Figure 37-1 A uniquely designed W-8 engine installed in some Audi and Volkswagen vehicles. Rebuilding the engine would require detailed service information to be sure that all steps are taken for proper assembly.

Figure 37-2 Deburring all sharp edges is an important step to achieve proper engine assembly.
Chart 37-1  The surface finish of the block and cylinder head depends on the type of gasket being used.

<table>
<thead>
<tr>
<th>ENGINE PART</th>
<th>GASKET MATERIAL</th>
<th>ACCEPTABLE SURFACE FINISH (RA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cast iron/cast iron</td>
<td>Composite</td>
<td>60 to 80 μin.</td>
</tr>
<tr>
<td>Aluminium/cast iron</td>
<td>Composite</td>
<td>20 to 30 μin.</td>
</tr>
<tr>
<td>Aluminium/cast iron</td>
<td>Rubber-coated</td>
<td>15 to 30 μin.</td>
</tr>
<tr>
<td></td>
<td>multi-layered steel</td>
<td></td>
</tr>
</tbody>
</table>

Figure 37-3  Studs installed in the block, replacing head bolts.

Figure 37-4  Main bearing studs installed on a V-8 block.
TECH TIP: Be Aware of BMW Engine Procedures
If rebuilding a BMW engine, check service information carefully because most BMW engines require that threaded inserts be installed in all head bolt threads. Performing this operation can increase the cost and time needed. Always follow all recommended service procedures on the engine being serviced. **SEE FIGURE 37-5**.

**Figure 37-5** A Cadillac Northstar engine being rebuilt. The shop doing the work is installing Heli-coils® in all threaded cylinder head bolt holes as a precaution. Using duct tape to cover the engine helps prevent aluminum chips from getting into passages.

**Figure 37-6** A thread chaser (top) is the preferred tool to clean threaded holes because it cleans without removing metal compared to a tap (bottom).
TECH TIP

Keep the Engine Covered
Using a large plastic trash bag is an excellent way to keep the engine clean when storing it between work sessions.

SEE FIGURE 37–7.

Figure 37–7 Using a plastic trash bag is an excellent way to keep the engine clean during all stages of assembly.

Figure 37–8 A trial assembly showed that some grinding of the block will be needed to provide clearance for the counterweight of the crankshaft. Also, notice that the engine has been equipped with studs for the four main bearing caps.
A typical high-performance aftermarket rocker arm which is equipped with needle roller bearings at the valve stem end and caged needle bearing at the pivot shaft end to reduce friction, which increases engine horsepower and improves fuel economy.

Figure 37-9

Fogging oil is used to cover bare metal parts when the engine is being stored to prevent corrosion.

Figure 37-10

TECH TIP: Fogging Oil and Assembly Lube

When assembling an engine, the parts should be coated with a light oil film to keep them from rusting. This type of oil is commonly referred to as fogging oil and is available in spray cans. SEE FIGURE 37–10.

During engine assembly, the internal parts should be lubricated. While engine oil or grease could be used, most experts recommend the use of a specific lubricant designed for engine assembly. This lubricant, designed to remain on the parts and not drip or run, is called assembly lube. SEE FIGURE 37–11.
Figure 37-11  Engine assembly lube is recommended to be used on engine parts during assembly.

Figure 37-12  An angle gauge being used to check the angle between the cylinder heads on this small block Chevrolet V-8 engine.

Figure 37-13  The best way to thoroughly clean cylinders is to use soap (detergent), water, and a large washing brush. This method floats the machining particles out of the block and washes them away.
All oil galleries should be cleaned using soap (detergent), water, and a long oil gallery cleaning brush.

This engine uses many cup plugs to block off coolant and oil passages as well as a large plug over the end of the camshaft bore.

Sealer should be applied to the cup plug before being driven into the block.
FREQUENTLY ASKED QUESTION

What Causes Premature Bearing Failure?

According to a major manufacturer of engine bearings, the major causes of premature (shortly after installation) bearing failure include the following:

- Dirt (45%)
- Misassembly (13%)
- Misalignment (13%)
- Lack of lubrication (11%)
- Overloading or lagging (10%)
- Corrosion (6%)
- Other (4%)

Many cases of premature bearing failure may result from a combination of several of these items. Therefore, to help prevent bearing failure, keep everything as clean as possible.

Figure 37-17  Screw-type puller being used to install a new cam bearing. Most cam bearings are dry fit. The full round bearing is forced into the cam bearing bore. Most vehicle manufacturers specify that the cam bearings be installed "dry" without lubrication to help prevent them from spinning, which would cause the bearing to block the oil feed hole.

Figure 37-18  Typical main bearing sets. Note that the upper halves are grooved for better oil flow, whereas the lower halves are plain for better load support. This bearing set uses the center main bearing for thrust control. Notice that the upper bearing set has the holes for oil, whereas the lower set does not.
Figure 37-19  The width of the plastic gauging strip determines the oil clearance of the main bearing. An alternate method of determining oil clearance includes careful measurement of the crankshaft journal and bearings after they are installed and the main housing bolt caps are torqued to specifications.

Figure 37-20  Lip-type rear main bearing seal in place in the rear main bearing cap. The lip should always be pointing toward the inside of the engine.

Figure 37-21  Always use the proper driver to install a main seal. Never pound directly on the seal.
TECH TIP:

“One to Three”

When engine technicians are talking about clearances and specifications, the unit of measure most often used is thousandths of an inch (0.001 in.). Therefore, a clearance expressed as “one to three” would actually be a clearance of 0.001 to 0.003 in. The same applies to parts of a thousandth of an inch. For example, a specification of 0.0005 to 0.0015 in. would be spoken of as simply being “one-half to one and one-half.” The unit of a thousandth of an inch is assumed, and this method of speaking reduces errors and misunderstandings.

HINT: Most engine clearance specifications fall within one to three thousandths of an inch. The written specification could be a misprint. Therefore, if the specification does not fall within this general range, double-check the clearance value using a different source.

Figure 37-22 The rear seal for this engine mounts to a retainer plate. The retainer is then bolted to the engine block.

Figure 37-23 Many engine builders prefer to stagger the parting lines of a rope-type seal.
Figure 37-24  A dial indicator is being used to check the crankshaft end play, known as thrust bearing clearance. Always follow the manufacturer’s recommended testing procedures.

Figure 37-25  A thrust bearing insert being installed before the crankshaft is installed.

TECH TIP

Use a Long Bolt to Hold the Camshaft

To help install a camshaft without harming the cam bearings, install a long bolt into one of the end threaded holes in the camshaft. Then tilt the engine vertically so that gravity will cause the camshaft to fall straight down while holding onto the camshaft using the long bolt.

SEE FIGURE 37-26.
TECH TIP: Two Choices If Using Flat-Bottom Lifters

An old or rebuilt engine that uses flat-bottom lifters must use one of the following:

1. Oils that contain at least 0.15% or 1,500 parts per million (ppm) of zinc in the form of ZDDP. Oils that contain this much zinc are designed for off-road use only and are suitable for use in vehicles that do not have a catalytic converter. If a vehicle is equipped with a catalytic converter, the use of oil with lower levels of zinc is recommended. If the vehicle is used on the street, replace the camshaft and lifters to roller type, so that newer oils with lower levels of zinc can be used.

2. Use a newer oil and an additive such as:
   - GM engine oil supplement (EOS) (Part #1052367 or #88862586)
   - Comp Cams® camshaft break-in oil additive (Part #159)
   - Crane Cams® Moly Paste (Part #99002-1)
   - Crane Cams® Super Lube oil additive (Part #99003-1)
   - Lumati Assembly lube (Part #99010)
   - Mell-Lube camshaft tube oil additive (Part #M-10012)
   - Other available additives designed to protect the camshaft (see Figure 37-27).

Figure 37-26 Installing a camshaft is easier if the engine is vertical so gravity can help, and this method reduces the possibility of damaging the cam bearings.

Figure 37-27 A commercial additive designed to protect a flatbottom lifter camshaft used in older vehicles when using newer oils that do not have enough ZDDP to protect the camshaft and lifters.
Figure 37-28 A feeler gauge is used to check piston ring gap.

Chart 37-2 The approximate ring gap based on the size of the bore in inches. Always check service information for the exact specifications for the engine being assembled.

<table>
<thead>
<tr>
<th>PISTON DIAMETER</th>
<th>RING GAP</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 to 3 in.</td>
<td>0.007 to 0.015 in.</td>
</tr>
<tr>
<td>3 to 4 in.</td>
<td>0.01 to 0.02 in.</td>
</tr>
<tr>
<td>4 to 5 in.</td>
<td>0.013 to 0.023 in.</td>
</tr>
</tbody>
</table>

Figure 37-29 The notch on a piston should always face toward the front of the engine.
On V-type engines that use paired rod journals, the side of the rod with the large chamfer should face toward the crank throw (inward).

An inside micrometer can be used to measure the inside diameter of the big end of the connecting rod with the bearings installed. This dimension subtracted from the rod journal diameter is equal to the bearing clearance.

One method of piston ring installation showing the location of ring gaps. Always follow the manufacturer’s recommended method for the location of ring gaps and for ring gap spacing.
Figure 37-33 A gapless ring is made in two pieces that overlap.

Figure 37-34 This style of ring compressor uses a ratchet to contract the spring band and compresses the rings into their grooves.

Figure 37-35 This pliers-like tool is used to close the metal band around the piston to compress the rings. An assortment of bands is available to service different size pistons.
Figure 37-36  When threaded onto the rod bolts, these guides not only help align the rod but also prevent the threads and bolts the bearing shell in place. The soft ends also will not damage the crankshaft journal.

Figure 37-37  Installing a piston using a ring compressor to hold the rings into the ring grooves of the piston and then using a hammer handle to drive the piston into the bore. Connecting rod bolt protectors have been installed to help prevent possible damage to the crankshaft during piston installation.

Figure 37-38  The connecting rod side clearance is measured with a feeler gauge.
TECH TIP: Tightening Tip for Rod Bearings
Even though the bearing clearances are checked, it is still a good idea to check and record the torque required to rotate the crankshaft with all piston rings dragging on the cylinder walls. The retaining nuts on one bearing should be torqued, and then the torque that is required to rotate the crankshaft should be rechecked and recorded. Follow the same procedure on all rod bearings. If tightening any one bearing causes a large increase in the torque required to rotate the crankshaft immediately stop the tightening process. Determine the cause of the increased rotating torque using the same method as used on the main bearings. Rotate the crankshaft for several revolutions to ensure that the assembly is turning freely and that there are no tight spots.

The rotating torque of the crankshaft with all connecting rod cap bolts fully torqued should be as follows:
- 4-cylinder engine: 20 lb-ft maximum (88 N·m)
- 6-cylinder engine: 25 lb-ft maximum (110 N·m)
- 8-cylinder engine: 30 lb-ft maximum (132 N·m)

**Figure 37-39 (a)** Valve clearance allows the metal parts to expand and maintain proper operation, both when the engine is cold and at normal operating temperature. Adjustment is achieved by turning the adjusting screw.

**Figure 37-39 (b)** Valve clearance allows the metal parts to expand and maintain proper operation, both when the engine is cold and at normal operating temperature. Adjustment is achieved by changing the thickness of the adjusting shim.
Some overhead camshaft engines use valve lash adjusting shims to adjust the valve lash. A special tool is usually required to compress the valve spring so that a magnet can remove the shim.

**TECH TIP: Watch Out for Wet and Dry Holes**

Many engines, such as the small block Chevrolet V8, use head bolts that extend through the top deck of the block and end in a coolant passage. These bolt holes are called wet holes. When installing head bolts into holes that end up in the coolant passage, siempre se ponen en las uniones de los cabezas. Some engines have head bolts that are "wet," whereas others are "dry" because they end in solid cast-iron material. Dry hole bolts do not require sealant but will require some oil on the threads of the bolts for lubrication. Do not put all into a dry hole because the bolt may bottom out in the oil. Dry hole bolts do not require oil on the threads for lubrication. Do not put oil into a dry hole because the bolt may bottom out in the oil. The liquid oil cannot compress, so the force of the bolt being tightened is transferred to the block by hydraulic force, which can crack the block.

_HINT:_ Apply oil to a shop cloth and rotate the bolt in the cloth to lubricate the threads. This prevents lubrication without applying too much oil.

**Figure 37-40** Some overhead camshaft engines use valve lash adjusting shims to adjust the valve lash. A special tool is usually required to compress the valve spring so that a magnet can remove the shim.

**Figure 37-41** Typical cylinder head tightening sequence.
TECH TIP: The Piece of Paper Demonstration

Some students and beginning technicians forget the correct order to tighten head bolts or other fasteners of a component. Try the following demonstration:

1. Place a single sheet of paper on a table.
2. Place both hands on the paper in the center and then move them outward.
3. Nothing should have happened and the paper should not have moved.
4. Now place your hands on the paper at the ends and move them toward the center.
5. The paper will wrinkle as the hands move toward the center.

This demonstration shows that the forces are moved away toward the ends if the fasteners are tightened from the inside toward the outside. However, if the cylinder head bolts were tightened incorrectly, the head would likely crack due to the forces exerted during tightening.

TECH TIP: Always Exercise New Bolts

New bolts and studs are manufactured by rolling the threads and heat treating. Due to this operation, the threads usually have some rough areas, which affect the clamping force on the gasket. Many engine building experts recommend that all new bolts be installed in the engine using a new or used gasket and torqued to specifications at least five times, except for torque-to-yield bolts. This process burnishes the ramps of the threads and makes the fastener provide a more even clamping force. Using the recommended lubricant, the bolts should be torqued and removed and then torqued again.
FREQUENTLY ASKED QUESTION

Why Do Both Head Gaskets Have “Front” Marked?

A common question asked by beginning technicians or students include how to install head gaskets on a V-6 engine that is mounted transversely (sideways) in the vehicle. The technician usually notices that “front” is marked on one gasket and therefore installs that gasket on the block, on top of the forward-facing cylinder bank. Then, the technician notices that the other gasket is also marked with “front.” How could both be marked “front”? There must be some mistake. The mistake is in the terminology used. In the case of head gaskets, the “front” means toward the accessory drive belt end of the engine and not on the cylinder bank toward the front of the vehicle. SEE FIGURE 37–43.

Figure 37–43 Typical head gasket markings. The front means that the gasket should be at the accessory drive belt end of the block.

Figure 37–44 Due to variations in clamping force with turning force (torque) of head bolts, some engines are specifying the torque-to-yield procedure. The first step is to torque the bolts by an even amount called the initial torque. Final clamping load is achieved by turning the bolt a specified number of degrees. Bolt stretch provides the proper clamping force.
To ensure consistent clamp force (load), many manufacturers are recommending the torque-angle or torque-to-yield method of tightening head bolts. The torque-angle method specifies tightening between to a low-torque setting and then giving an additional angle of rotation. Notice that the difference in clamping force is much smaller than it would be if just a torque wrench with dirty threads were used.

Figure 37-45

Figure 37-46 Torque angle can be measured using a special adaptor.

TECH TIP: Creep Up on the Torque Value
Do not jerk or rapidly rotate a torque wrench. For best results and more even torque, slowly apply force to the torque wrench until it reaches the preset value or the designated torque. Jerky or rapidly moving the torque wrench will often cause the torque to be uneven and not accurate.
Figure 37-47 An electronic torque wrench showing the number of degrees of rotation. These very accurate and expensive torque wrenches can be programmed to display torque or number of degrees of rotation.

Figure 37-48 Both crankshafts have to be timed on this engine and the timing belt also drives the water pump.

Figure 37-49 Some timing chains have plated links that are used to correctly position the chain on the sprockets.
TECH TIP: Soak the Timing Chain

Many experts recommend that a new timing chain be soaked in engine oil prior to engine assembly to help ensure full lubrication at engine start-up. The timing chain is one of the last places in the engine to get lubrication when the engine first starts. This procedure may even extend the life of the chain.

Figure 37-50 A special tool may be needed to bleed air from the hydraulic lash adjusters (HLA) through the bleed hole. These lash adjusters are part of the valve end of the rocker arms in this example.

Figure 37-51 Timing chain and gears can be installed after the crankshaft and camshaft have been installed and the timing marks are aligned with cylinder 1 at top dead center (TDC).
Figure 37-52  With the lifter resting on the base circle of the cam, zero lash is achieved by tightening the rocker arm lock nut until the pushrod no longer rotates freely.

Figure 37-53  Most adjustable valves use a nut to keep the adjustment from changing. Therefore, to adjust the valves, the nut has to be loosened and the screw rotated until the proper valve clearance is achieved. Then the screw should be held while tightening the lock nut to keep the adjustment from changing. Double-check the valve clearance after tightening the nut.

TECH TIP
Watch Out for Different Length Pushrods
The very popular General Motors family of engines, including 2.8 liter, 3.1 liter, 3.100, 3.4 liter, 3.400, and 3.5 liter, each use different pushrod lengths for intake and exhaust valves. If the wrong pushrods are used, two things can occur:
1. The pushrod(s) can be bent.
2. The engine will run rough because the longer pushrod prevents the valve from closing all the way.
Always check service information for the exact location of the pushrods.
This intake manifold gasket includes end seals and a full shield cover for the valley to keep hot engine oil from heating the intake manifold.

An exhaust manifold gasket is used on some engines. It seals the exhaust manifold to the cylinder head.

A 1/8 to 3/16 in. (3 to 5 mm) bead of RTV silicon on a parting surface with silicon going around the bolt face.
Figure 37–57 A beam-type torque wrench being used to tighten the oil pump pickup assembly to factory specifications.

Figure 37–58 A TECH TIP: Check the Oil Pump Pickup to Oil Pan Clearance

Whenever installing the oil pan on an internal engine, it is wise to check the clearance between the oil pump pickup and the bottom of the oil pan. This clearance should be 5/16 to 3/8 in. (8 to 9 mm). To check the clearance, two methods can be used.

METHOD 1: With the engine upside down and the oil pump and pickup installed, measure the distance from the oil pan rail to the bottom (actually the top) of the oil pump pickup. Then measure the distance from the oil pan to the top of the oil pan and subtract the two measurements to get the clearance.

METHOD 2: Place about 1/2 in. (13 mm) of modeling clay on the pickup of the oil pump. Then temporarily install the oil pan with a gasket. Press down on the oil pan to compress the modeling clay. Remove the oil pan and measure the thickness of the clay. This thickness is the oil pan to oil pump pickup clearance. **SEE FIGURE 37–58.**

Figure 37–58 Using clay to determine the oil pan to oil pump clearance, which should be about 5/16 in.
Using a hammer to straighten the gasket rail surface of the oil pan before installing the new gasket. When the retaining bolts are tightened, some distortion of sheet metal covers occurs. If the area around the bolt holes is not straightened, leaks can occur with the new gasket.

Real World Fix: The New Oil Pump That Failed

A technician replaced the oil pump and screen on a V-8 with low oil pressure. After the repair, the oil pressure returned to normal for two weeks, but then the oil pressure light came on and the valve train started making noise. The vehicle owner returned to the service garage where the oil pump had been replaced. The technician removed the oil pan and pump. The screen was almost completely clogged with the RTV sealant that the technician had used to seal the oil pan gasket. The technician failed to read the instructions that came with the oil pan gasket. Failure to follow directions, and using too much of the wrong sealer, cost the repair shop an expensive comeback repair.

Oil should be seen flowing to each rocker arm as shown.
REAL WORLD FIX:

Oops

After overhauling a big block Ford V-8 engine, the technician used an electric drill to rotate the oil pump while turning on the drill. When the drill was turned off, the pressure would slowly drop to about 10 PSI. The technician checked the oil level for the drill oil. The drill oil was very low and the technician added more drill oil to the drill. However, when the drill was turned back on, the oil pressure would start to increase to about 10 PSI and then drop to zero. In addition, the oil was very aerated (full of air). Replacing the oil pump did not solve the problem. After hours of troubleshooting and disassembly, it was discovered that an oil gallery plug had been left out underneath the intake manifold. The oil pump was working correctly and was pumping oil throughout the engine and out of the end of the unplugged oil gallery. It was not necessary for the oil to be drawn into the engine and it did not take long for the oil pan to empty. The oil pump began drawing in air that aerated the oil which caused the oil pressure to drop. Installing the gallery plug solved the problem. It was smart of the technician to check the oil pressure before starting the engine. This oversight of leaving out one gallery plug could have resulted in a ruined engine shortly after the engine was started.

NOTE: Many overhead camshaft engines use an oil passage check valve in the block near the deck. The purpose of this valve is to help hold oil in the cylinder head around the camshaft and lifter when the engine is stopped. Failure to reinstall this check valve can cause the valve train to be noisy after engine start-up.

TECH TIP: Install Heat Tabs

The wise engine builder should install a heat tab to the back of the cylinder head(s). A heat tab uses a special heat-sensitive metal in the center of a mild steel disc. If the temperature of the cylinder head exceeds 250°F (121°C), the center of the tab will melt and flow out indicating that the engine was overheated. SEE FIGURE 37-61.

Figure 37-61 Heat tabs can be purchased from engine supply companies.
Figure 37-62: A dynamometer measures engine torque by applying a resistive force to the engine and measuring the force applied. Water is being used as the resistive load on this dynamometer.

Figure 37-63: A chassis dynamometer is used to measure torque at the drive wheels. There is a power loss through the drive train so the measured values are about 20% less than when measuring engine output at the flywheel using an engine dynamometer.

Figure 37-64: A magnetic pickup is being used to monitor engine speed when the vehicle is being tested on a chassis dynamometer.
TECH TIP: Look at the Crossing Point

All dynamometers measure torque of an engine, then calculate the horsepower. Horsepower is torque multiplied by engine speed (RPM) divided by 5,252 (a constant). Therefore, all graphs should show that the two curves for horsepower and torque should be the same at 5,252 RPM. • SEE FIGURE 37-65.

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Figure 37-65: Because horsepower is calculated from measured torque, the horsepower and torque curves should always cross at exactly 5,252 RPM.

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TECH TIP: Compare Dyno Results from the Same Dyno Only

There are too many variables between dynamometers to allow a fair comparison when testing an engine. If changes are made to the engine, try to use the same dynamometer and use the same correction factors. Using another dynamometer can result in readings that may not be equivalent when testing on the original tester.
PLASTIGAGE 1
Clean the main bearing journal and then place a strip of Plastigage material across the entire width of the journal.

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

PLASTIGAGE 3
Torque main bearing cap bolts to factory specifications.
PLASTIGAGE 4 Carefully remove the bearing cap and, using the package that contained the Plastigage, measure the width of the compressed material. The gauge is calibrated in thousandths of an inch. Repeat for each main bearing.

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

PLASTIGAGE 6 Clean the rod bearing journal and then place a strip of Plastigage across the entire width of the journal.
PLASTIGAGE 7

Torque the rod bearing cap nuts to factory specifications.

PLASTIGAGE 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.