27-11.

The offset usually varies from 1/16 to 1/2 inch, depending on make and model. Most gasoline engines used in hybrid gasoline/electric vehicles use an offset crankshaft.

Crankshaft deflections are directly related to the operating roughness of an engine. When back-and-forth deflections occur at the same vibration **frequency** (number of vibrations per second) as that of another engine part, the parts will vibrate together. When this happens, the parts are said to **resonate.** These vibrations may become great enough to reach the audible level, producing a thumping sound. If this type of vibration continues, the part may fail. See Figure 27-12.

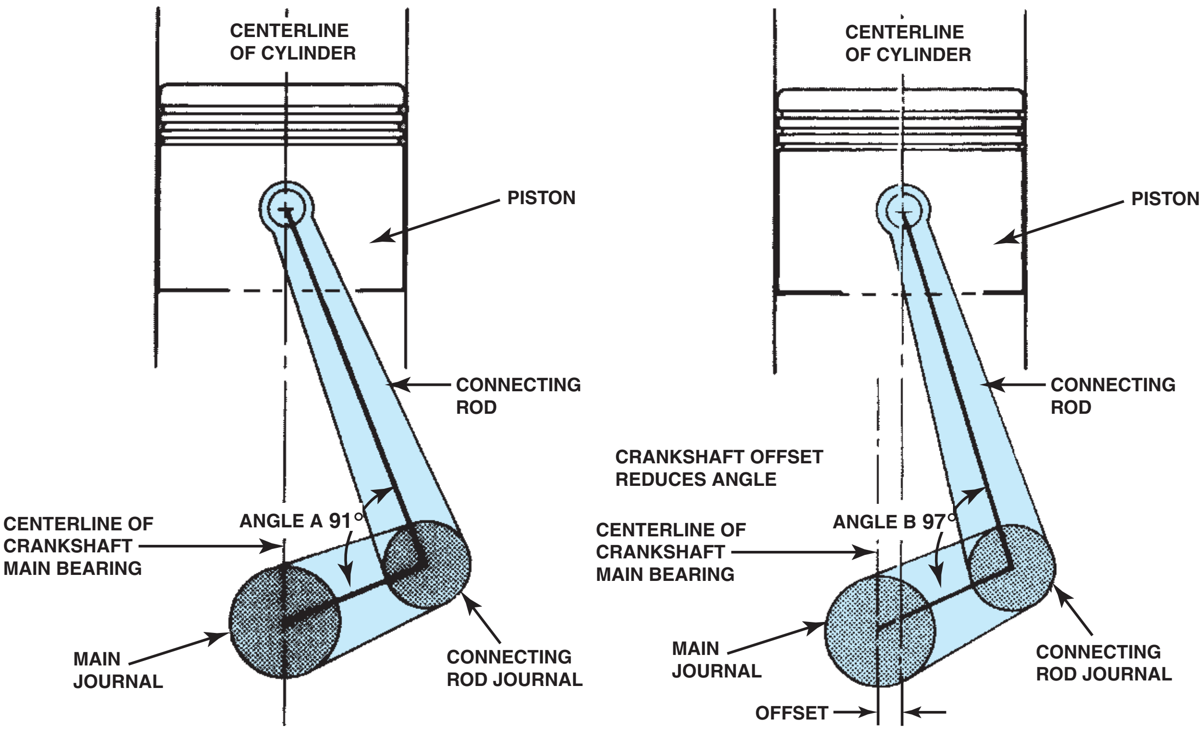


FIGURE 27-11 The crank throw is halfway down on the power stroke. The position on the left without an offset crankshaft has a sharper angle than the engine on the right with an offset crankshaft.

FIGURE 27-12 A crankshaft broken as a result of using the wrong torsional vibration damper.

FIGURE 27-13 This Chevy V-8 harmonic balancer also has a line cut into the outer ring that is used to indicate top dead center to set the ignition timing on engines that are equipped with a distributor ignition.

Harmful crankshaft twisting vibrations are dampened with a torsional vibration damper. It is also called a harmonic balancer. This damper or balancer usually consists of a cast-iron **inertia ring** mounted to a cast-iron **hub** with an **elastomer** sleeve. An example is shown in Figure 27-13.

NOTE: Push on the rubber (elastomer sleeve) of the vibration damper with your fingers or a pencil. *If the rubber does not spring back, replace the damper.*

Elastomers are actually synthetic, rubber-like materials. The inertia ring size is selected to control the **amplitude** of the crankshaft vibrations for each specific engine model. See Figure 27-14.

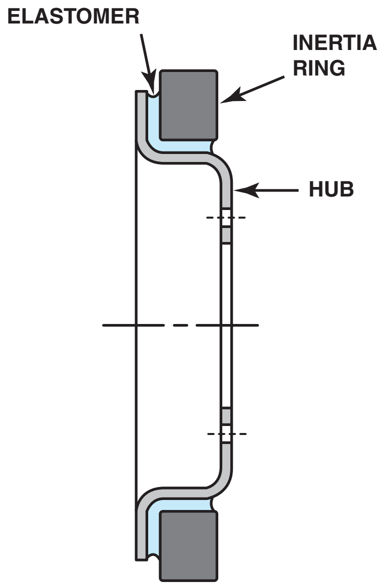


FIGURE 27-14 The hub of the harmonic balancer is attached to the front of the crankshaft. The elastomer (rubber) between the inertia ring and the center hub allows the absorption of crankshaft firing impulses.

TECH TIP

HIGH ENGINE SPEEDS REQUIRE HIGH-PERFORMANCE PARTS

Do not go racing with stock parts. The harmonic balancer shown in Figure 27-15 came apart and the resulting vibration broke the crankshaft when the owner attempted to race with his stock engine.

The owner had made some engine modifications, but he did not change the stock harmonic balancer even though the other changes allowed the engine to rev to much higher speeds than stock parts normally would permit.

EXTERNALLY AND INTERNALLY BALANCED ENGINES

Most crankshaft balancing is done during manufacture. Holes are drilled in the counterweight to lighten it to improve balance. Sometimes these holes are drilled after the crankshaft is

FIGURE 27-15 Harmonic balancer that separated at high engine speed.

installed in the engine. Some manufacturers are able to control casting quality so closely that counterweight machining for balancing is not necessary.

There are two ways engine manufacturers balance an engine:

- **Externally balanced**—Weight is added to the harmonic balancer (vibration damper) and flywheel or the flex plate.
- **Internally balanced**—All rotating parts of the engine are individually balanced, including the harmonic balancer and flywheel (flex plate).

For example, the 350-cubic-inch Chevrolet V-8 is internally balanced, whereas the 400-cubic-inch Chevrolet V-8 uses an externally balanced crankshaft. The harmonic balancer used on an externally balanced engine has additional weight.

CRANKSHAFT OILING HOLES

The crankshaft is drilled, as shown in Figure 27-16, to allow oil from the main bearing oil groove to be directed to the connecting rod bearings.

The oil on the bearings forms a hydrodynamic oil film to support bearing loads. Some of the oil may be sprayed out through a spit or bleed hole in the connecting rod. The rest of the oil leaks from the edges of the bearing. It is thrown from the bearing against the inside surfaces of the engine. Some of the oil that is thrown from the crankshaft bearings will land on the camshaft to lubricate the lobes. A part of the throw-off oil splashes on the cylinder wall to lubricate the piston and rings.

Stress tends to concentrate at oil holes drilled through the crankshaft journals. These holes are usually located where the crankshaft loads and stresses are the lowest. The edges of the oil holes are carefully chamfered to relieve as much stress concentration as possible. Chamfered oil holes are shown in Figure 27-17.

FIGURE 27-16 Crankshaft sawed in half, showing drilled oil passages between the main and rod bearing journals.

FREQUENTLY ASKED QUESTION

WHAT DOES A "CROSS-DRILLED CRANKSHAFT" MEAN?

A cross-drilled crankshaft means that there are two instead of only one oil hole leading from the main bearing journal to the rod bearing journal. Oil is supplied to the main bearing journals through oil galleries in the block. A cross-drilled crankshaft has two outlet holes for oil to reach the drilled passage that supplies oil to the rod journal. See Figure 27-18.

CRANKSHAFT INSPECTION

Shaft damage includes scored bearing journals, bends or warpage, and cracks. Damaged shafts must be reconditioned or replaced.

The crankshaft is one of the most highly stressed engine parts. *The stress on the crankshaft increases by four times every time the engine speed doubles.* Any sign of a crack is a cause to reject the crankshaft. Most cracks can be seen during a close visual inspection. Crankshafts should also be checked with Magnaflux, which will highlight tiny cracks that would lead to failure.

Bearing journal scoring is a common crankshaft defect. Scoring appears as scratches around the bearing journal surface. Generally, there is more scoring near the center of the bearing journal, as shown in Figure 27-19.

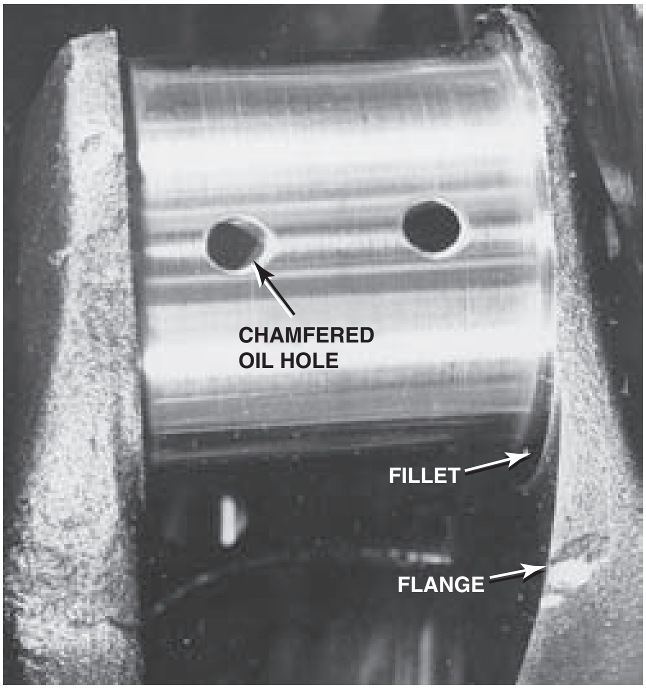


FIGURE 27-17 Typical chamfered hole in a crankshaft bearing journal.

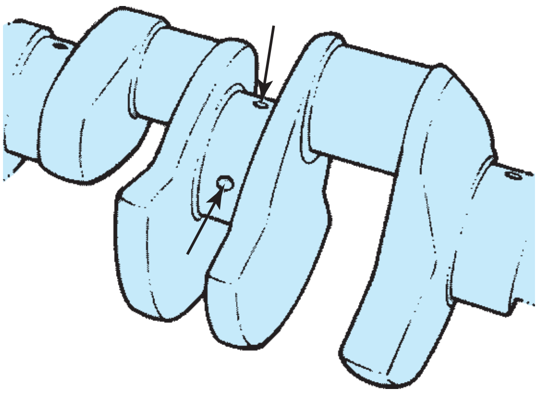


FIGURE 27-18 A cross-drilled crankshaft is used on some production engines and is a common racing modification.

Crankshaft journals should be inspected for nicks, pits, or corrosion. Roughness and slight bends in journals can be corrected by grinding the journals.

NOTE: If your fingernail catches on a groove when rubbed across a bearing journal, the journal is too rough to reuse and must be reground. Another test is to rub a copper penny across the journal. If any copper remains on the crankshaft, it must be reground.

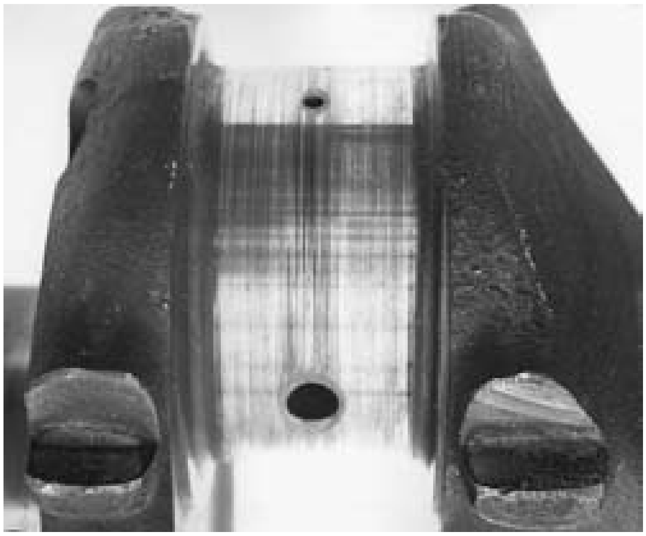


FIGURE 27-19 Scored connecting rod bearing journal.

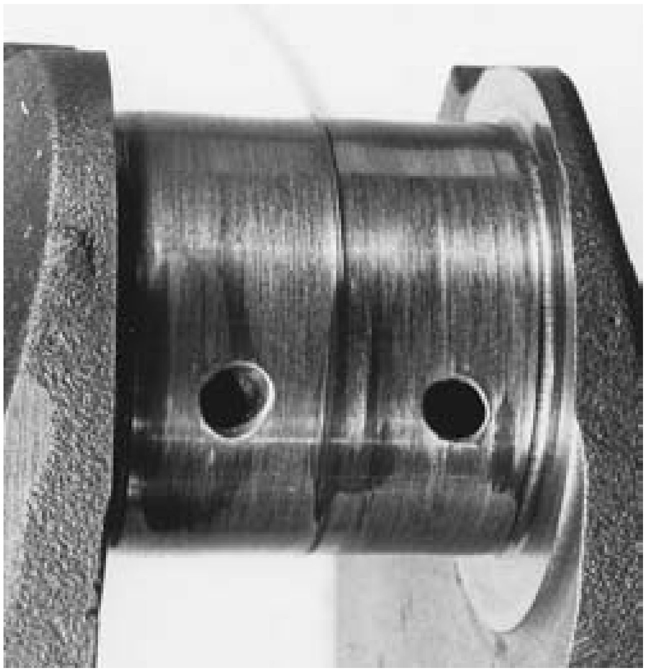


FIGURE 27-20 Connecting rod journal badly worn from lack of lubrication.

CRANKSHAFT GRINDING

Crankshaft journals that have excessive scoring, out-of-round, or taper should be reground. See Figure 27-20.

Crankshafts may require straightening before grinding. Both crankshaft ends are placed in rotating heads on one style of crankshaft grinder. The main bearing journals are ground on the centerline of the crankshaft. The crankshaft is then offset in the two rotating heads just enough to make the crankshaft main bearing journal centerline rotate around the centerline of the crankpin. The crankshaft will then be rotating around the crankpin centerline. The journal on the crankpin is reground in this position. The crankshaft must be repositioned for each different crankpin center.

In another type of crankshaft grinder, the crankshaft always turns on the main bearing centerline. The grinding head is programmed to move in and out as the crankshaft turns to grind the crankpin bearing journals. The setup time is reduced when this type of grinder is used. Figure 27-21 shows a crankshaft being ground.

Crankshafts are usually ground to the following undersize:

- 0.010 inch
- 0.020 inch
- 0.030 inch

The finished journal should be accurately ground to size with a smooth-surface finish. The radius of the fillet area on the sides of the journal should also be the same as the original. The journal is polished after grinding using a 320-grit polishing cloth and oil to remove the fine metal "fuzz" remaining on the journal. See Figure 27-22.

This fuzz feels smooth when the shaft turns in its direction. As the shaft turns in the opposite direction, the fuzz feels like a fine milling cutter. Polishing removes this fuzz. The crankshaft is rotated in its normal direction of rotation so that the polishing cloth can remove the fuzz. This leaves a smooth shaft with the proper surface finish. *Most crankshaft grinders grind in the direction opposite of rotation and then polish in the same direction as rotation.* The oil hole chamfer in the journal should be smoothed so that no sharp edge remains to cut the bearing. Finally, the crankshaft oil passages are thoroughly cleaned.

FIGURE 27-21 A crankshaft being ground.

The reground journals are coated with oil to keep them from rusting until they are to be cleaned for assembly.

WELDING A CRANKSHAFT

Sometimes it is desirable to salvage a crankshaft by building up a bearing journal and then grinding it to the original journal size. This is usually done by either electric arc welding or a metal spray. See Figure 27-23.

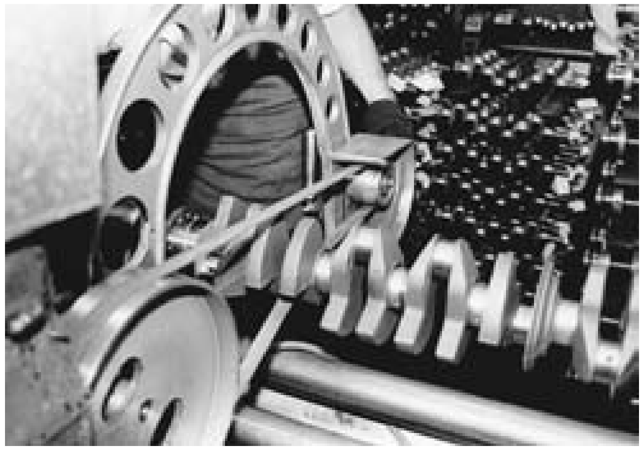


FIGURE 27-22 All crankshafts should be polished after grinding. Both the crankshaft and the polishing cloth are being revolved.

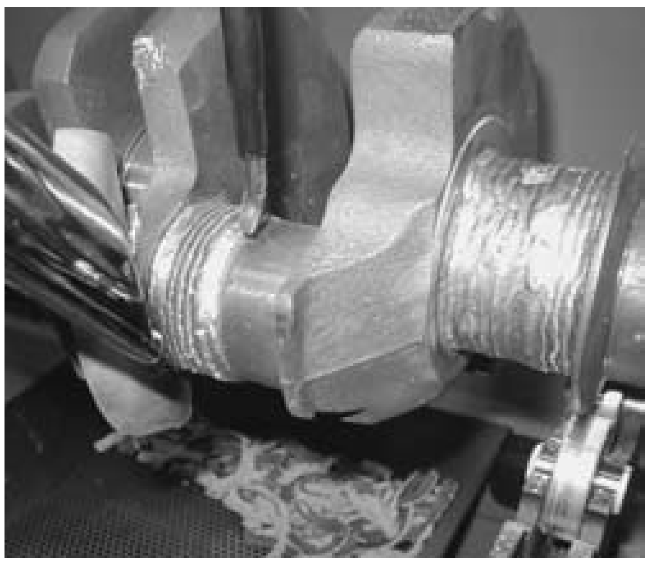


FIGURE 27-23 An excessively worn crankshaft can be restored to useful service by welding the journals, and then machining them back to the original size.

Sometimes the journal is chrome plated. Chrome plating makes an excellent bearing surface when the chrome is well bonded. If the bonding loosens, it will cause an immediate bearing failure.

STRESS RELIEVING THE CRANKSHAFT

The greatest area of stress on a crankshaft is the fillet area. See Figure 27-24.

Stress relief is achieved by blasting the fillet area of the journals with #320 steel shot. This strengthens the fillet area and helps to prevent the development of cracks in this area. Gray duct tape is commonly used to cover the journal to prevent damage to the rest of it. Stress relief procedures are usually performed after the grinding and polishing of the crankshaft.

ENGINE BEARINGS

Engine bearings are the main supports for the major moving parts of any engine. Engine bearings are important for the following reasons:

1. The clearance between the bearings and the crankshaft is a major factor in maintaining the proper oil pressure throughout the entire engine. Most engines are designed to provide the maximum protection and lubrication to the engine bearings above all else.

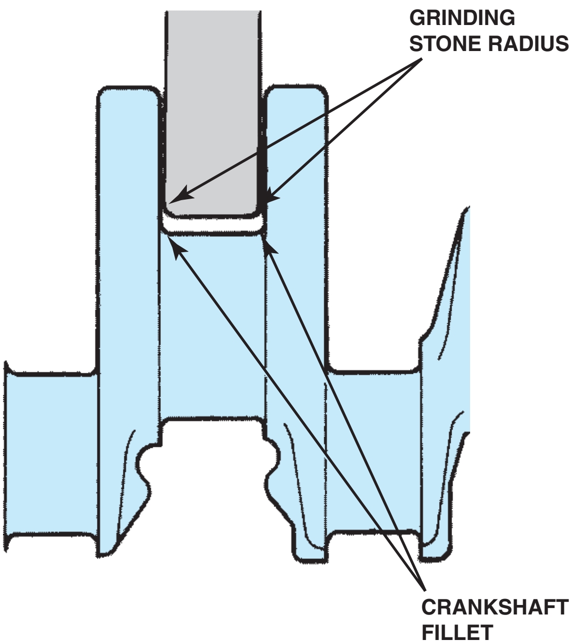


FIGURE 27-24 The rounded fillet area of the crankshaft is formed by the corners of the grinding stone.

TECH TIP

THE KNOCK OF A FLEX PLATE

The source of a knocking noise in an engine is often difficult to determine without disassembling the engine. Generally, a deep engine knocking noise means that serious damage has occurred to the rods or main bearings and related parts. A flex plate (drive plate) is used on automatic transmission-equipped engines to drive the torque converter and provide a ring gear for the starter motor to crank the engine. Two common flex plate-related noises and their causes are as follows:

- Torque converter attaching bolts or nuts can loosen (this is most common in 4-cylinder engines, where vibration is more severe than in 6- or 8-cylinder engines). The torque converter can then pound on the holes of the flex plate, causing a loud knocking sound. However, if there is a load on the engine, as when the transmission is in drive or while driving under load, the sound should stop. At idle in park or neutral, the noise will be loudest, because the torque converter can float and will hit the sides of the holes in the flex plate.
- If the flex plate is cracked, the resulting noise is very similar to a connecting rod or main bearing knock. The noise also seems to change at times, leading many technicians to believe that it involves a moving internal part that is lubricated, such as a rod or main bearing. The drive belts can also make a similar noise when they are loose, and belt-driven accessories can also produce similar noises.

Diagnosis should proceed as follows:

During the diagnostic procedure, the technician should disconnect one drive belt at a time (if there is more than one) and then start the engine in an attempt to isolate the noise. Noises can be transmitted throughout the entire length of the engine through the crankshaft, making the source of the noise more difficult to isolate. If the flex plate is cracked, the noise is most noticeable when there is a change in engine speed or load. To help diagnose a cracked flex plate, raise engine speed to a high idle (1500 to 2000 RPM), then turn the ignition switch off. Before the engine stops, turn the ignition back on. If a knocking noise is heard when the engine restarts, the flex plate is cracked.

2. Engine durability relies on bearing life. Bearing failure usually results in immediate engine failure.
3. Engine bearings are designed to support the operating loads of the engine and, with the lubricant, provide minimum friction. This must be achieved at all designed engine speeds. The bearings must be able to operate for long periods of time, even when small foreign particles are in the lubricant.

Most engine bearings are of the **plain** or **sleeve bearing** type. See Figure 27-25.

Most bearing halves, or shells, do not have uniform thickness. The wall thickness of most bearings is largest in the center, called the **bearing crown.** The bearing thickness then tapers to a thinner measurement at each parting line. See Figure 27-26.

The tapered wall keeps bearing clearances close at the top and bottom of the bearing, which are the more loaded areas and allow more oil flow at the sides of the bearing. Both need a constant flow of lubricating oil. In automotive engines, the lubricating system supplies oil to each bearing continuously when the engine runs. Bearings and journals *only* wear when the parts come in contact with each other or when foreign particles are present.

Oil enters the bearing through the oil holes and grooves. It spreads into a smooth wedge-shaped oil film that supports the bearing load.

Bearing Loads

It is important that the engine have large enough bearings that the bearing load is within the strength limits of the bearings. Bearing load capacity is calculated by dividing the bearing load in pounds by the projected area of the bearing. The projected area is the bearing length multiplied by the bearing diameter. The load on engine bearings is determined by developing a polar bearing load diagram that shows the amount and direction of the instantaneous bearing loads. Bearing load diagrams are shown in Figure 27-27.

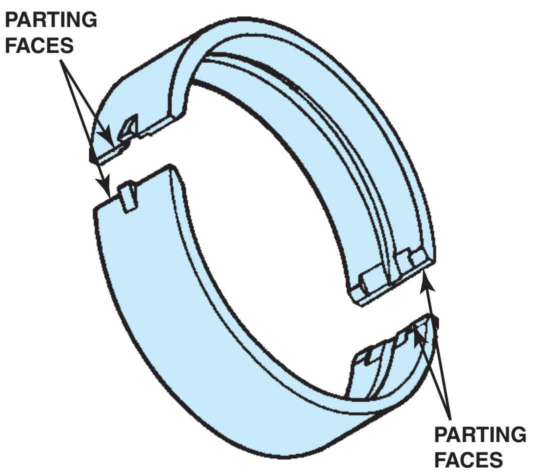


FIGURE 27-25 The two halves of a plain bearing meet at the parting faces.

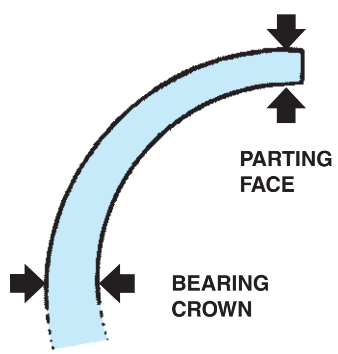


FIGURE 27-26 Bearing manufacturers refer to this bearing wall shape as a eccentric wall.

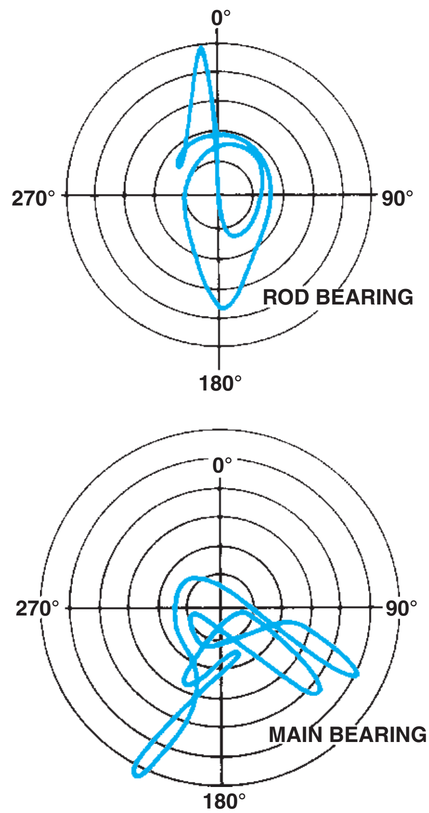


FIGURE 27-27 Typical rod and main bearing load diagrams. The circles on these polar diagrams indicate the amount of force on the bearing as it rotates. Notice that most of the forces on the connecting rod bearing are vertical (up and down), as you would expect; most of the forces on the main bearing are downward, again as expected.

The forces on the engine bearings vary with engine speed and load. On the intake stroke, the inertia force is opposed by the force of drawing in the air–fuel mixture. On the compression and power strokes, there is also an opposing force on the rod bearings. On the exhaust stroke, however, there is no opposing force to counteract the inertia force of the piston coming to a stop at TDC. The result is a higher force load on the *bottom* rod bearing due to inertia at TDC of the exhaust stroke. These forces tend to stretch the big end of the rod in the direction of rod movement.

1. As engine speed (RPM) increases, rod bearing loads decrease because of the balancing of inertia and opposing loads.
2. As engine speed (RPM) increases, the main bearing loads increase.

NOTE: This helps explain why engine blocks with four-bolt main bearing supports are really only needed for high-engine speed stability.

3. Because the loads on bearings vary and affect both rod and main bearings, it is generally recommended that *all* engine bearings be replaced at one time.

Bearing Fatigue

Bearings tend to flex or bend slightly under changing loads. This is especially noticeable in reciprocating engine bearings. Bearing metals, like other metals, tend to fatigue and break after being flexed or bent a number of times. Flexing starts fatigue, which shows up as fine cracks in the bearing surface because the bearing material became **work hardened.** These cracks gradually deepen almost to the bond between the bearing metal and the backing metal. The cracks then cross over and intersect with each other, as illustrated in Figure 27-28.

In time, this will allow a piece of bearing material to fall out. The length of time before fatigue will cause failure is called the **fatigue life** of the bearing. Bearings must have a long fatigue life for normal engine service. The harder the bearing material, the longer its fatigue life. Soft bearings have a short fatigue life and low bearing load strength. They are generally low in cost and can only be used where the bearing requirements are low. See Figures 27-29 and 27-30.

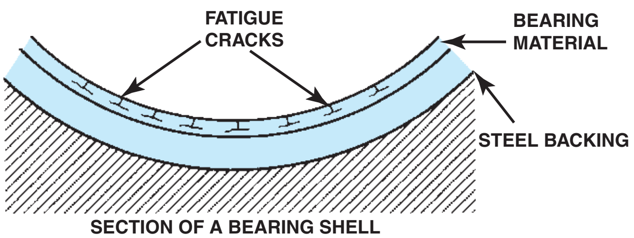


FIGURE 27-28 Shape of fatigue cracks in a bearing. If the bearing is subjected to continued high loads, the cracks expand and eventually cause the bearing material to flake off from the steel backing.

Bearing Conformability

The ability of bearing materials to creep or flow slightly to match shaft variations is called **conformability.** The bearing conforms to the shaft during the engine break-in period. In modern automobile engines, there is little need for bearing conformability or break-in, because automatic processing has achieved machining tolerances that keep the shaft very close to the designed size. See Figure 27-31.

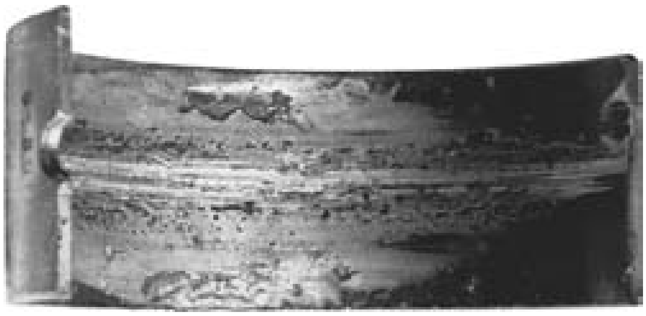


FIGURE 27-29 Bearing material missing from the shell as a result of fatigue.

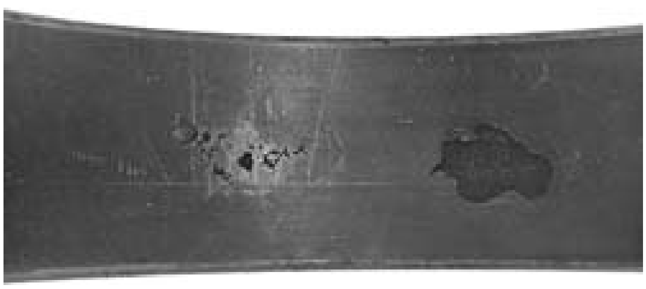


FIGURE 27-30 Bearing material missing from the bearing as a result of fatigue failure.

FIGURE 27-31 Bearing wear caused by a misaligned journal. A bent connecting rod could also cause similar bearing wear.

Bearing Embedability

Engine manufacturers have designed engines to produce minimum crankcase deposits. This has been done by providing them with oil filters, air filters, and closed crankcase ventilation systems that minimize contaminants. Still, some foreign particles get into the bearings. The bearings must be capable of embedding these particles into the bearing surface so that they will not score the shaft. To fully embed the particle, the bearing material gradually works across the particle, completely covering it. The bearing property that allows it to do this is called **embedability.** Embedability is illustrated in Figures 27-32 and 27-33.

Bearing Damage Resistance

Under some operating conditions, the bearing will be temporarily overloaded. This will cause the oil film to break down and allow the shaft metal to come in contact with the bearing metal. As the rotating crankshaft contacts the bearing high spots, the spots become hot from friction. The friction causes localized hot spots in the bearing material that seize or weld to the crankshaft. The crankshaft then breaks off particles of the bearing material and pulls the particles around with it, scratching or scoring the bearing surface. See Figures 27-34 and 27-35.

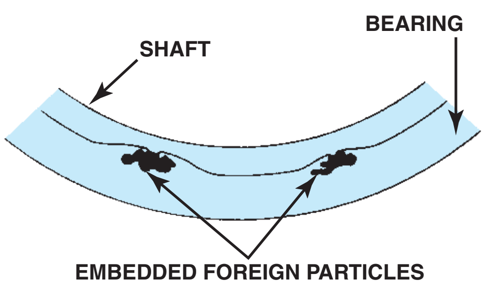


FIGURE 27-32 Bearing material covers foreign material as it embeds into the bearing.

Bearings have a characteristic called **score resistance.** It prevents the bearing materials from seizing to the shaft during oil film breakdown.

By-products of combustion form acids in the oil. The bearings' ability to resist attack from these acids is called **corrosion resistance.** Corrosion can occur over the entire surface of the bearing. This will remove material and increase the oil clearance. It can also leach or eat into the bearing material, dissolving some of the bearing material alloys. Either type of corrosion will reduce bearing life.

BEARING CONSTRUCTION

Materials

Three materials are used for automobile engine bearings: **babbitt, copper-lead alloy,** and *aluminum.* A layer of the bearing materials 0.010 to 0.020 inch (0.25 to 0.50 millimeter) thick is applied over a low-carbon steel backing. An engine bearing is called a *bearing shell,* which is a steel backing with a surface coating of bearing material. The steel provides support needed for the shaft load. The bearing material meets the rest of the bearing operating requirements.

FIGURE 27-33 Foreign particles such as dirt embedded in the bearing material.

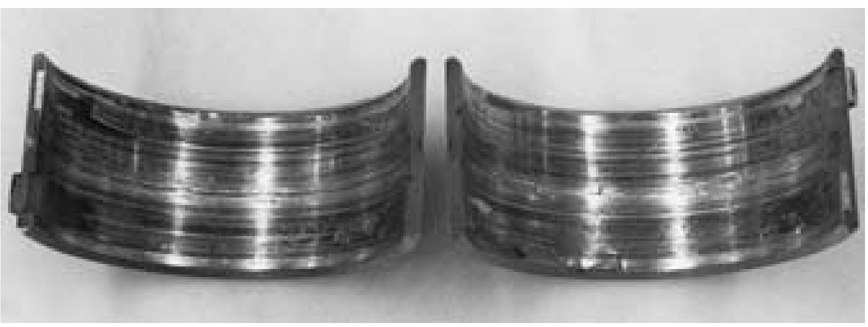


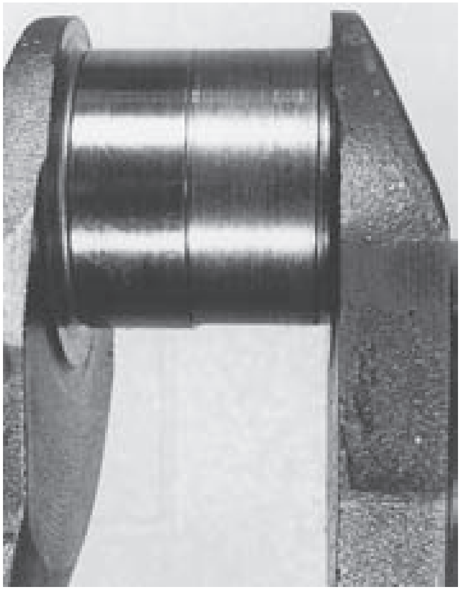
FIGURE 27-34 Bearing material starting to leave the steel backing.

Babbitt. Babbitt is the oldest automotive bearing material. Isaac Babbitt (1799–1862) first formulated this material in 1839. An excellent bearing material, it was originally made from a combination of lead, tin, and antimony. Lead and tin are alloyed with small quantities of copper and antimony to give it the required strength. Babbitt is still used in applications in which material is required for soft shafts running under moderate loads and speeds. It will work with occasional borderline lubrication and oil starvation without failure.

Tri-Metal. Copper-lead alloy is a stronger and more expensive bearing material than babbitt. It is used for intermediate- and high-speed applications. Tin, in small quantities, is often alloyed with the copper-lead bearings. This bearing material is most easily damaged by corrosion from acid accumulation in the engine oil. Corrosion results in bearing journal wear as the bearing is eroded by the acids.

Many of the copper-lead bearings have an **overlay,** or third layer, of metal. This overlay is usually of babbitt. Babbitt-overlayed bearings have high fatigue strength, good conformity, good embedability, and good corrosion resistance. The overplated bearing is a premium bearing. It is also the most expensive because the overplating layer, from 0.0005 to 0.001 inch (0.0125 to 0.025 millimeter) thick, is put on the bearing with an **electroplating** process. The layers of bearing material on a bearing shell are illustrated in Figure 27-36.

Aluminum. Aluminum was the last of the three materials to be used for automotive bearings. Automotive bearing aluminum has small quantities of tin and silicon alloyed with it. This makes a stronger but more expensive bearing than either babbitt or copper-lead alloy.



(a)

(b)

FIGURE 27-35 Typical results of oil pressure loss: (a) extreme wear of the connecting rod journal, (b) overheating finally leading to failure of the bearing.

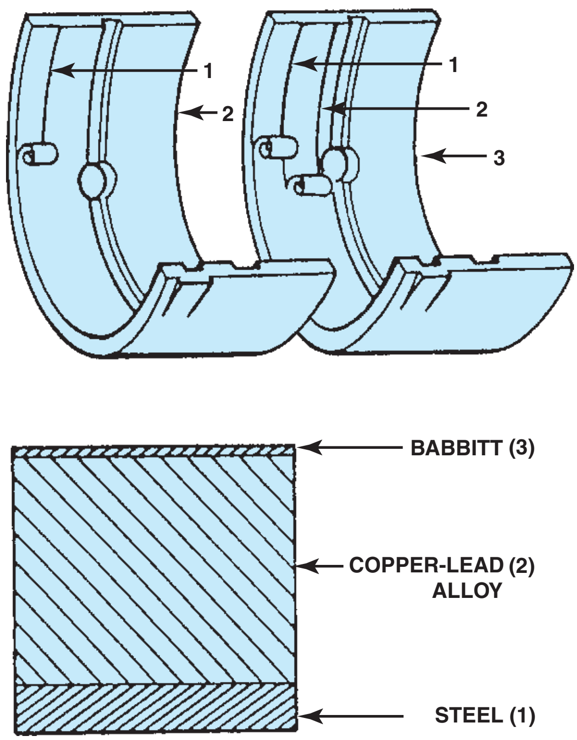


FIGURE 27-36 Typical two-layer and three-layer engine bearing insert showing the relative thickness of the various materials.

Most of its bearing characteristics are equal to or better than those of babbitt and copper lead. **Aluminum bearings** are well suited to high-speed, high-load conditions and do not contain lead, which is a benefit to the environment both at the manufacturing plant and for the technician who may be exposed to the bearings.

BEARING MANUFACTURING

Modern automotive engines use **precision insert-type bearing shells,** sometimes called **half-shell bearings.** The bearing is manufactured to very close tolerance so that it will fit correctly in each application. The bearing, therefore, must be made from precisely the correct materials under closely controlled manufacturing conditions. Figure 27-37 shows the typical bearing shell types found in most engines.

Bearing Sizes

Bearings are usually available in standard (std) size, and in measurements 0.010, 0.020, and 0.030 inch *undersize*. See Figure 27-38.

Even though the bearing itself is thicker for use on a machined crankshaft, the bearing is referred to as undersize because the crankshaft journals are undersize. Factory bearings may be available in 0.0005 or 0.001 inch undersize for precision fitting of a production crankshaft.

Before purchasing bearings, be sure to use a micrometer to measure *all* main and connecting rod journals.

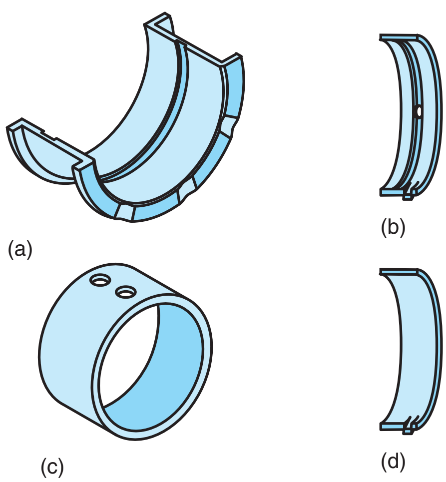


FIGURE 27-37 Typical bearing shell types found in modern engines: (a) half-shell thrust bearing, (b) upper main bearing insert, (c) full round-type camshaft bearing, (d) lower main bearing insert.

BEARING CLEARANCE

The bearing-to-journal clearance may be from 0.0005 to 0.0025 inch (0.025 to 0.060 millimeter), depending on the engine. Doubling the journal clearance will allow more than *four* times as much oil to flow from the edges of the bearing. The oil clearance must be large enough to allow an oil film to build up, but small enough to prevent excess oil leakage, which would cause loss of oil pressure. A large amount of oil leakage at one of the bearings would starve other bearings farther along in the oil system. This would result in the failure of the oil-starved bearings. See Figure 27-39.

BEARING SPREAD AND CRUSH

A lip or tang locates the bearing shell in the housing, as shown in Figure 27-40. The bearing design also includes bearing **spread** and **crush,** as illustrated in Figure 27-41.

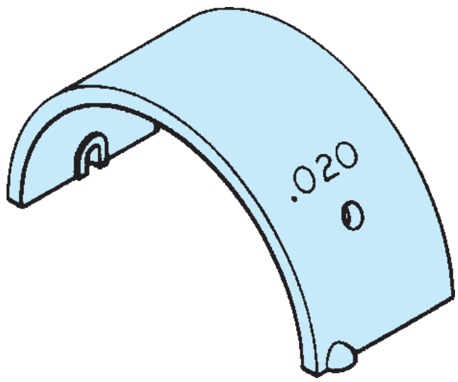


FIGURE 27-38 Bearings are often marked with an undersize dimension. This bearing is used on a crankshaft with a ground journal that is 0.020-inch smaller in diameter than the stock size.

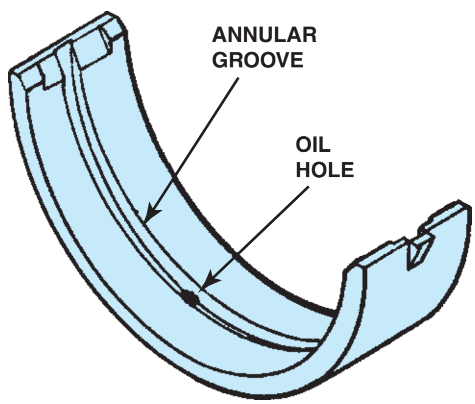


FIGURE 27-39 Many bearings are manufactured with a groove down the middle to improve the oil flow around the main journal.

The bearing shell has a slightly larger arc than does the bearing housing. This difference is called bearing spread and it makes the shell 0.005 to 0.020 inch (0.125 to 0.500 millimeter) wider than the housing bore. Spread holds the bearing shell in the housing while the engine is being assembled. When the bearing is installed, each end of the bearing shell is slightly above the parting surface. When the bearing cap is tightened, the ends of the two bearing shells touch and are forced together. This force is called bearing crush. Crush holds the bearing in place and keeps the bearing from turning when the engine runs. Crush must exert a force of at least 12,000 PSI (82,740 kPa) at 250°F (121°C) to hold the bearing securely in place. A stress of 40,000 PSI (275,790 kPa) is considered maximum to avoid damaging the bearing or housing. See Figure 27-42.

Bearing shells that do not have enough crush may rotate with the shaft. The result is called a **spun bearing,** as pictured in Figure 27-43.

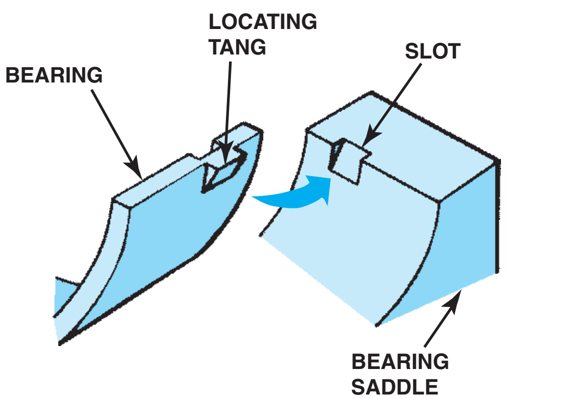


FIGURE 27-40 The tang and slot help index the bearing in the bore.

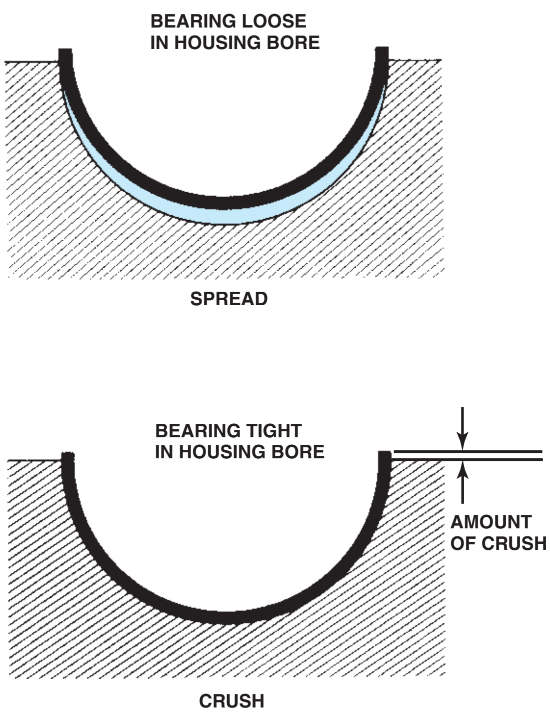


FIGURE 27-41 Bearing spread and crush.

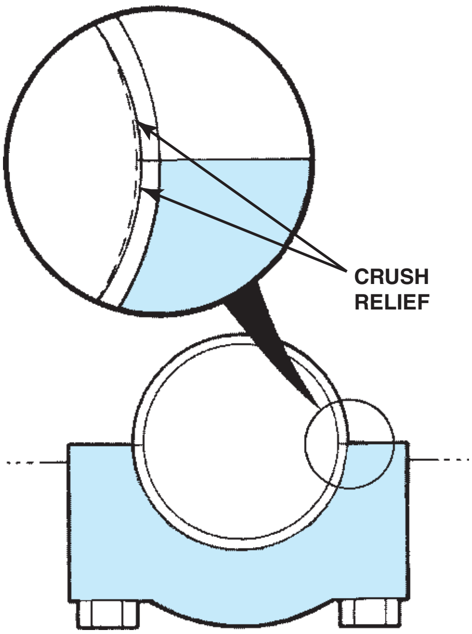


FIGURE 27-42 Bearings are thinner at the parting line faces to provide crush relief.

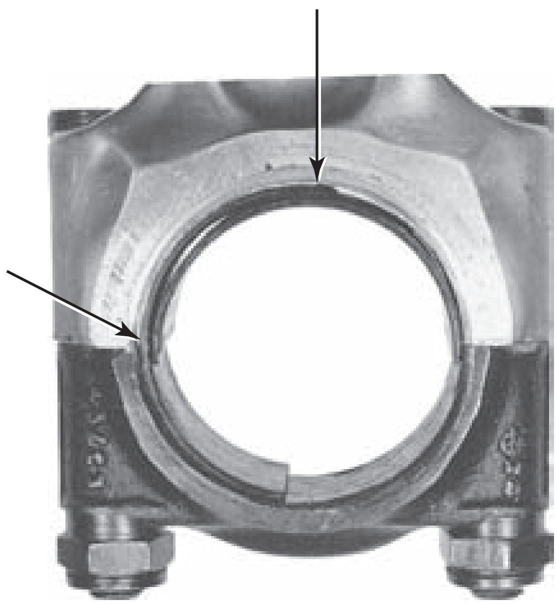


FIGURE 27-43 Spun bearing. The lower cap bearing has rotated under the upper rod bearing.

Replacement bearings should be of a quality as good as or better than that of the original bearings. The replacement bearings must also have the same oil holes and grooves.

CAUTION: Some bearings may have oil holes in the top shell only. If these are incorrectly installed, no oil will flow to the connecting rods or main rods, which will result in instant engine failure.

Modified engines have more demanding bearing requirements and therefore usually require a higher-quality bearing to provide satisfactory service.

CAMSHAFT BEARINGS

The camshaft in pushrod engines rotates in sleeve bearings that are pressed into bearing bores within the engine block. Overhead camshaft bearings may be either sleeve-type bushings called **full round bearings** or **split-type (half-shell) bearings,** depending on the design of the bearing supports. In pushrod engines, the cam bearings are installed in the block. See Figure 27-44.

The best rule of thumb to follow is to replace the cam bearings whenever the main bearings are replaced. The replacement cam bearings must have the correct outside diameter to fit snugly in the cam bearing bores of the block. They must have the correct oil holes and be positioned correctly. See Figure 27-45. Cam bearings must also have the proper inside diameter to fit the camshaft bearing journals.

In many engines, each cam bearing is a different size—the largest is in the front and the smallest is in the rear. The cam bearing journal size must be checked and each bearing identified before assembly is begun. The location of each new cam bearing can be marked on the outside of the bearing with a felt-tip marker to help avoid mixing up bearings. Marking in this way will not affect the bearing size or damage the bearing in any way. Cam bearings should be installed “dry” (not oiled) to prevent the cam bearing from moving (spinning) after installation. If the cam bearing were oiled, the rotation of the camshaft

TECH TIP

COUNT YOUR BLESSINGS AND YOUR PAN BOLTS!

Replacing cam bearings can be relatively straightforward or can involve keeping count of the number of oil pan bolts! For example, Buick-built V-6 engines use different cam bearings depending on the number of bolts used to hold the oil pan to the block.

- Fourteen bolts in the oil pan. The front bearing is special, but the rest of the bearings are the same.
- Twenty bolts in the oil pan. Bearings #1 and #4 use two oil feed holes. Bearings #2 and #3 use single oil feed holes.

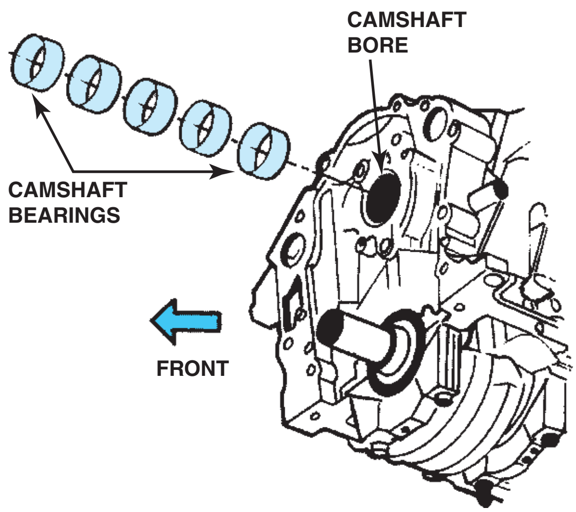


FIGURE 27-44 Cam-in-block engines support the camshaft with sleeve-type bearings.

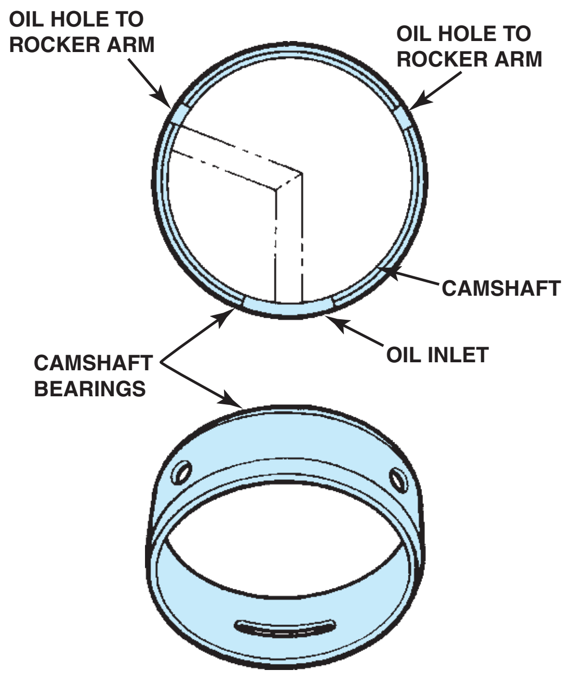


FIGURE 27-45 Camshaft bearings must be installed correctly so that oil passages are not blocked.

could cause the cam bearing to rotate and block oil holes that lubricate the camshaft.

Camshaft bearings used on overhead camshaft engines may be either full round or split depending on the engine design. See Figure 27-46.

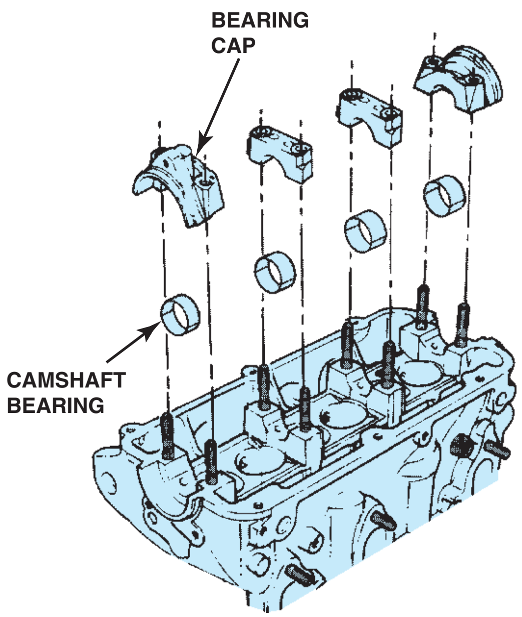


FIGURE 27-46 Some overhead camshaft engines use split bearing inserts.

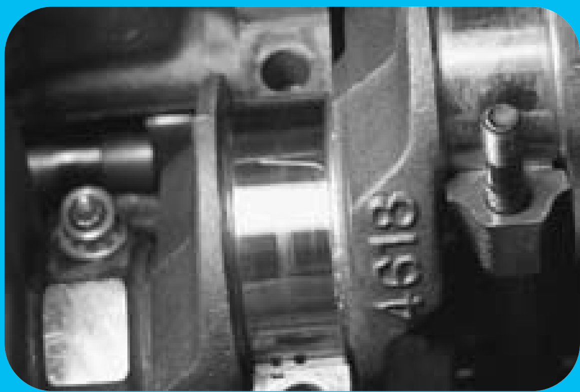
TECH TIP

DO NO HARM

All engine parts should be stored in a safe location to help avoid damage prior to being installed in an engine. All camshafts and crankshafts should be stored vertically to avoid causing bending or warpage of these parts that could cause difficulty when the engine is being assembled. See Figure 27-47 for one method of safely storing crankshafts.

FIGURE 27-47 Crankshafts should be stored vertically to prevent possible damage or warpage. This clever bench-mounted tray for crankshafts not only provides a safe place to store crankshafts but it is out-of-the-way and cannot be accidentally tipped.

CHECKING BEARING CLEARANCE WITH PLASTIGAGE Step-by-Step



STEP 1 Clean the main bearing journal and then place a strip of Plastigage material across the entire width of the journal.

STEP 2 Carefully install the main bearing cap with the bearing installed.

STEP 3 Torque the main bearing cap bolts to factory specifications.

STEP 4 Carefully remove the bearing cap and, using the package that contained the Plastigage strips, measure the width of the compressed material. The gauge is calibrated in thousanths of an inch. Repeat for each main bearing.

STEP 5 To measure rod bearing oil clearance, start by removing the rod cap.

STEP 6 Clean the rod bearing journal and then place a strip of Plastigage across the entire width of the journal.

(continued)

CHECKING BEARING CLEARANCE WITH PLASTIGAGE continued

STEP 7 Torque the rod bearing cap nuts to factory specifications.

STEP 8 Remove the rod cap and measure the oil clearance using the markings on the Plastigage package. The wider the compressed gauge material, the narrower the bearing oil clearance. Repeat for all rod bearings.

SUMMARY

1. Cast crankshafts have a narrow mold parting line.
2. Even-fire 90-degree V-6 engines require that the crankshaft be splayed to allow for even firing.
3. Lubrication to the main bearings is fed through the main oil gallery in the block. Oil for the rod bearings comes from holes in the crankshaft drilled between the main journal and the rod journal.
4. A vibration damper, also known as a harmonic balancer, is used to dampen harmful twisting vibrations of the crankshaft.
5. Most engines are internally balanced. This means that the crankshafts and vibration damper are both balanced. Other engines use the vibration damper to balance the crankshaft and are called externally balanced engines.
6. Most crankshafts can be reground to be 0.010, 0.020, or 0.030 inch undersize.
7. Most engine bearings are constructed with a steel shell for strength and are covered with a copper-lead alloy. Many bearings also have a thin overlay of babbitt.
8. Bearings should have spread and crush to keep them from spinning when the crankshaft rotates.

REVIEW QUESTIONS

1. How many degrees of crankshaft rotation are there between cylinder firings on an inline 4-cylinder engine, an inline 6-cylinder engine, and a V-8 engine?
2. List four engine bearing properties.
3. Describe bearing crush and bearing spread.

CHAPTER QUIZ

1. A forged crankshaft has ______.
   - **a.** A wide parting line
   - **b.** A thin parting line
   - **c.** A parting line in one plane
   - **d.** Both b and c
2. A typical V-8 engine crankshaft has ______ main bearings.
   - **a.** Three
   - **b.** Four
   - **c.** Five
   - **d.** Seven
3. A 4-cylinder engine fires one cylinder at every ______ degrees of crankshaft rotation.
   - **a.** 27
   - **b.** 180
   - **c.** 120
   - **d.** 90
4. A splayed crankshaft is a crankshaft that _________.
   - **a.** Is externally balanced
   - **b.** Is internally balanced
   - **c.** Has offset main bearing journals
   - **d.** Has offset rod journals
5. The thrust bearing surface is located on one of the main bearings to control thrust loads caused by ______.
   - **a.** Lugging the engine
   - **b.** Torque converter or clutch release forces
   - **c.** Rapid deceleration forces
   - **d.** Both a and c
6. If any crankshaft is ground, it must also be ______.
   - **a.** Shot peened
   - **b.** Chrome plated
   - **c.** Polished
   - **d.** Externally balanced
7. If bearing-to-journal clearance is doubled, how much oil will flow?
   - **a.** One-half as much
   - **b.** The same amount if the pressure is kept constant
   - **c.** Double the amount
   - **d.** Four times the amount
8. Typical journal-to-bearing clearance is ______.
   - **a.** 0.00015 to 0.00018 inch
   - **b.** 0.0005 to 0.0025 inch
   - **c.** 0.150 to 0.250 inch
   - **d.** 0.020 to 0.035 inch
9. A bearing shell has a slightly larger arc than the bearing housing. This difference is called ______.
   - **a.** Bearing crush
   - **b.** Bearing tang
   - **c.** Bearing spread
   - **d.** Bearing saddle
10. Bearing ______ occurs when a bearing shell is slightly above the parting surface of the bearing cap.
    - **a.** Overlap
    - **b.** Crush
    - **c.** Cap lock
    - **d.** Interference fit