3.0 DIESEL ENGINE CONSTRUCTION

This chapter presents the basic principle of construction and methodology used to counteract the unbalanced forces created within the engine to produce uniform output shaft horsepower and minimize engine vibration.

Learning Objectives

As a result of this lesson, you will be able to:

1. Describe the basic construction and identify the loads imposed on the structural components of a diesel engine.

2. Describe the basic construction and function of major rotating and reciprocating components of a diesel engine.

3. Describe the basic construction and state the function of the cylinder head, valves, and related components of a diesel engine.

4. Describe the basic construction and the purpose of camshafts, cam followers, and valve operating mechanisms.

3.1 Structural Components

3.1.1 Structural Loading

The engine frame or block assembly forms the main structural component of the engine. During engine operation, it is subjected to a complex set of forces. The design and construction of the frame or block assembly must withstand these forces while keeping the operational components properly oriented with respect to each other.

3.1.1.1 Cylinder Forces (Figure 3-1) - The gas pressure created in the cylinder acts to force the piston, and therefore the crankshaft, away from the cylinder head. As the piston moves away from TDC or BDC, the angularity of the connecting rod generates a lateral force pushing the crankshaft sideways while thrusting the piston against the wall of the cylinder. The magnitude of these lateral forces varies with the angle of the connecting rod and the pressure of the gas against the piston.

Figure 3-1A shows the magnitude of the vertical and lateral forces in the engine as a result of the pressure acting on the piston, superimposed on the PV diagram shown in Chapter 2. This is the case of the 8-1/8 OP lower piston with similar forces imposed by the upper piston. Note the magnitude of these forces (the vertical up to about 63 thousand pounds). The lateral forces are small in comparison.

The frame or block assembly provides sufficient rigidity to maintain the alignment of the cylinder to the crankshaft and absorb the lateral or sideways forces of the piston against the cylinder wall.

3.1.1.2 Crankshaft Rotation - The power developed by the engine creates a rotating force or torque output from the crankshaft to the generator rotor. In turn, there is an opposite and equal reactionary force between the generator and the engine frame or block assembly. Therefore, the generator must be structurally connected to the engine to prevent any relative motion between the generator and engine. This can be accomplished in one of three ways:

The generator can be connected directly to the engine frame or block assembly. This keeps the reactionary forces within the engine itself.

A second approach involves mounting the engine and the generator on a common **structural steel frame** or base assembly. The rigidity of the frame compensates for the reactionary forces between the engine and generator. The complete assembly is then mounted to the building. With the accessories also attached to the steel base, a somewhat "packaged" configuration is created.

The third method, applied at a generic plant, involves mounting the engine assembly and generator to a **reinforced concrete basemat** that is part of the diesel generator building structure. The mounting scheme is Seismic Category I in accordance with NRC Regulatory Guide 1.29, "Seismic Design Classification." The Category I design provides protection from the effects of tornados, missile hazards and floods. The mounting scheme is constructed to withstand a safe shutdown earthquake (SSE).

3.1.2 Engine Block

The engine block or block assembly can be manufactured as either a single piece or from several individual components secured by bolts, studs or other such fasteners.

3.1.2.1 Single Piece Design - The single piece engine block is manufactured as either a single casting as in the automotive type engines or as a weldment of steel plate and forged sub-components. With this design, the crankshaft is supported below the cylinders by a set of main bearings. Internal passages for oil and water are incorporated in the block.

3.1.2.2 Multi-piece Design (Figure 3-2) - With the multi-piece design, the crankshaft is sup-ported in the engine base, which also serves to mount the engine to its basemat.

The engine frame, sometimes called a "doghouse", mounts to the engine base and surrounds the crankshaft. It also provides for mounting of the cylinder blocks.

The cylinder block or blocks for V-type engines mount to the engine frame and provides for locating and supporting the cylinder assemblies. These blocks may be in groups or banks, or they may be individual components for each cylinder. Coolant passages are provided as well as provisions for mounting the cylinder heads.

3.1.2.3 Block Construction - Small engines and some medium-sized engines use single piece alloy iron castings to form their engine block. Alloy castings may also be used for the components of the multi-piece design.

Medium size engines and some larger engines use steel plates welded to specially forged sub- components. The welded plate design offers good structural rigidity making it ideal for marine and locomotive applications.

Typical cylinder blocks for the 12-cylinder

FM OP and the 16-cylinder FM PC engines are shown in Figures 3-3 and 3-4 respectively.

3.1.3 Engine Cylinders

The bore of each cylinder provides the enclosure which acts to guide the motion of the pistons. The wall of the cylinder works in conjunction with the piston rings to create a gas- tight seal to prevent the loss of combustion pressure.

Most diesel engines use replaceable inserts or cylinder liners rather than boring the cylinders directly into the block. In this way, the liners may be replaced on an individual basis rather than replacing the entire cylinder block.

3.1.3.1 Dry Type Liners (Figure 3-5) - Dry type cylinder liners have a precision ground outside diameter which is fitted into a machined bore in the cylinder block. Heat transfer from combustion is through the cylinder liner with metal-to-metal contact between the liner and the block and through the cylinder block to the engine coolant. Engine coolant does not come into direct contact with the liner.

3.1.3.2 Wet Type Liners (Figure 3-6) - With wet type liners, the coolant comes into direct contact with the outer surface of the cylinder liner. This allows for better heat transfer than is available with dry type liners by conducting heat directly through the liner wall to the engine coolant.

Sealing is accomplished at the top of the liner by the cylinder head gasket and the fit of the liner into the block. Rubber o-rings or seal rings prevent coolant leakage at the bottom of the liner.

3.1.3.3 Integral Type Liners (Figure 3-7) On some engines, the water jacket is incorporated as an integral part of the liner. The General Motors EMD Models 567, 645 and 710 2-stroke cycle diesels have the water jacket cast as part of the liner. A special sleeve, shrink fitted to the outside of the liner, is used to create the water jacket on the Fairbanks-Morse opposed piston engines. Integral type liners offer the same direct heat transfer as the wet type liners.

3.2 <u>Engine Bearings</u>

Engine operation involves relative motion of a vast number of individual components. Where there is motion and where loads or forces are being transmitted, some form of bearing is normally employed.

3.2.1 Journal Bearings

Journal bearings are plain cylindrical-shaped devices which must support the loads and forces imposed on them while allowing free movement. Journal bearings must also provide for lubrication of the bearing and shaft. Bearing lubrication is discussed in Chapter 5, "Engine Lubrication System."

The engine main and connecting rod bearings as well as camshaft bearings and rocker arm bushings are replaceable, precision insert journal type bearings. The main and connecting rod bearings are split to allow them to be placed around the crankshaft journals. OP engine main bearings are illustrated in Figure 3-8. Also see Figure 3-24.

3.2.2 Rolling Element Bearings

With rolling element bearings, a spherical or cylindrical device is placed between the two surfaces. As one surface moves, the element must roll reducing friction and wear.

Rolling element bearings can be found in various engine components such as the jacket water pump, lube oil pump, cam followers and governor drive mechanism.

3.3 Rotating and Reciprocating Components

Figure 3-9 shows a view of a piston with its connecting rod and other associated parts that make up the reciprocating components of the power assemblies.

3.3.1 Pistons

The engine's pistons form the lower closure of the cylinder while transmitting the forces of combustion to the connecting rod and crankshaft. These components are subjected to peak temperatures of 3500 to 4500F.

3.3.1.1 Trunk Type Pistons -- The common type of piston used is the *trunk* type shown in Figure 3-10. The upper portion or *crown* absorbs the forces created by combustion and transmits them to the connecting rod through the piston pin boss and piston pin (see section 3.3.3). The lower portion of the piston or *skirt* acts to guide the movement of the piston in the cylinder while transmitting the side thrust, created by connecting rod angularity, to the wall of the cylinder liner.

For the piston shown in Figure 3-10, the crown is attached to the skirt with four connecting studs, castle nuts and roll pins. The belville spring pack compensates for thermal expansion between the skirt and crown. Seal rings prevent lubrication oil inside the piston from reaching the combustion space.

3.3.1.2 Floating Skirt Pistons -- A variation in piston design is the *floating skirt* piston shown in Figure 3-11. This type piston is commonly used on 2-stroke cycle engines. The *crown* and *skirt* are a single piece supported by the *piston carrier.* The piston carrier is secured to the skirt by either a lock ring (as shown) or by bolts or studs.

Combustion forces are transmitted from the piston crown through the thrust washer to the piston carrier, which is linked to the connecting rod by the piston pin.

3.3.1.3 Piston Materials -- Pistons must be relatively light weight to reduce the inertial forces acting on the connecting rod and crank-shaft, while being strong enough to transmit the forces of combustion.

Cast or forged alloy iron and steel are frequently used for pistons on medium and large diesel engines. These pistons are usually multi-piece design as shown in Figures 3-10 and 3-11.

3.3.2 Piston Rings

Piston rings may be classified as either compression rings or oil control rings. Compression rings act to seal against the high pressure combustion gases while transmitting heat from the piston to the cylinder wall. Oil control rings prevent excess lubricating oil from reaching the combustion chamber.

3.3.2.1 Compression Ring Design (Figure 3-12) The compression rings are circular with an uncompressed outer diameter slightly larger than the bore of the cylinder and with an inner diameter smaller than the piston diameter. An end gap in the piston ring allows the ring to be expanded to fit over the piston into the ring grooves. The end gap also compensates for thermal expansion and allows the ring to conform to out-of-round or tapered conditions associated with worn cylinder liners.

3.3.2.2 Compression Ring Sealing (Figure 3-13) During operation, combustion gases pass down- ward between the piston crown and cylinder wall to the compression rings as shown. Gas pressure acting on top of the ring causes it to seal against the bottom of the ring groove while the pressure acting on the back of the ring helps to seal against the cylinder wall. The ring end gap, while allowing for thermal expansion of the ring, acts as a restricting orifice which reduces the pressure acting on each subsequent ring by a factor of approximately 50 percent.

The ring cross-section (See Figure 3-14) is generally rectangular with the face being either square, tapered, or barrel shaped. Some rings are wedge or "keystone" shaped which helps prevent the ring from sticking in the piston.

Various ring joints are used as shown in Figure 3-15. The square cut, or butt joint, and the angle cut are the most common and economical to produce. Step joints are sometimes used to improve piston ring sealing. Their more complex and costly design makes them less desirable for installation on diesel engines.

3.3.2.3 Compression Ring Material Compression rings are generally made from a high quality cast iron or iron alloy. Some use a surface treatment such as chromium or molybdenum on the ring face to improve ring performance and longevity.

3.3.2.4 Oil Control Ring Design (Figure 3-16) Oil control rings must prevent excess oil from reaching the combustion chamber while still leaving a sufficient film of oil to lubricate and seal the compression rings.

Like the compression rings, the oil control rings are circular with an uncompressed diameter slightly larger than the cylinder bore. A ring gap is provided for thermal expansion and to allow the ring to conform to the liner.

The narrow contact face of the ring reduces the ring to cylinder wall contact area, creating a large compressive force between the ring and the cylinder wall. The downward taper of the ring scrapes oil from the cylinder wall on the downward stroke while spreading a thin film of oil on the upward stroke. Linear drain slots in the oil control rings direct oil scraped from the cylinder wall toward the piston skirt where holes or slots in the piston skirt allow oil to return to the crankcase by gravity. Several versions of oil control rings are shown in Figure 3-17.

Compression rings are located in grooves near the top of the piston (see Figure 3-18). The uppermost ring is often referred to as the *fire* ring. Location of the oil control rings varies between 2- stroke cycle and 4-stroke cycle engines. On 4-stroke cycle engines, the oil control rings are located just below the compression rings and above the piston pin bore.

Because 2-stroke cycle engines require ports in the cylinder wall, the oil control rings are positioned in grooves at the bottom of the piston skirt. During operation, the oil control rings do not pass over the liner ports. If the oil control rings were positioned so they passed over the cylinder ports, the rings would catch on the ports and break. Even if the rings were designed to pass smoothly over the ports, lubricating oil would easily enter the engine air box. This would cause excessive oil consumption, smoking, and the possibility of explosions or fire in the air box.

3.3.3 Piston Pins

The piston pins, sometimes called wrist pins, transmit the forces acting on the piston to the upper end of the connecting rod while allowing for relative motion (rocking) between the two.

Cylindrical in shape with a hollow center, piston pins are generally made from high grade alloy steel. The outer surface of the pin is ground and polished. The piston pins are often heat treated or chrome plated to resist wear.

Piston pins are retained in either the piston or connecting rod by retaining rings, bolts, clamps or special plugs which prevent axial movement of the pin. The piston and connecting rod assembly for the OP engine is shown on Figure 3-19.

3.3.4 Connecting Rods

The connecting rod is the engine component which working with the crankshaft, converts the reciprocating motion of the piston into the rotary motion of the crankshaft needed to run the emergency generators.

The piston pin is linked to the upper end of the connecting rod either with a bushing or bearing or is bolted or clamped directly to the rod. The lower end of the connecting rod is split to allow it to be assembled around the crankshaft.

3.3.4.1 Conventional Rod (Figure 3-20) - The crankshaft end of a conventional connecting rod is split perpendicular to the axis of the rod. High strength alloy bolts or studs secure the cap to the rod. Dowel pins, sleeves, alignment pins, shoulders, or serrations are used to ensure alignment of the cap to the rod.

3.3.4.2 Angle Cut Rod (Figure 3-21) - To pre- vent interference with other engine components and make disassembly easier, some engines split their connecting rods at an angle to the axis of the rod. The rod cap is aligned and secured to the rod in the same manner as the conventional rod.

3.3.4.3 Articulating Rod (Figure 3-22) - The articulating type connecting rod, shown in Figure 3-22, is used on the Cooper and DeLaval Enterprise V-type engines to connect two pistons on opposite banks of cylinders to a single crankpin without having to offset the cylinders on one side from the other. The assembly consists of a master rod and a link rod. The crankshaft end of the master rod is split vertically with a serrated joint to maintain alignment. When assembled, the lower end of the master rod, including the connecting rod bearing, surrounds the crankshaft crank pin. The link rod connects to the master rod through a link pin which is similar to a piston pin.

3.3.4.4 Fork and Blade Rod (Figure 3-23) The fork and blade rod shown is used on the General Motors EMD 567, 645 and 710 two-stroke cycle diesel engines. The fork rod is split using a basket assembly rather than a bearing cap to secure the rod and connecting rod bearing to the crankshaft. The blade rod has a lower slipper foot (see Figure 3-23) which rides on the outer surface of the upper bearing shell. This upper surface of the bearing shell is coated with an appropriate bearing material and is grooved for lubricating oil distribution to the slipper surface.

3.3.4.5 Connecting Rod Materials - Connecting rods are normally forged from medium carbon or alloy iron and steel. They are often heat treated and in some cases shot peened or stress relieved to improve ductility and fatigue resistance.

3.3.5 Crankshaft

The crankshaft accepts the forces acting along the axis of the connecting rods and converts them into the rotary motion needed for operation. It collects the power from all the cylinders and transmits it axially to the crankshaft hub and engine flywheel.

3.3.5.1 Crankshaft Design (Figure 3-24)

The crankshaft consists of a number of main journals and crankpins or rod journals. The crankpins are connected to the crankshaft by webs. The main journals align with the rotational axis of the shaft. The crankpins are mounted offset to the axis of the crankshaft by a distance equal to one-half the piston stroke. The crankpins work in conjunction with the connecting rods to convert the linear motion of the piston into rotary motion of the crankshaft.

Lube oil is pumped into the main bearings on most engines. From there, the oil is transmitted to the connecting rod journal area via tubes or passages machined into the crank throws, as shown in Figure 3-25. From there, it goes up drilled passages in the connection rods to the piston wrist pin area and on to the piston crown (in many instances) for cooling of the underside of the piston crown. From the undercrown cocktail shaker cavity, the oil drains through a hole and drops back into the crankcase.

3.3.5.2 Crankshaft Materials - The crankshaft must be strong enough to resist the bending action caused by the downward forces of the connecting rod acting on the crankpins. It must also have enough rigidity to withstand the twisting or torsional forces which occur during engine operation.

Crankshafts are generally forged from carbon or alloy steel. They are heat treated to reduce internal stresses created by the forging process. The bearing surfaces are often heat treated to increase wear resistance.

3.3.6 Flywheel and Vibration Damper

The cyclical forces resulting from combustion and the inertial forces due to reciprocation, acting on the crankpins, impart a twisting motion to the crankshaft. This twisting motion combined with the natural torsional vibration of the crankshaft creates rpm dependent stresses in the crankshaft. If allowed to go unchecked, these stresses could lead to fatigue and the development of cracks in the crankshaft.

The engine flywheel and the vibration damper or harmonic balancer act in a manner which helps to reduce or dissipate the effects of torsional induced stresses.

3.3.6.1 Flywheel (Figure 3-26) - The flywheel is a large, disk-like inertial mass mounted to the rear or drive end of the crankshaft. It stores a portion of the rotating or kinetic energy of the engine. It dampens torsional vibration by resisting the crankshaft's tendency to accelerate at each power impulse.

Most engines used on EDG's in nuclear service do not have flywheels. The inertia of the generator rotor acts as the flywheel on these units.

3.3.6.2 Vibration Damper - Vibration dampers, which are usually mounted to the forward end of the crankshaft, function in a manner similar to the flywheel to reduce torsional vibration.

There are many different designs of vibration dampers used on diesel engines. Regardless of design, they all function by linking an inertial mass to the crankshaft through a flexible or elastic mechanism.

As the crankshaft rotates, the inertia mass shifts position in such a way as to counteract the acceleration and deceleration of the torsional activity.

The spring pack damper is shown in Figure 3-27. The inertia mass is connected to the hub through a set of leaf type springs or spring packs. The spring packs deflect to allow the inertia mass to move back and forth to dampen the vibration.

A gear type damper is shown in Figure 3-28. The spider is bolted to the crankshaft. The inertia mass consists of the front plate, rear plate, and intermediate ring. When assembled, engine lubricating oil is fed to the internal spaces of the unit. The lubricating oil acts as the elastic element or viscous fluid between the intermediate ring and spider. Oscillating motion of the two plates and the intermediate ring serves to dampen the vibrations.

Both the monofiler and bifiler type dampers (Figure 3-29) are selectively used on the Fairbanks Morse OP engines. As the crankshaft rotates, the individual weights oscillate around their respective pins. This movement counteracts the torsional vibration in the crankshaft. Figure 3- 29 shows a bifiler damper used on the lower crankshaft of the 12-cylinder OP engine. A monifiler damper is similar but consists of only one row of weight assemblies. These are used on the lower crankshafts of all other OP engines and on the upper crankshaft of the 12-cylinder engine.

3.4 Cylinder Heads

On all conventional engine designs, the cylinder head forms the upper closure of the combustion chamber. It provides for installation of valves (2- and 4-stroke cycle). A port is provided for mounting of the injection nozzle or unit injector and possibly for the installation of a starting air check valve. Bolted to the cylinder liner or block, the cylinder head provides passages for the flow of engine coolant.

3.4.1 Cylinder Head Construction

Cylinder heads (Figure 3-30) are castings of either alloy iron or steel. They may be con- figured so that each cylinder is provided with a cylinder head (large engines) or so that one head fits several cylinders or an entire bank.

The flat surface or fire deck of the head forms the upper closure of the combustion space. Seating surfaces are provided in the fire deck for intake and exhaust valves. A gasket surface around the circumference of the fire deck allows for sealing the head to the liner or block.

3.4.2 Valves and Valve Seats (Figure 3-31)

Intake and exhaust valves are mounted in the cylinder head to allow the flow of air and spent gas into and out of the cylinder. When closed, the valve seals against a machined valve seat in the fire deck.

Valve seats may be of the full contact or interference type (Figure 3-31). With the full contact valve seat, the angle on the face of the valve is exactly the same as that of the valve seat. With the interference type, the valve seat and valve face angle differ by one-half to one and one-half degrees. The angles are such that a line contact is created near the outermost part of the valve face. Full contact seats provide the best cooling for the valve while the interference seat offers faster initial seating and has less tendency for carbon deposits to build up. The intake valves (4-stroke cycle) and exhaust valve seats may be machined directly into the fire deck or installed as separate valve seat inserts.

3.4.3 Valve Guides (Figure 3-32)

Valve guides are precision-bored holes in the cylinder head in line with the axis of the valve seat. The valve guide controls the linear motion of the valve as it opens and closes.

Valve guides may be bored directly into the head or installed as replaceable inserts. The replaceable guides are either bolted to or pressed into the head.

3.4.4 Valve Springs and Retainers (Figure 3-32)

Valves are held in the closed position by coil springs which surround the valve stem and guide. A spring retainer and a pair of keepers or locks transmit the spring force to the valve stem. Some installations include devices which cause the valve to rotate slightly each time the valve is lifted from its seat. This movement helps keep the seating surfaces free of deposits and substantially increases the life of the valve.

Engines which use valve rotators must use full contact valve seats. Use of valve rotators with interference valve seats will cause improper seating and premature valve failure.

3.5 Camshafts and Valve Mechanisms

Engine camshafts function to open intake and exhaust valves, operate fuel injection pumps and in some cases operate starting air check valves.

3.5.1 Cams (Figure 3-33)

Cams are irregularly shaped circles or ovals which convert the rotating motion of the camshaft into the linear motion needed to operate the valves and injectors. The specific shape of the cam lobe determines the amount and the duration of the lift for the cam operated component. Intake and exhaust valve cam lobes tend to be more oval or eccentrically shaped while the lobes used to operate the fuel injection pumps are more circular.

3.5.2 Cam Followers (Figure 3-34)

Cam followers, which mount in or are connected to the cylinder block, track the contour of the cam along a linear path and transmit this motion to the push rods or rocker arms. The three types of cam followers shown in Figure 3-34 are commonly used on diesel engines.

The flat tappet follower is the most economical to produce but also exhibits the greatest rate of wear. As such, flat tappet followers are generally limited to smaller diesel engines. The roller tappet is the most common type for medium and large size diesel engines. The roller rides on a needle or sleeve type bearing. The rolling contact of the roller on the cam lobe produces the least amount of friction and wear. For both the flat tappet and roller tappet followers, a precision bore must be provided in the cylinder block to control the linear motion of the follower.

The hinged follower is a variation of the roller tappet follower. The roller contacts the cam lobe as before while the hinged arm controls the motion of the follower limiting it to a shallow arc.

3.5.3 Camshaft Drive Mechanism (Figures 3-35 and 3-36)

The camshaft must maintain a positive relationship with the crankshaft. On 4-stroke cycle engines, the camshaft rotates once for every two rotations of the crankshaft. On 2-stroke cycle engines, the camshaft and crankshaft operate at the same speed. This positive relationship is maintained through the use of gears (Figure 3-35) or chains, with gears being the most common. Figure 3-36 shows the timing chain drive used on the Fairbanks Morse opposed piston engines.

3.5.4 Rocker Arms and Pushrods (Figure 3-37)

The location of the camshaft relative to the valves is often less than optimum. Frequently, the camshaft is mounted in the cylinder block or engine frame below the cylinder heads. Rocker arms and pushrods are used to transmit the motion of the cam followers to the intake or exhaust valves.

Pushrods are tubular steel components which transmit motion of the cam followers to the appropriate end of the rocker arm. Rocker arms are lever type devices which pivot on a fixed axis to change the direction and control the motion of the valve-operating bridge. The valve-operating bridge is used to operate two intake or two exhaust valves from one rocker arm.

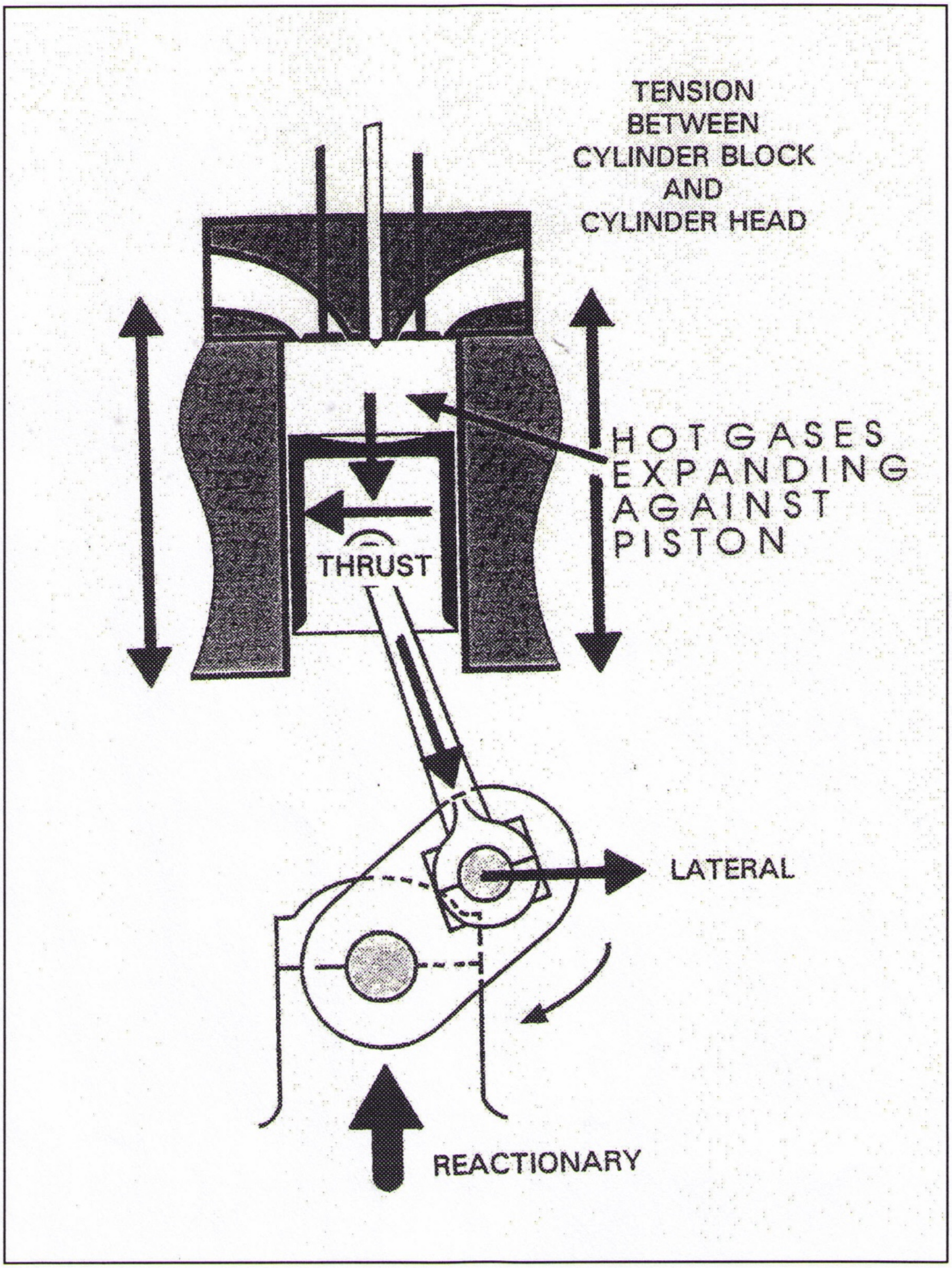


Figure 3-1 Cylinder Forces

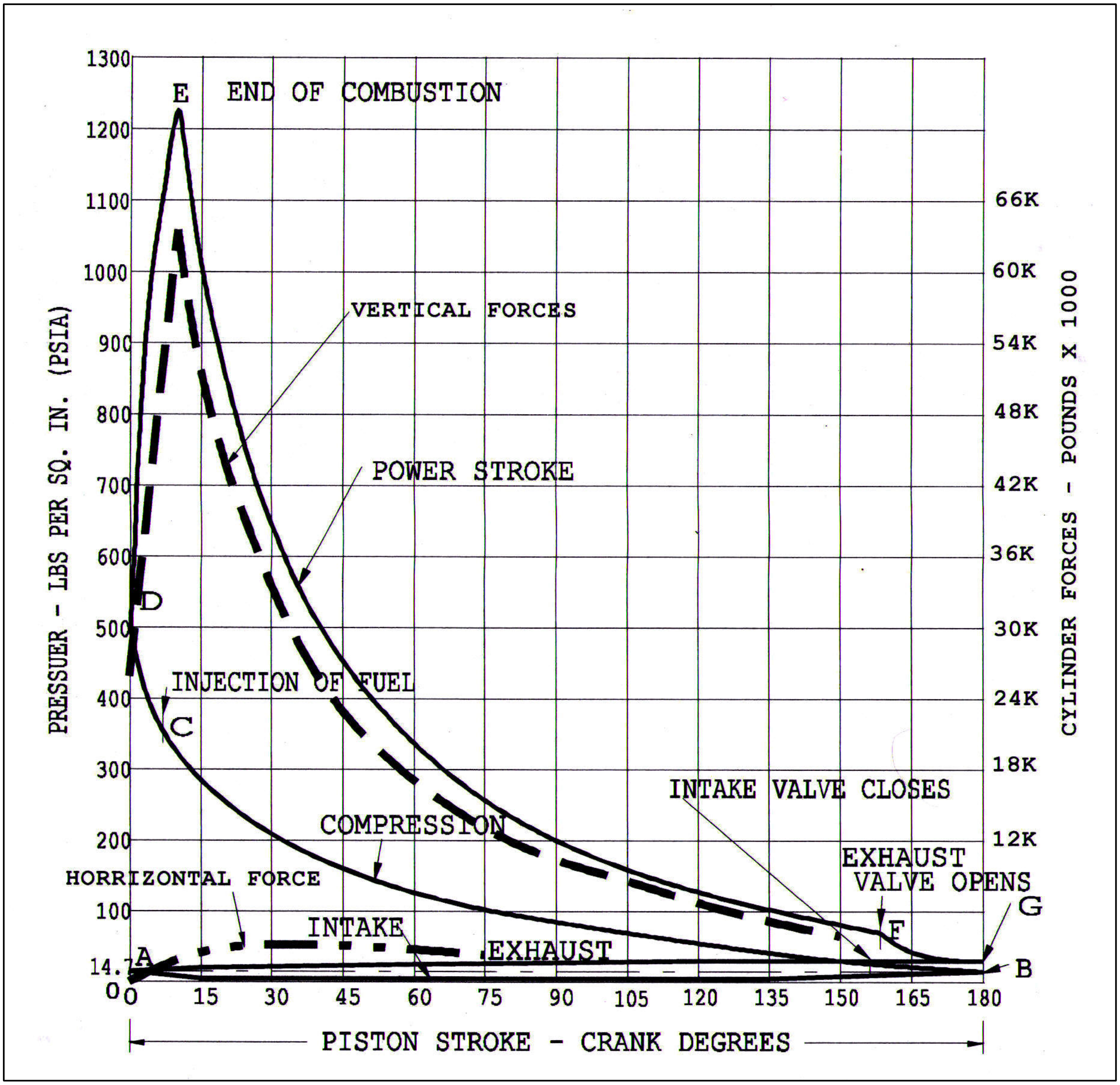


Figure 3-1A Vertical & Lateral Forces during Power Stroke Superimposed on Pressure vs Crank Angle Diagram

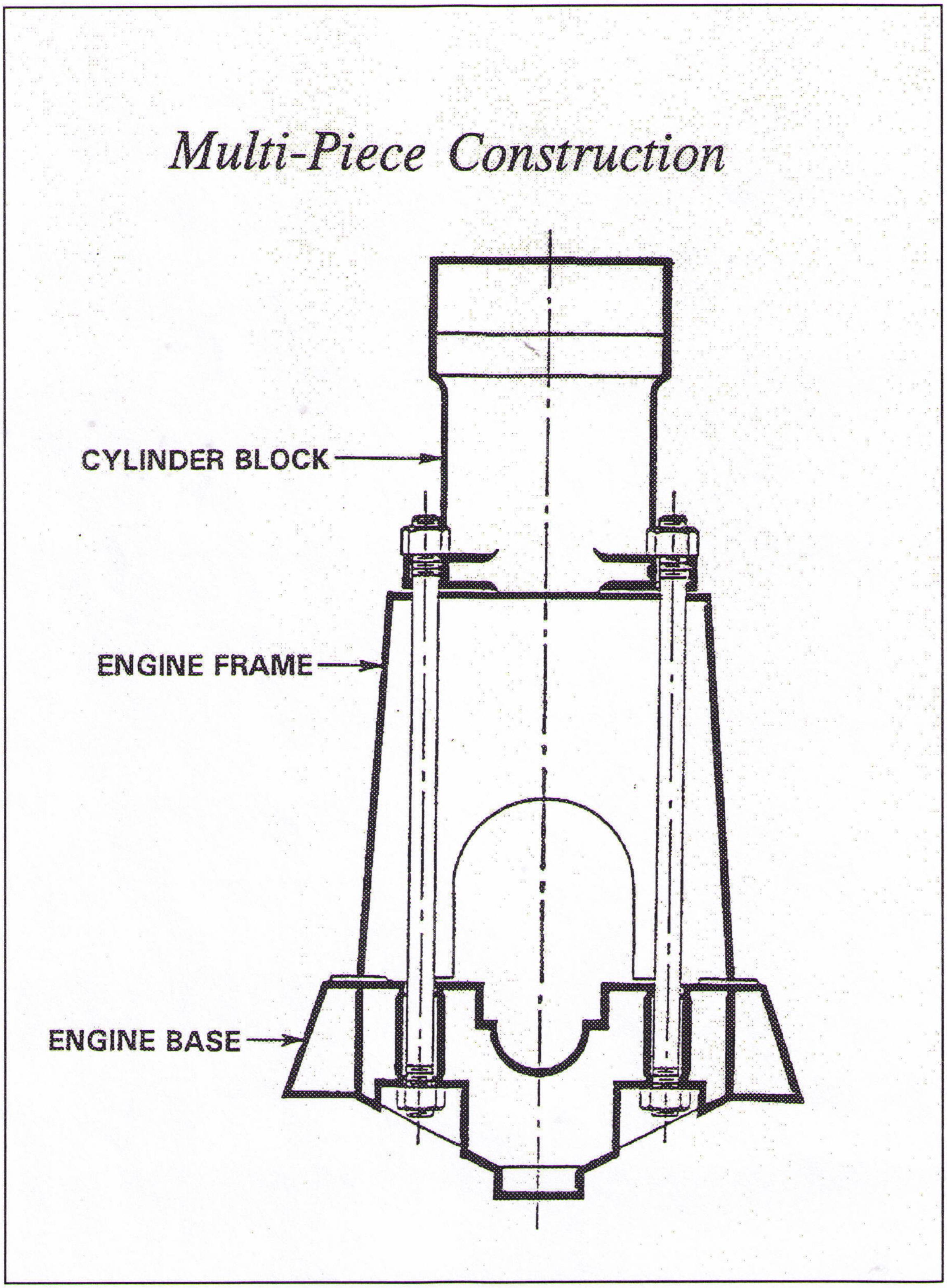


Figure 3-2 Multi-Piece Construction

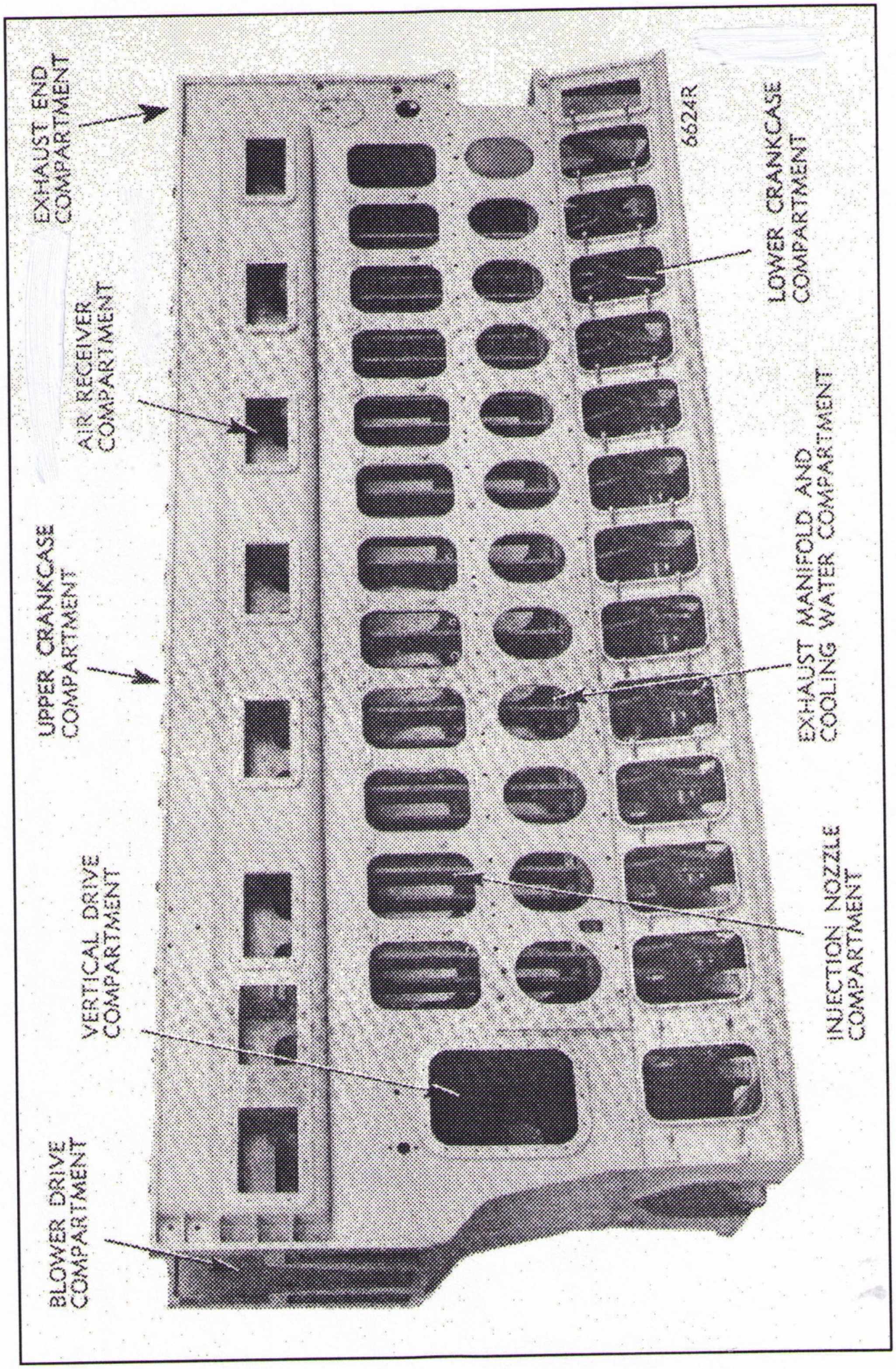


Figure 3-3 12-Cylinder OP Engine Cylinder Block

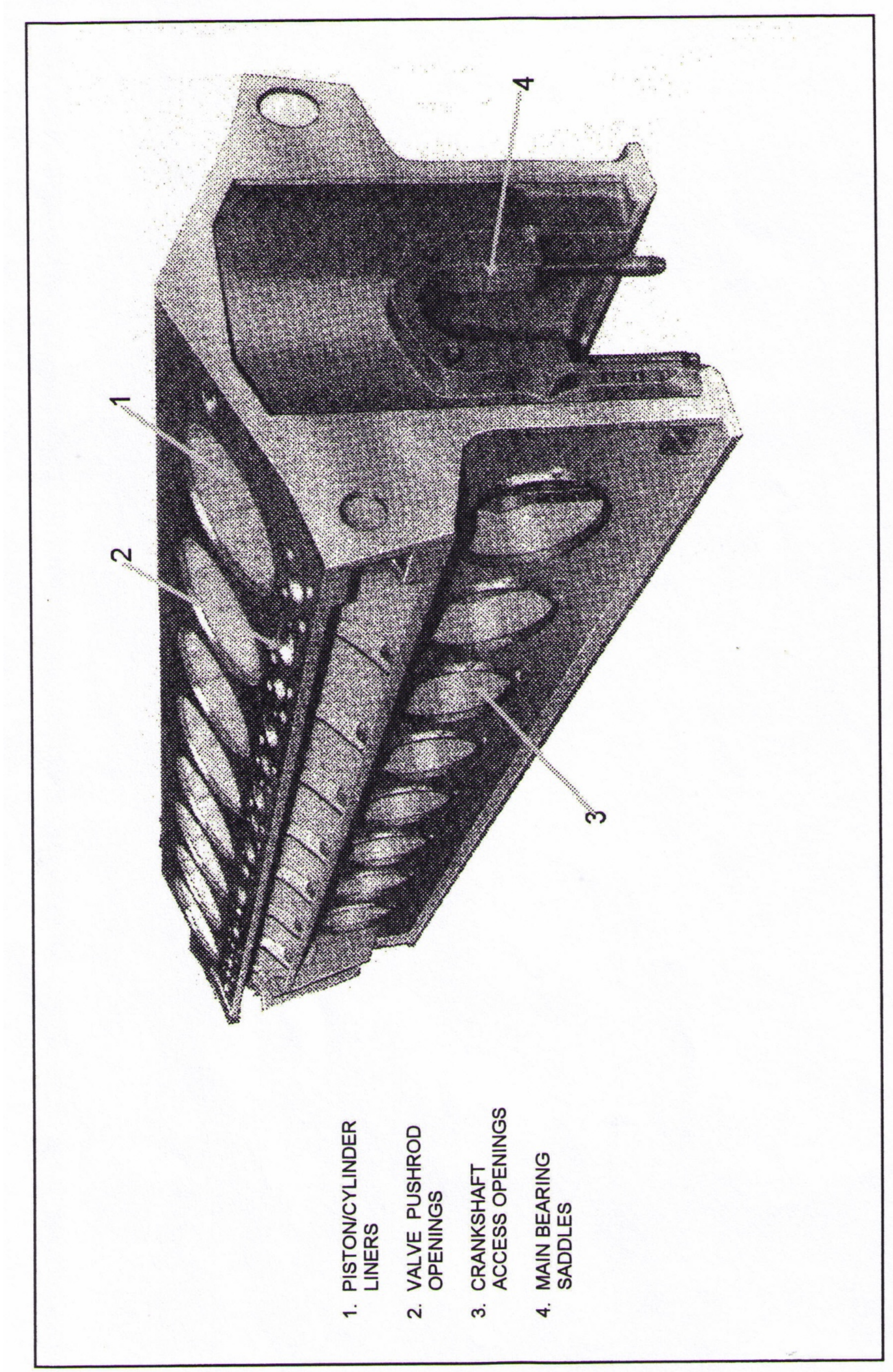


Figure 3-4 16-Cylinder PC Engine Cylinder Block

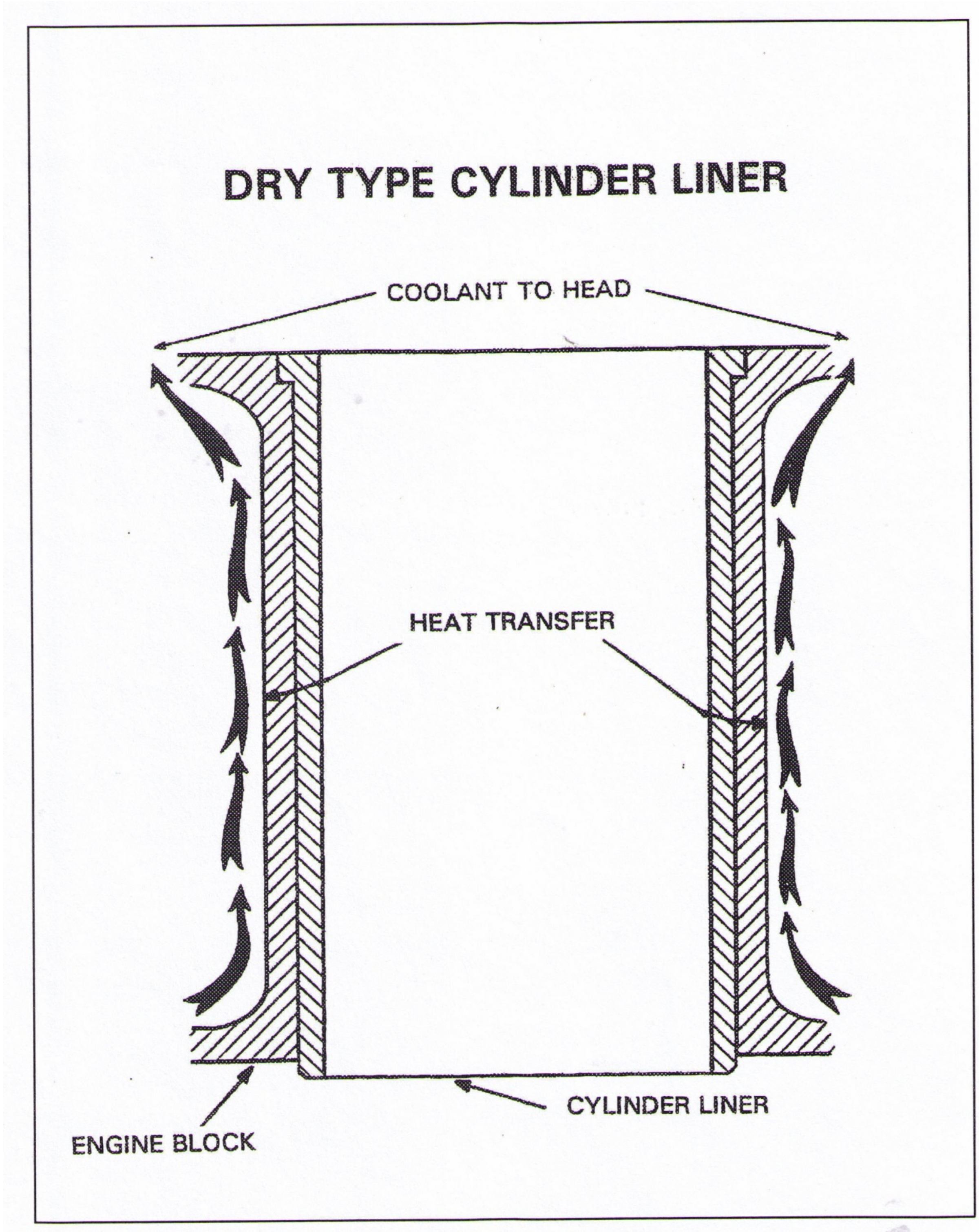


Figure 3-5 Dry Type Cylinder Liner

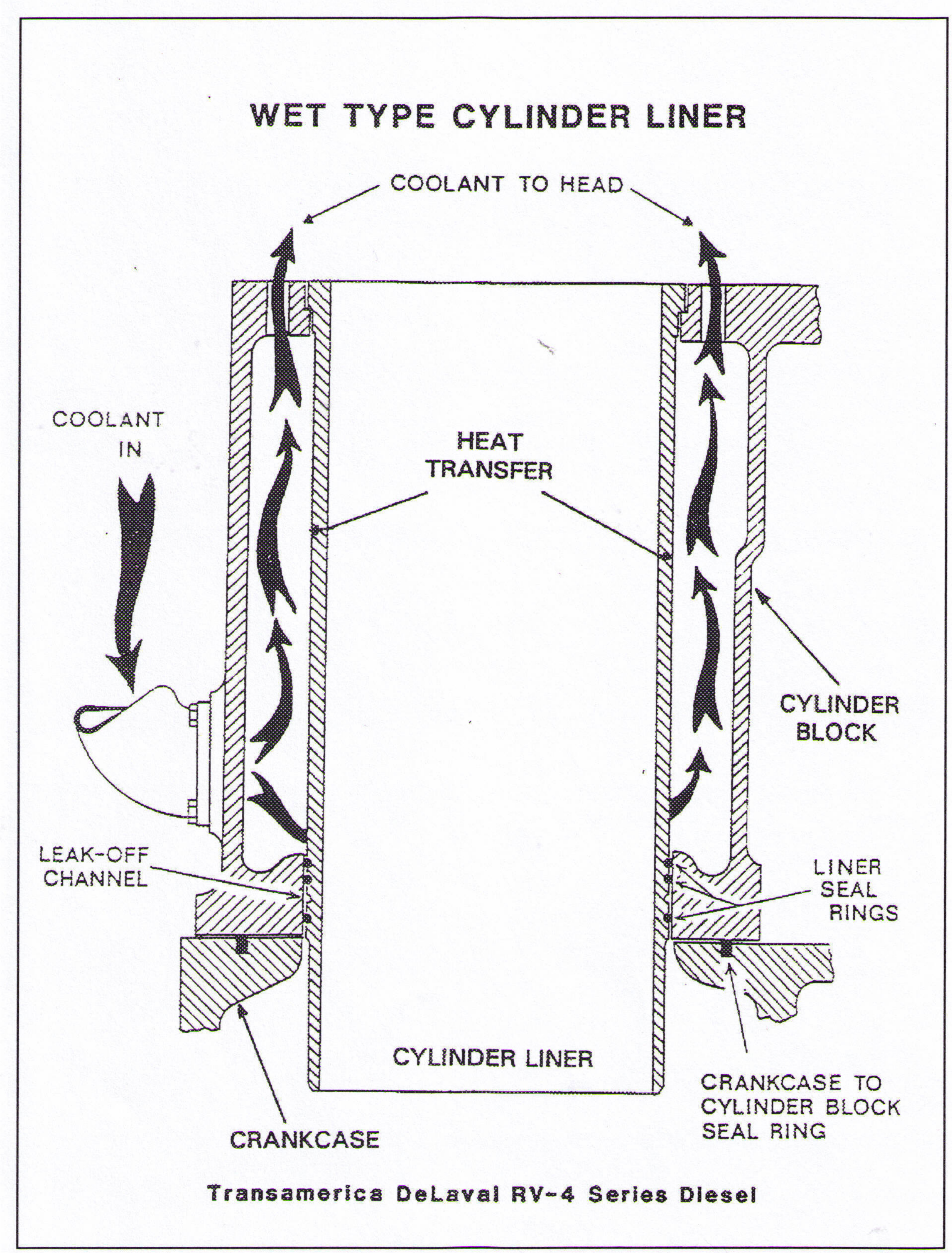


Figure 3-6 Wet Type Cylinder Liner

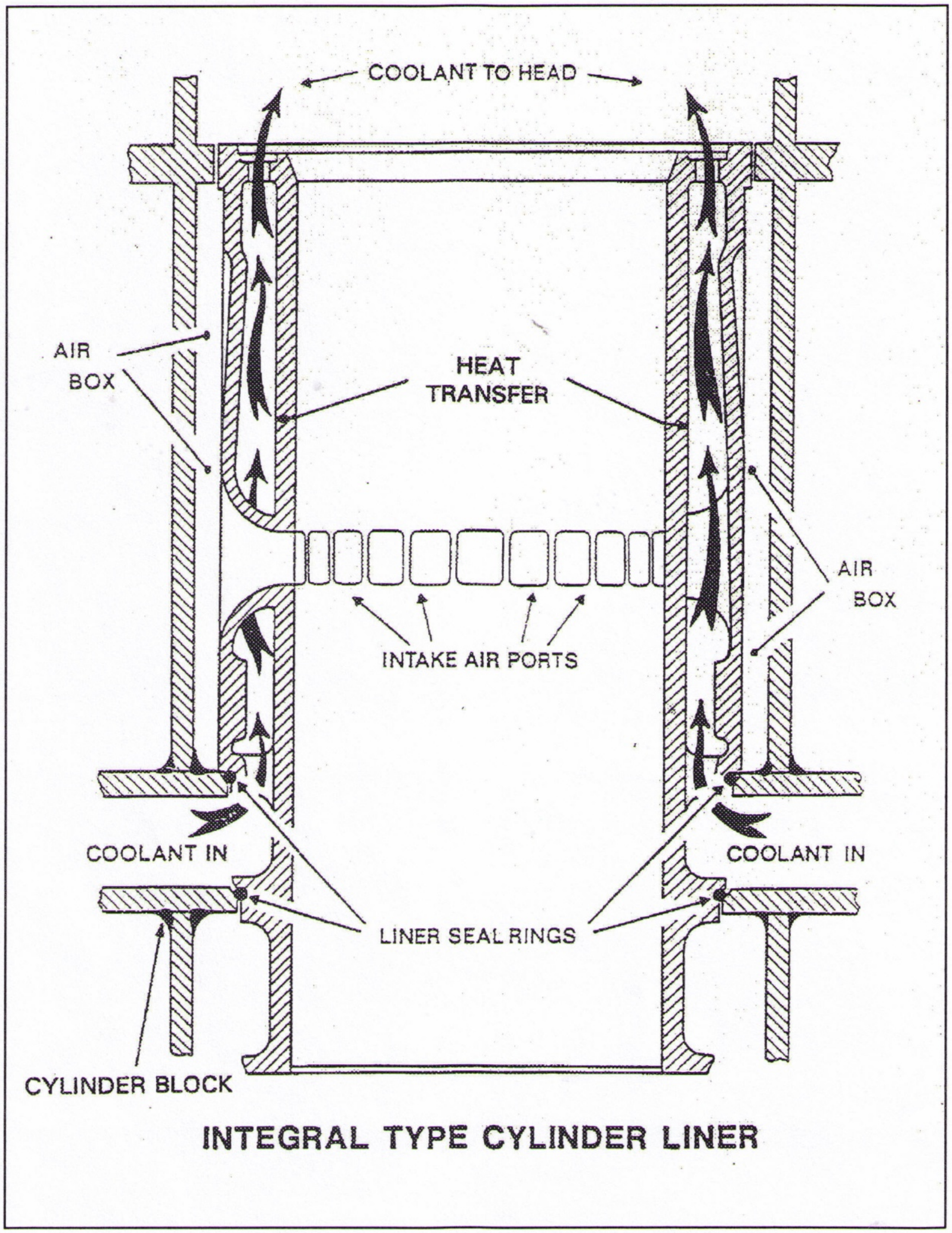


Figure 3-7 Integral Type Cylinder Liner

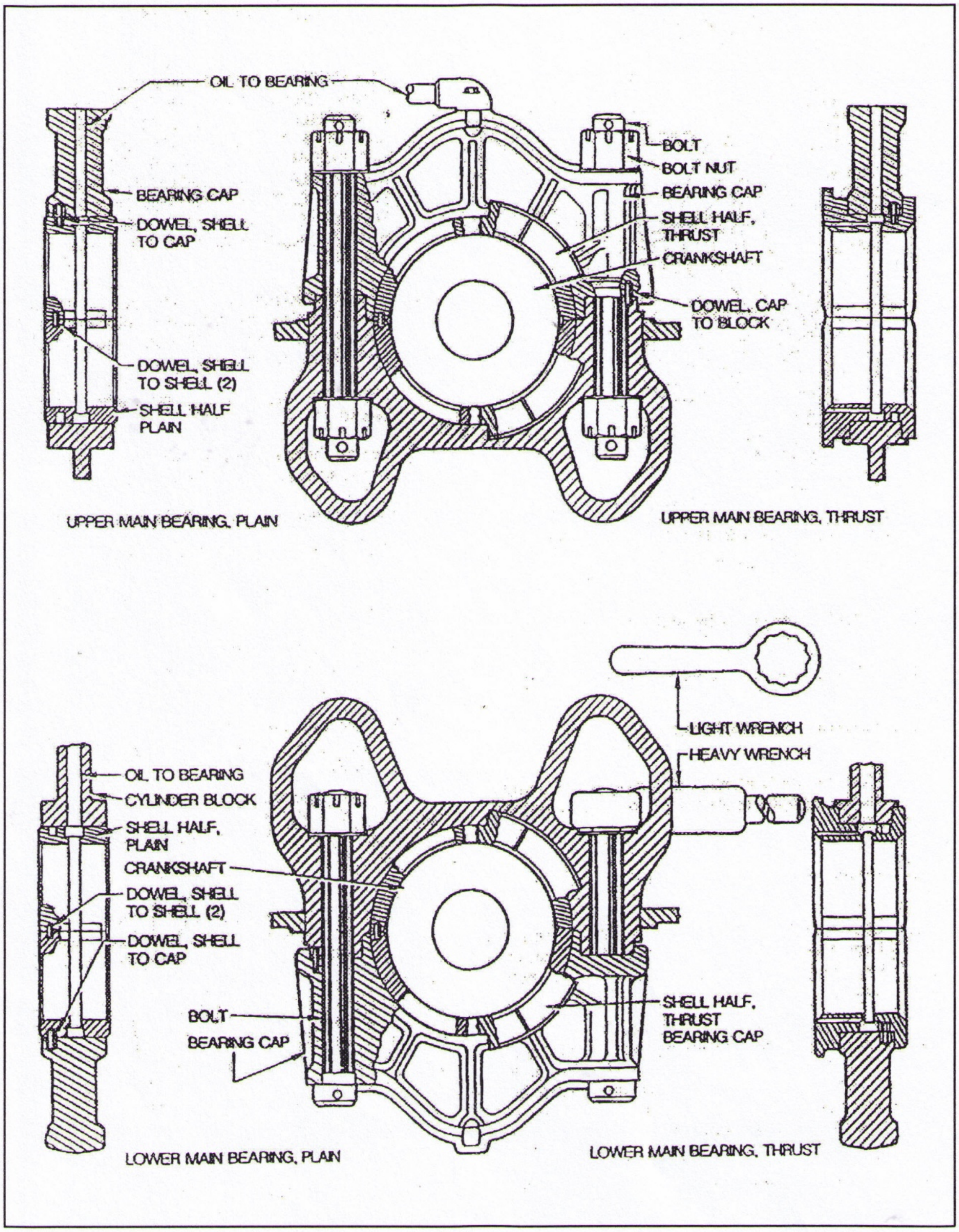


Figure 3-8 OP Engine Main Bearings

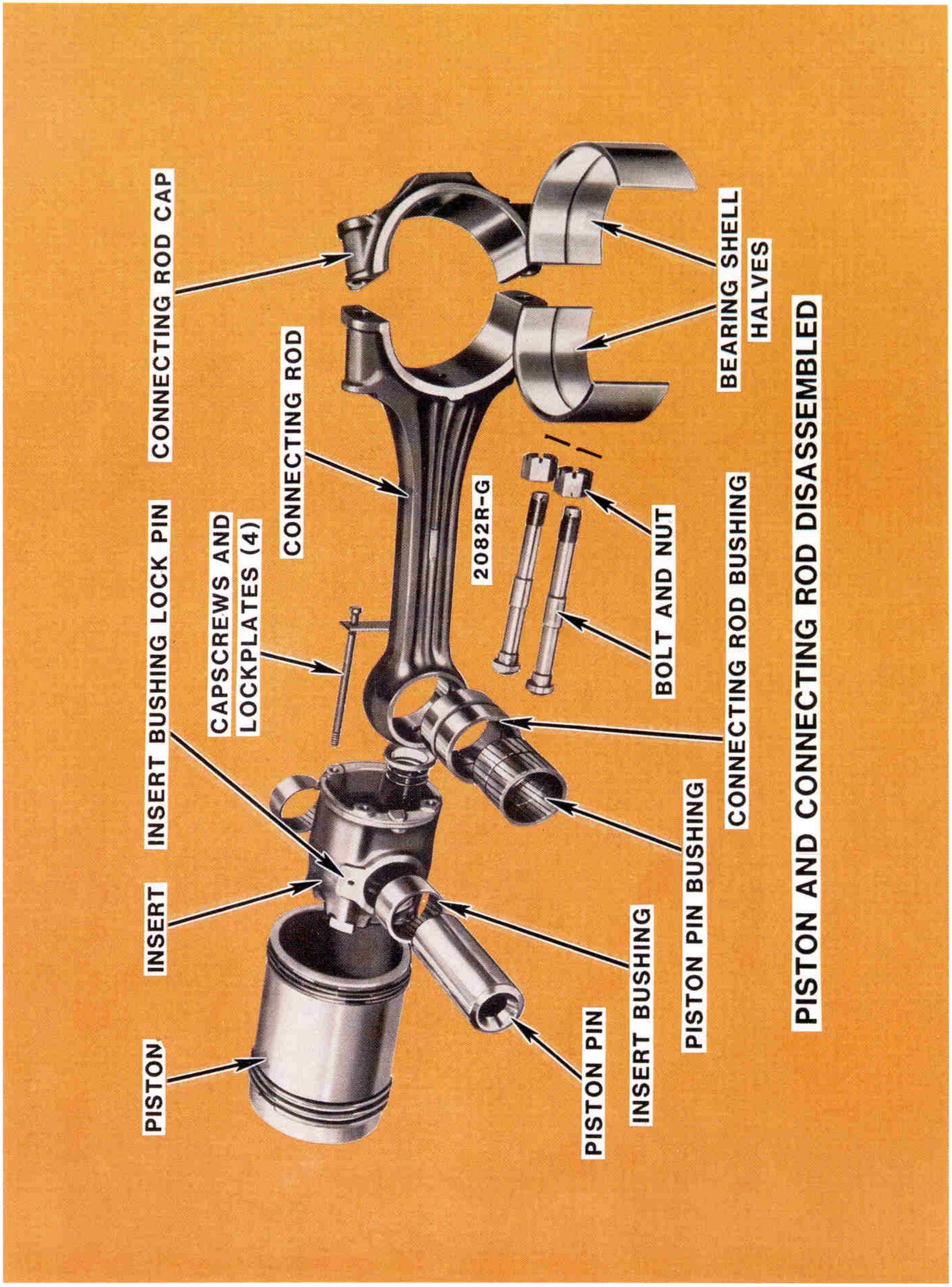


Figure 3-9 OP Piston and Con-Rod Assembly

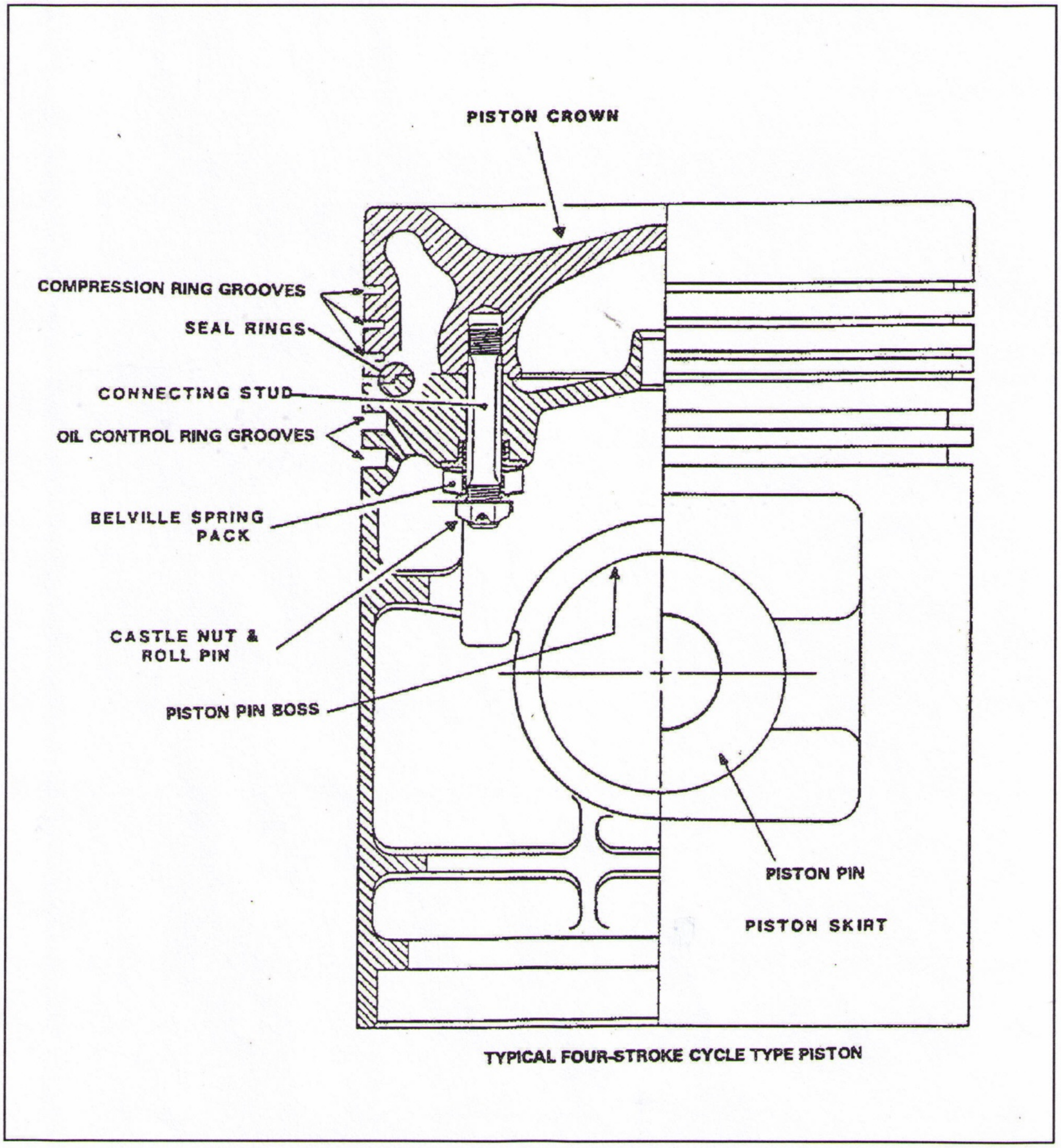


Figure 3-10 Trunk Type Piston

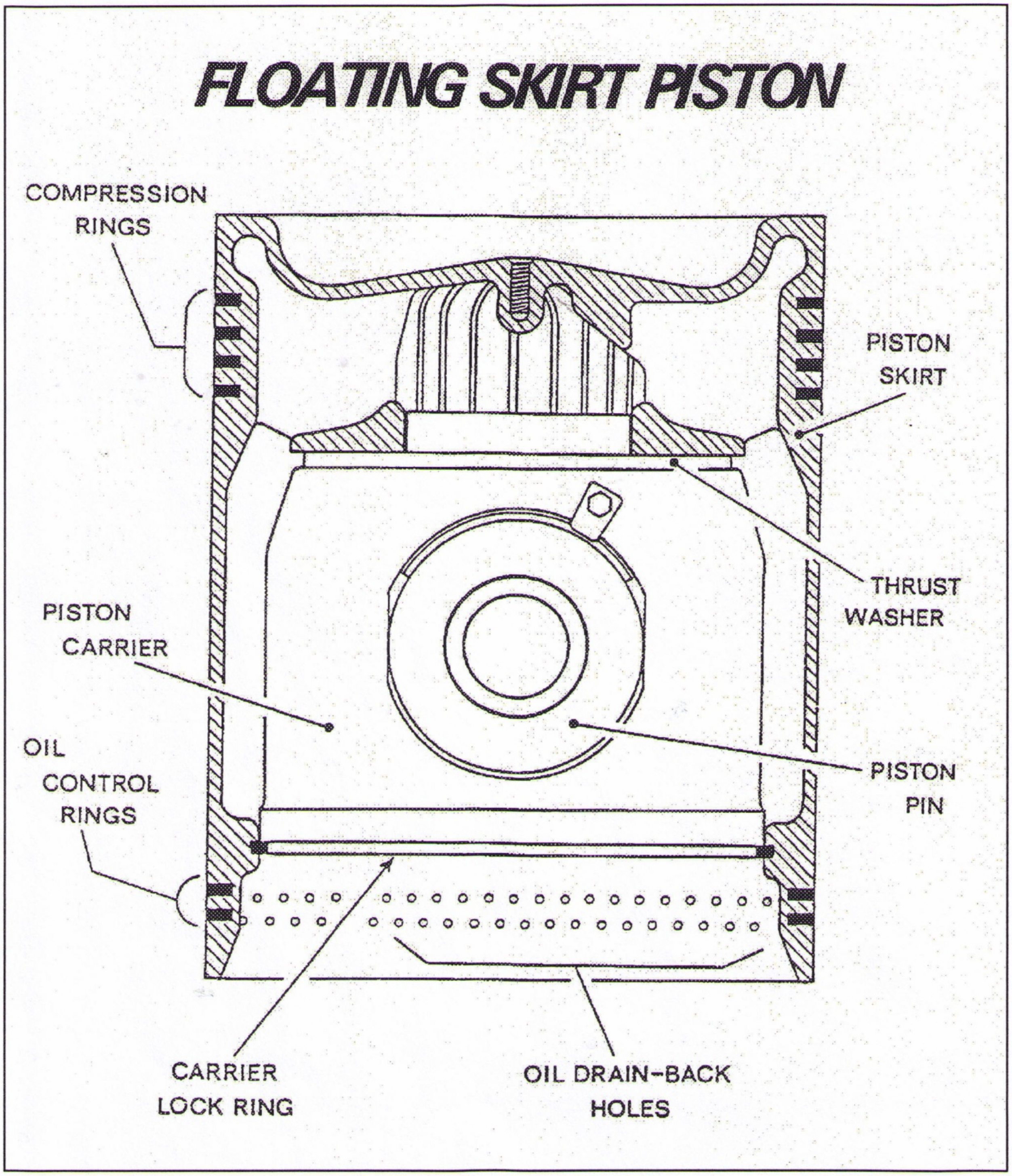


Figure 3-11 Floating Skirt Piston

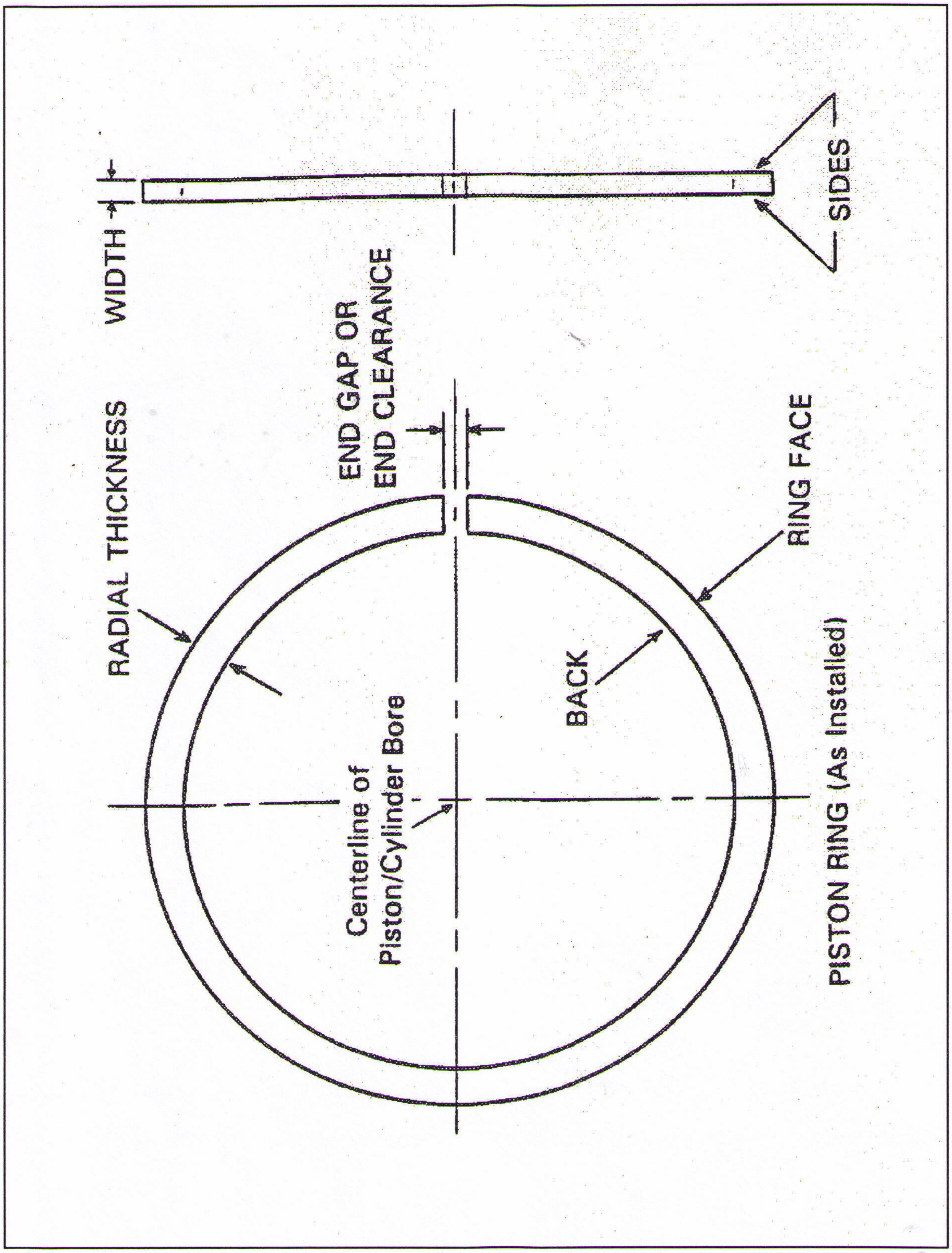


Figure 3-12 Piston Ring Nomenclature

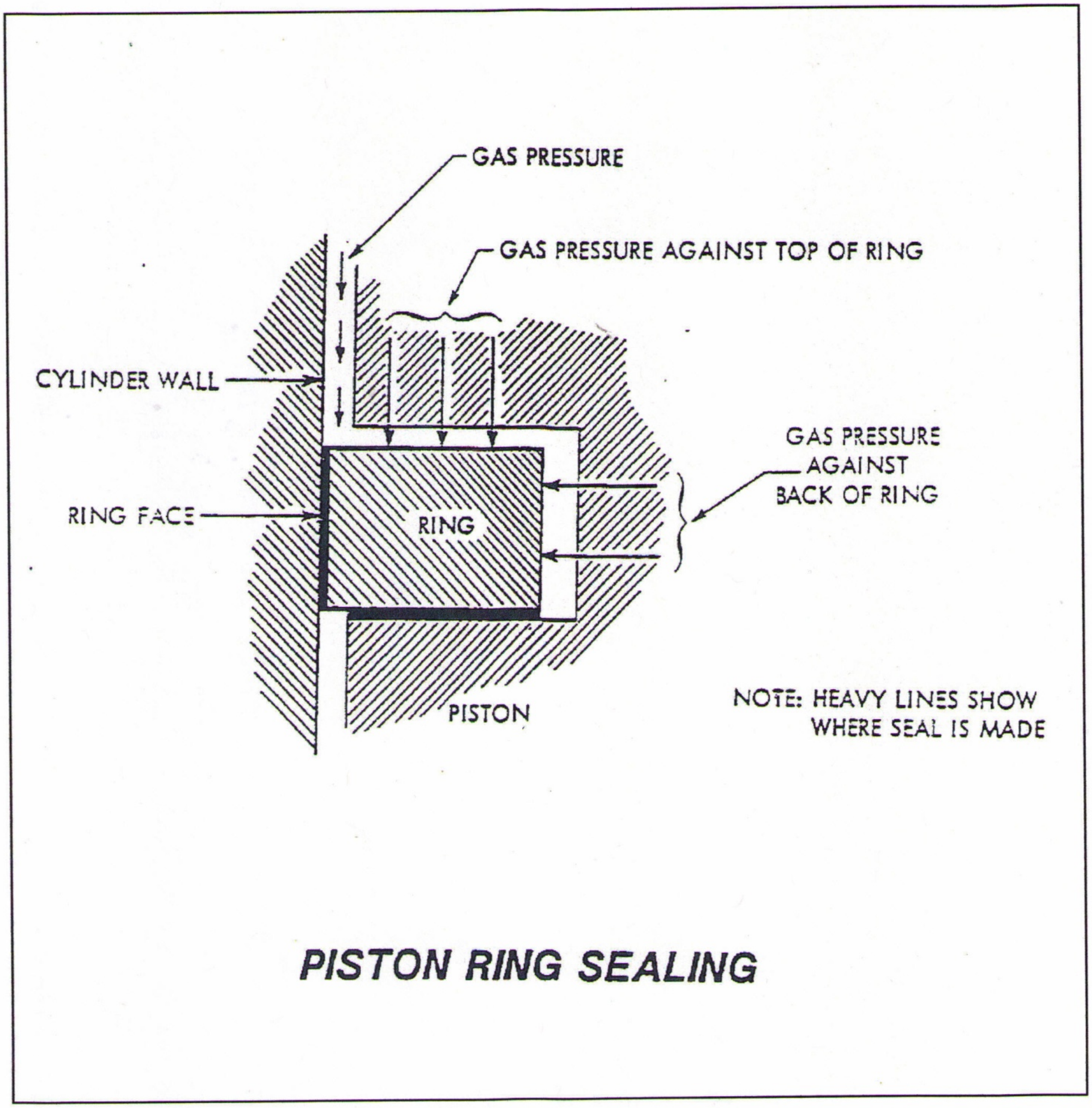


Figure 3-13 Piston Ring Sealing (Compression Rings)

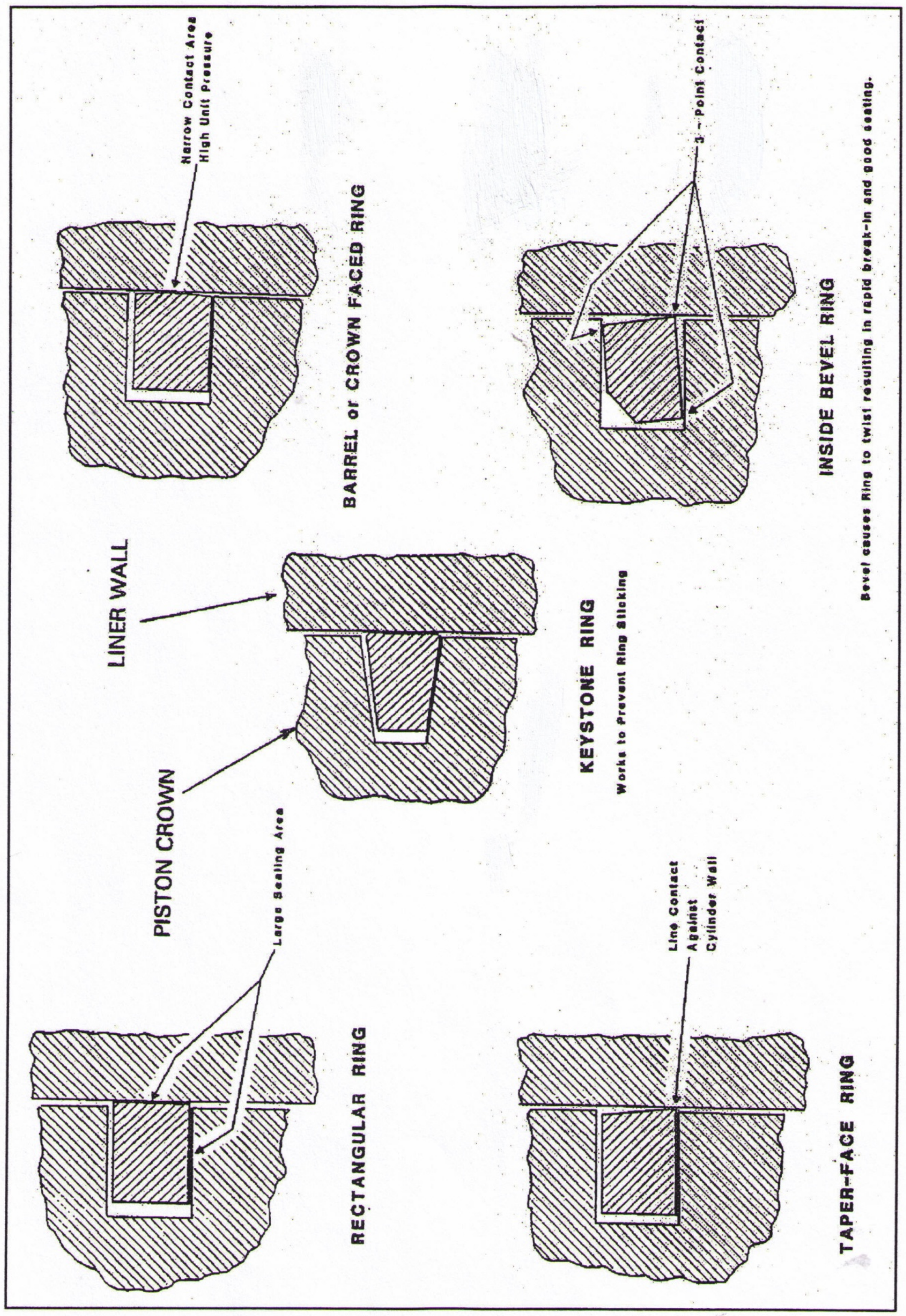


Figure 3-14 Compression Ring Designs

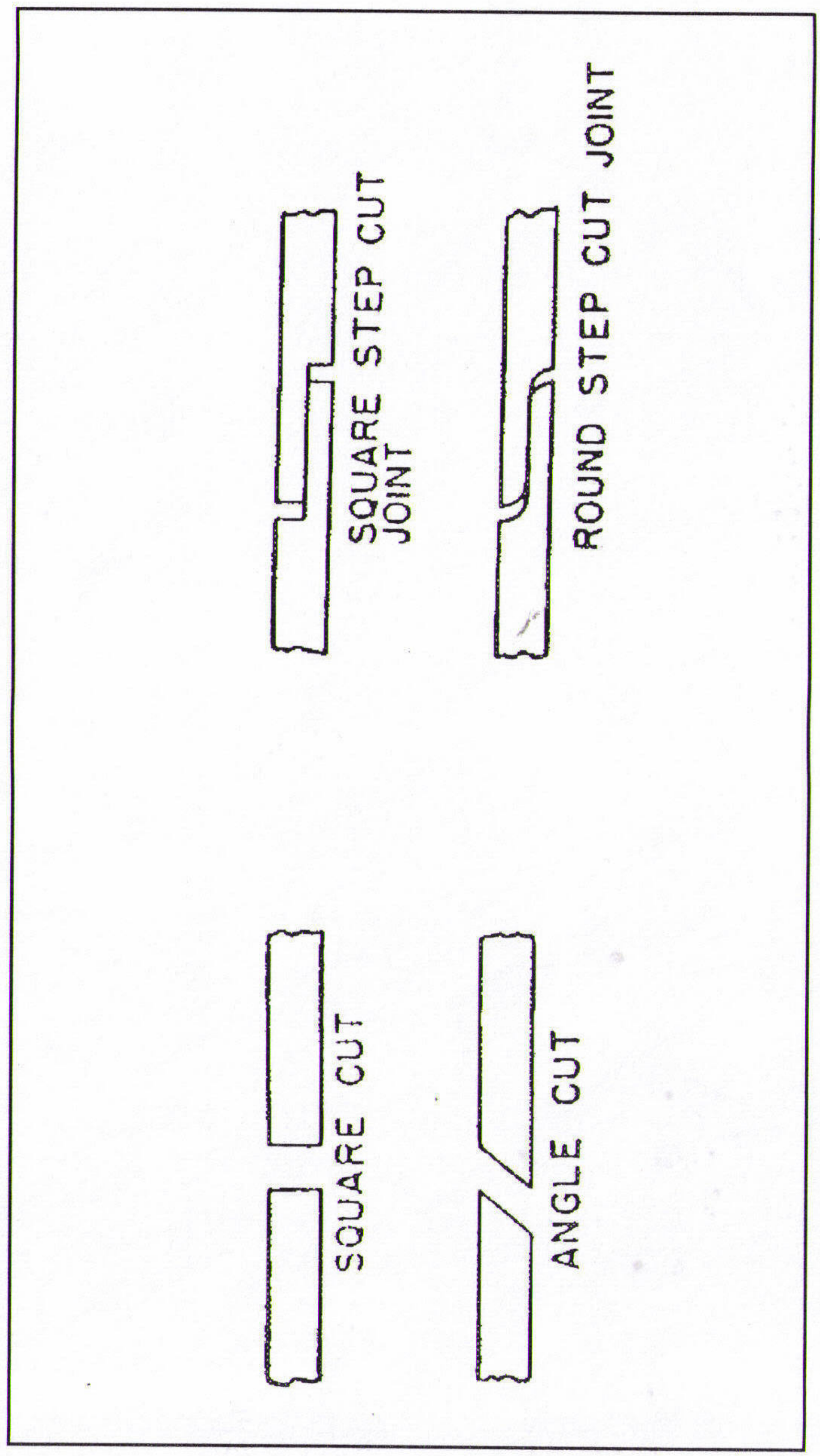


Figure 3-15 Piston Ring Joint Design

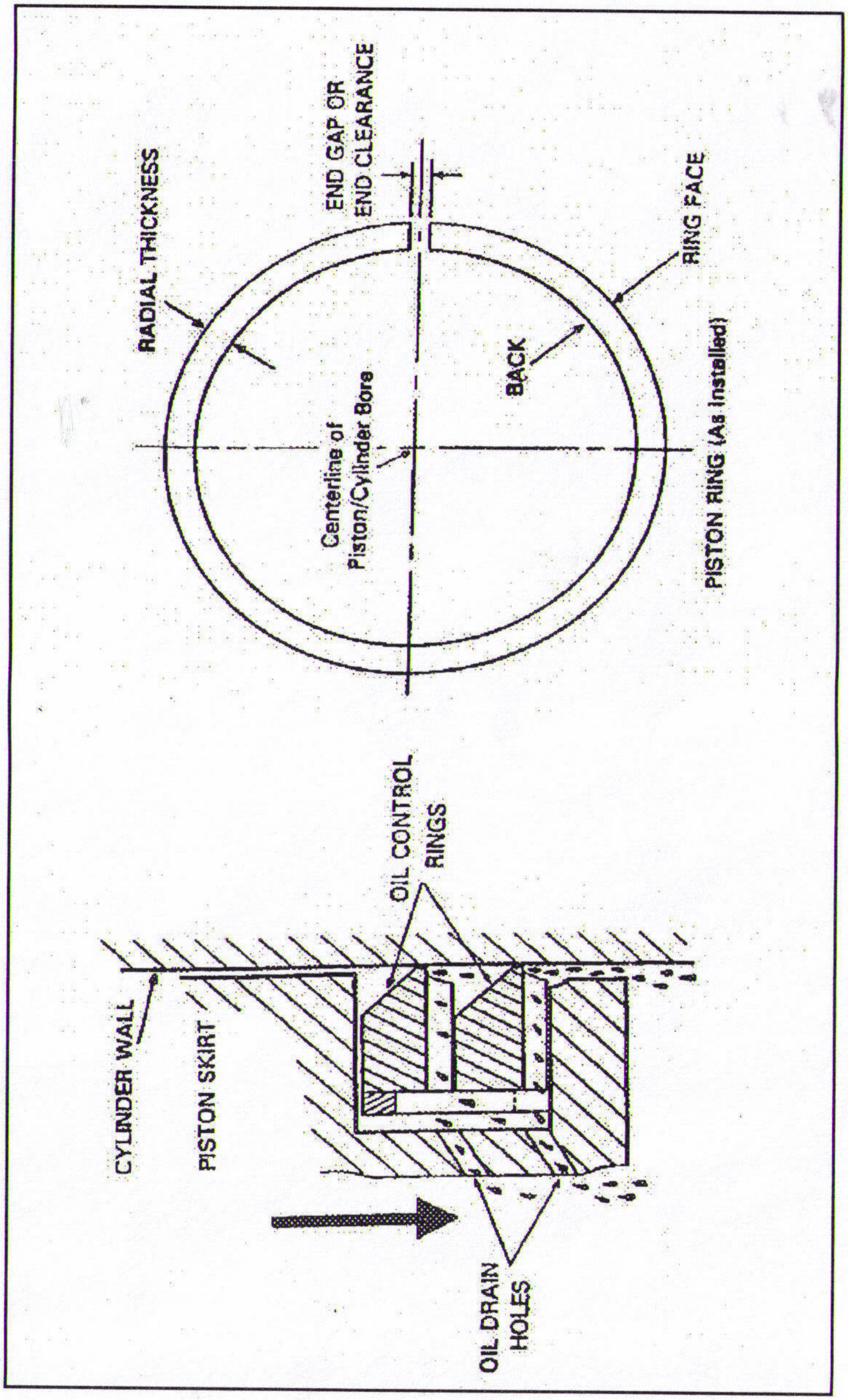


Figure 3-16 Oil Control Ring

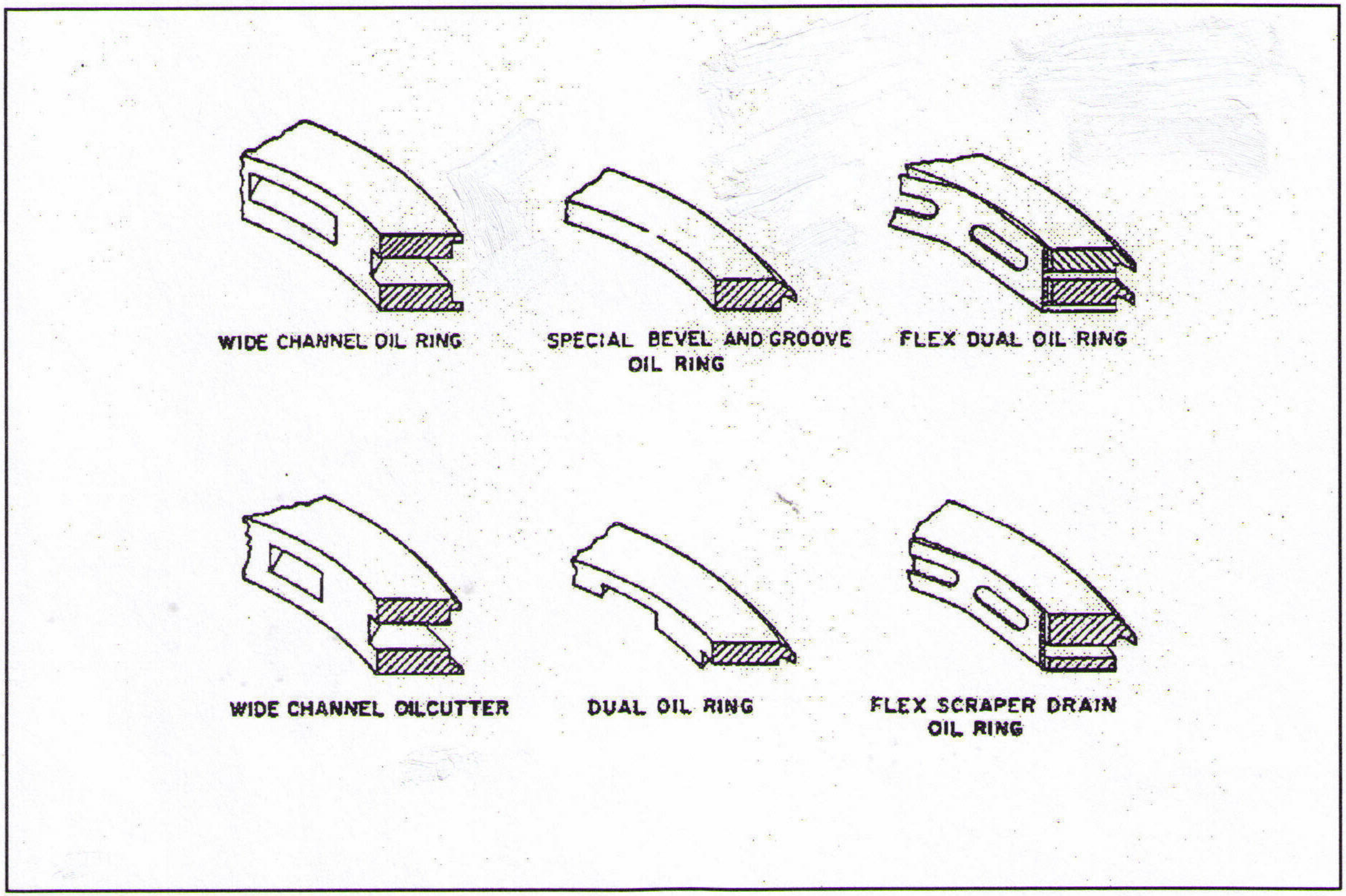


Figure 3-17 Oil Control Ring Designs

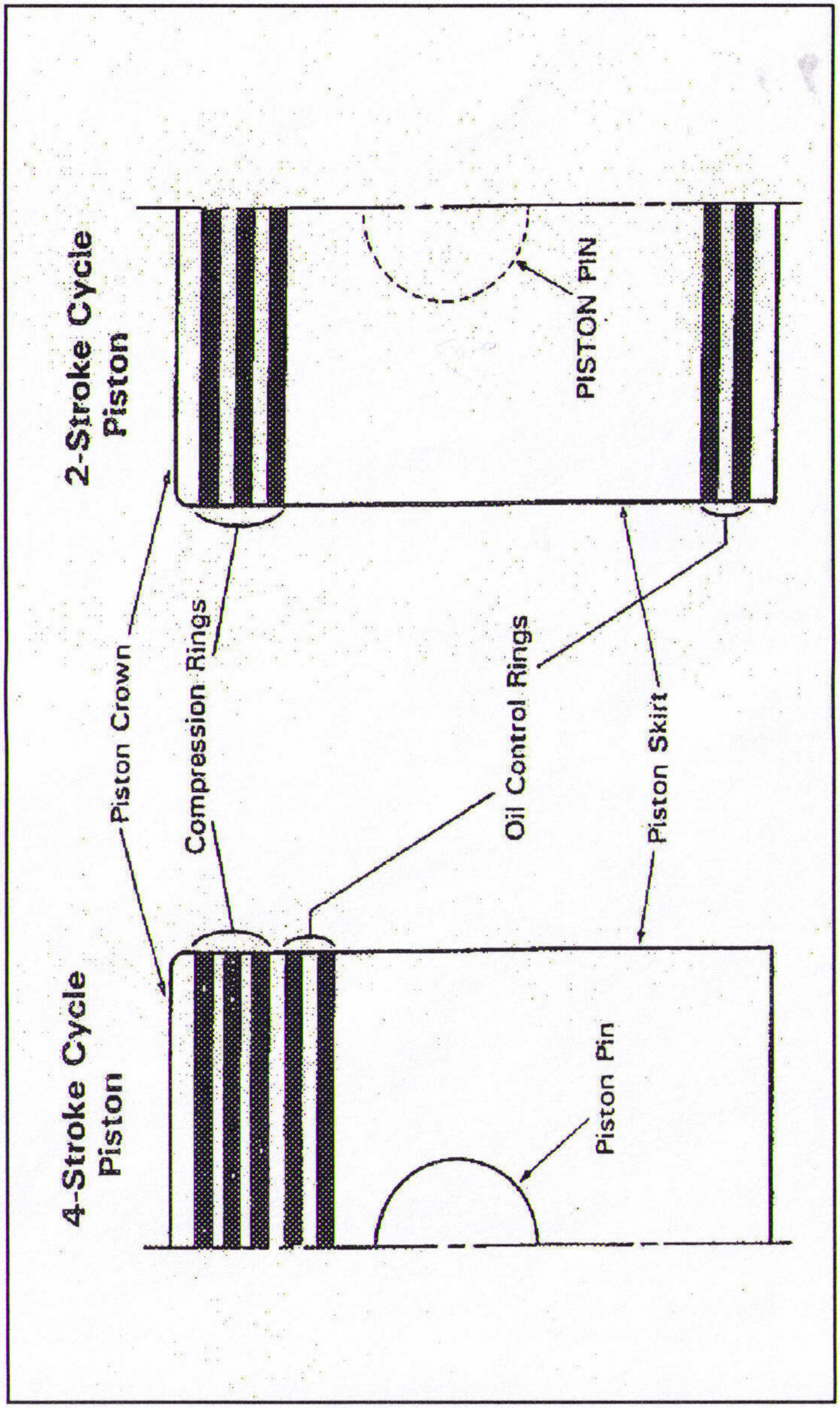
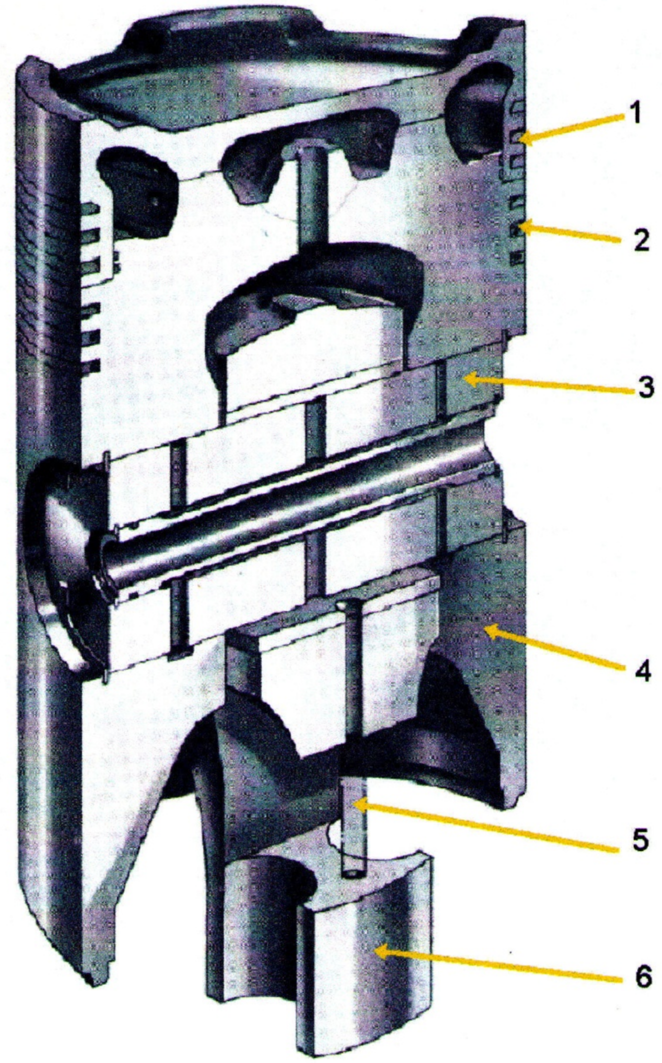


Figure 3-18 Piston Ring Placement



1. Piston crown, Compression rings
2. Piston skirt, Oil control rings
3. Wrist pin, Bushing, Oil retaining insert, Retaining ring
4. Piston skirt
5. Lube oil flow
6. Connecting rod

Figure 3-19 Two-piece Crown Piston with Connecting Rod & Wrist Pin Assembly

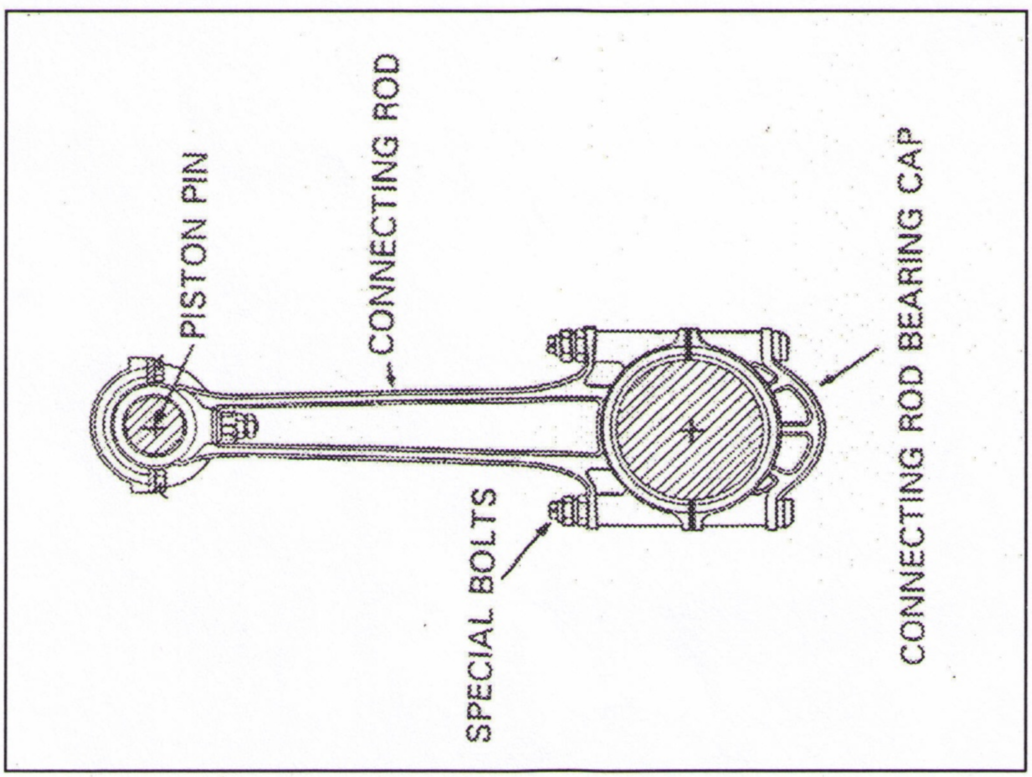


Figure 3-20 Conventional Connecting Rod

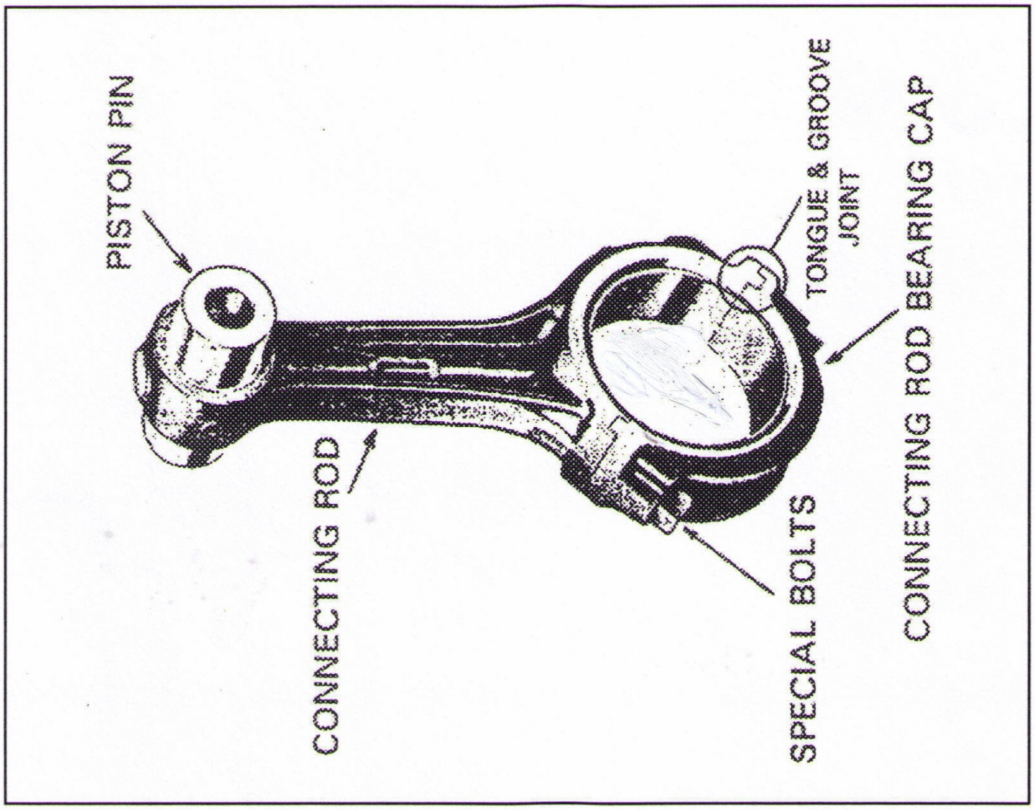


Figure 3-21 Angle-Cut Connecting Rod

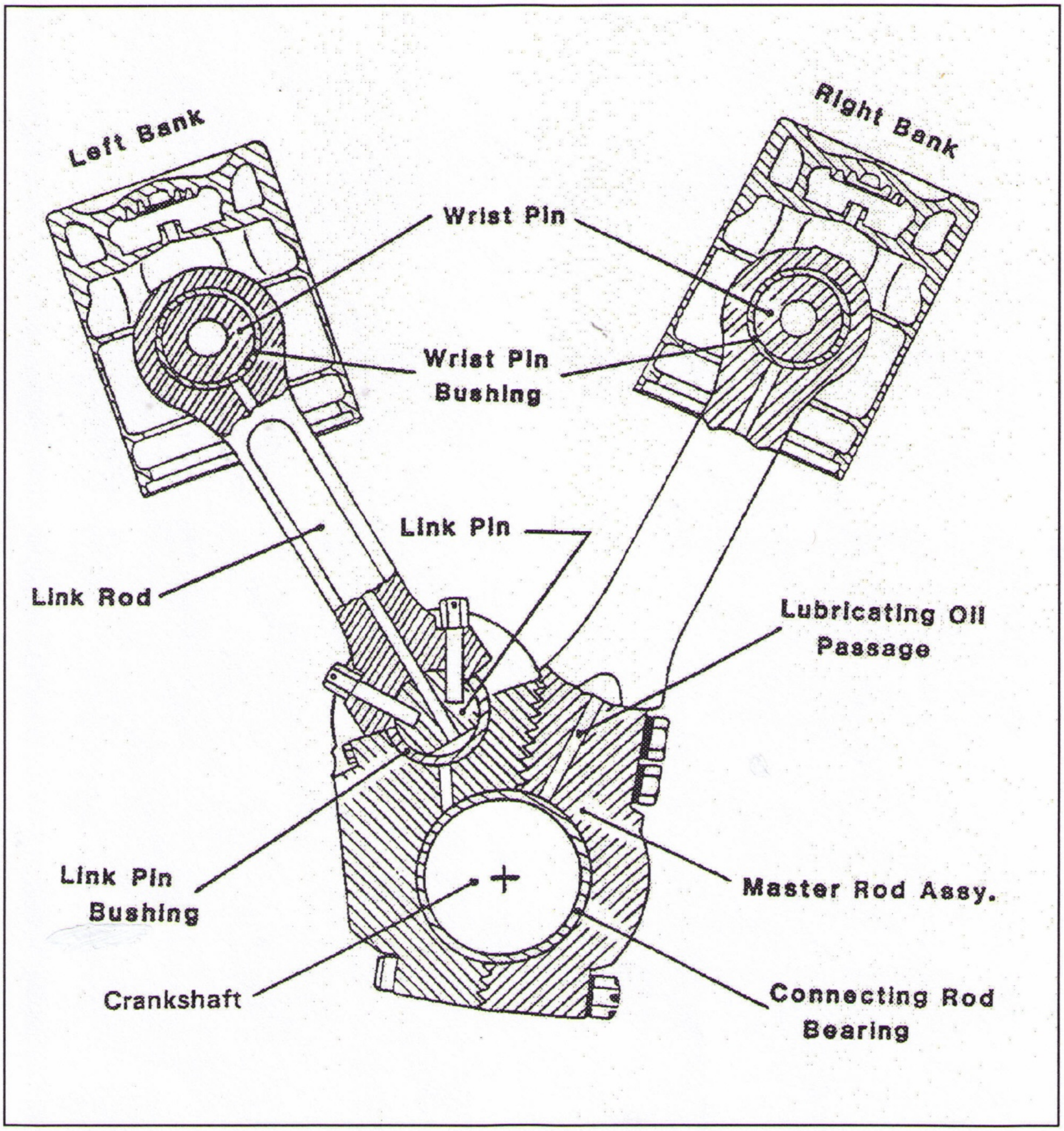


Figure 3-22 Articulating Connecting Rod Assembly

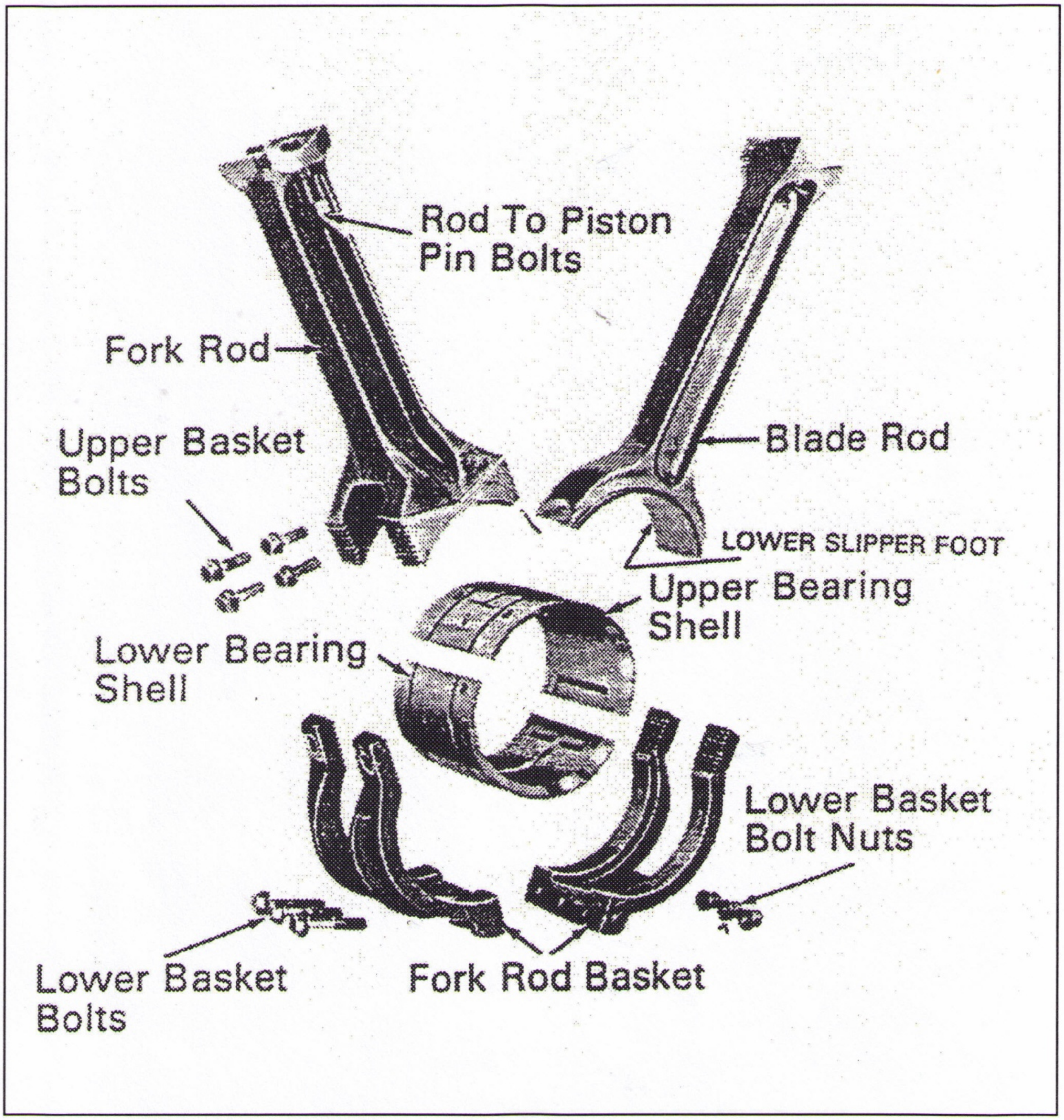


Figure 3-23 Fork and Blade Connecting Rod Design - EMD

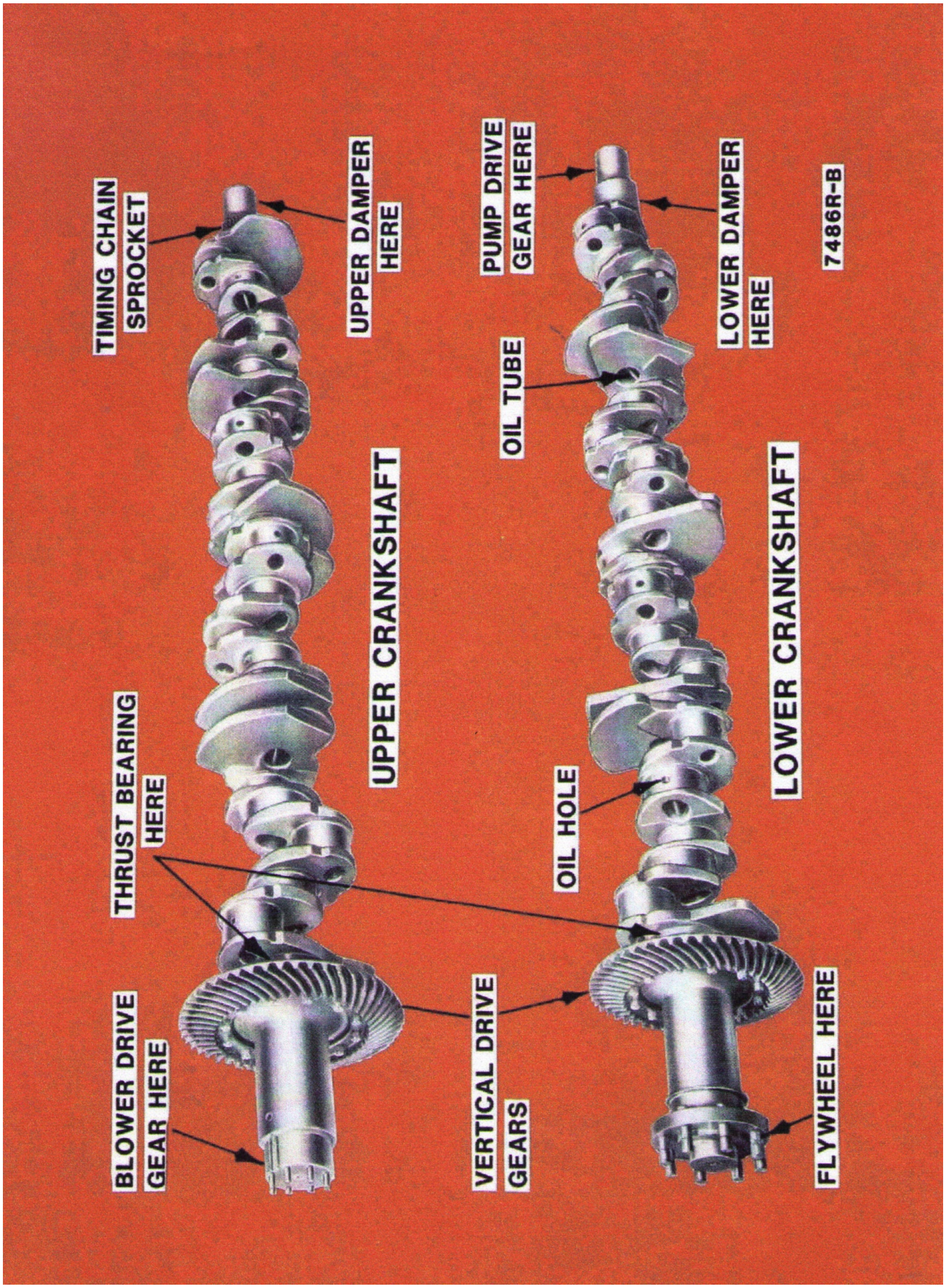


Figure 3-24 OP Engine Crankshaft

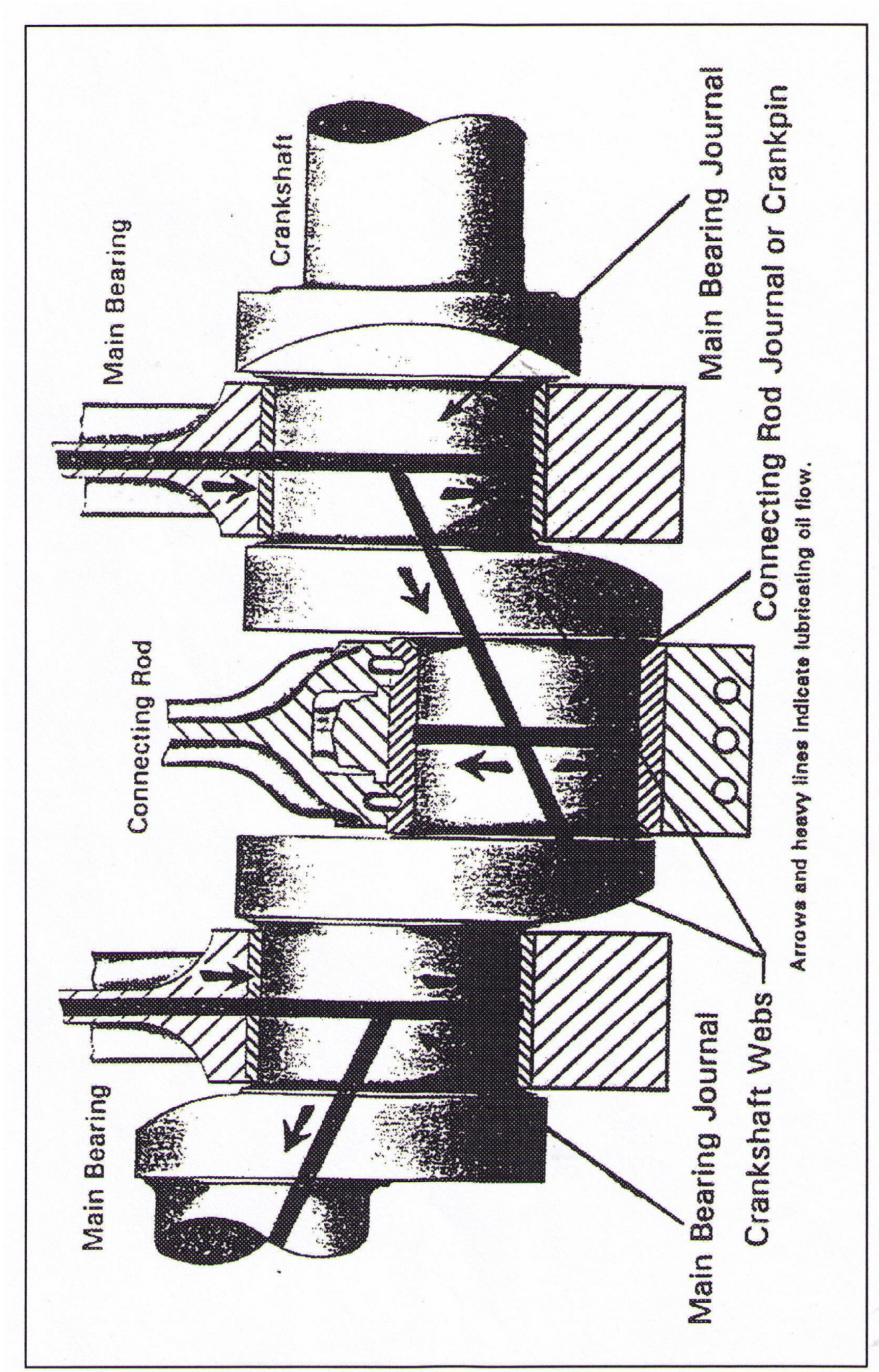


Figure 3-25 Engine Crankshaft Oil Passages

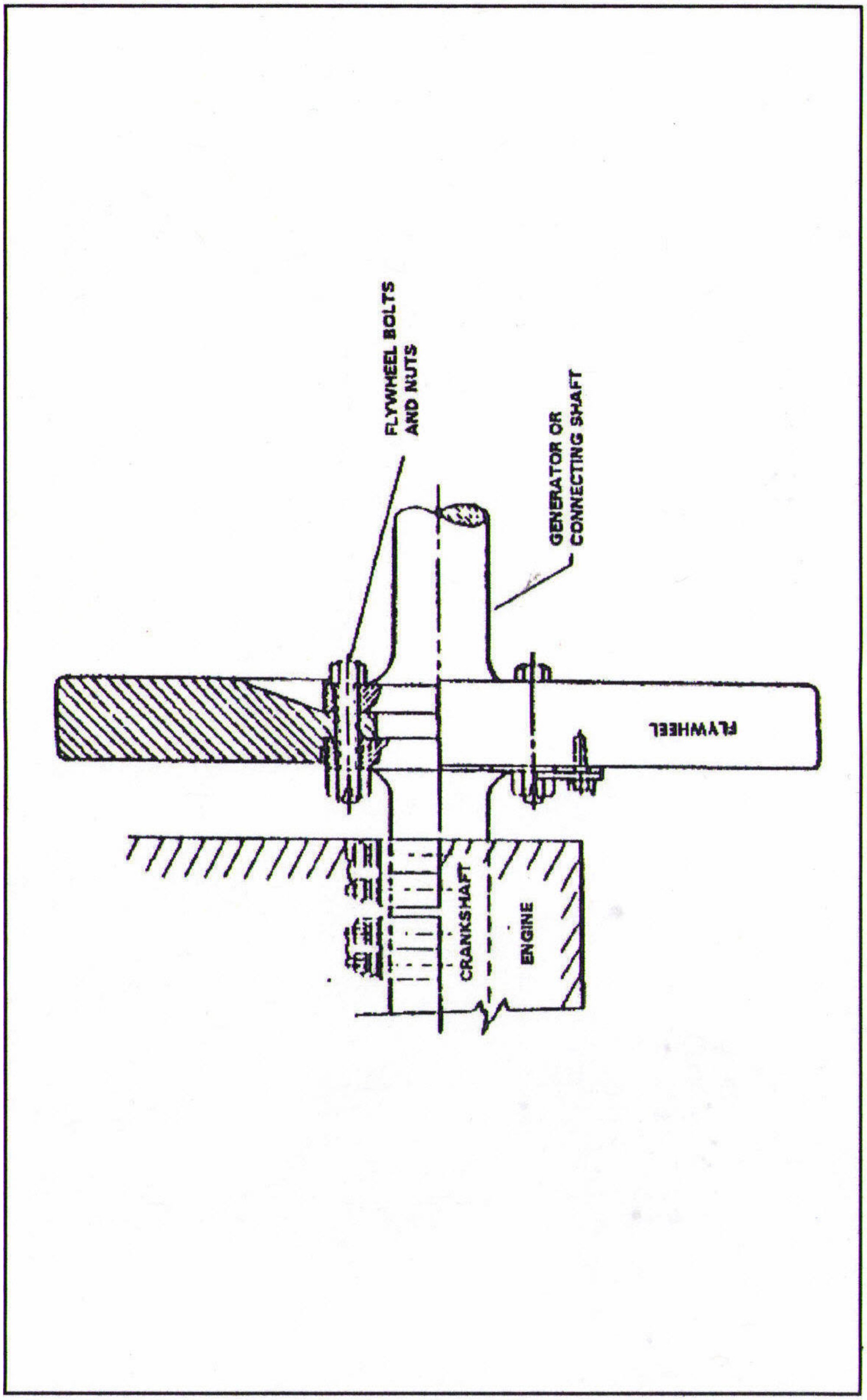


Figure 3-26 Engine Flywheel

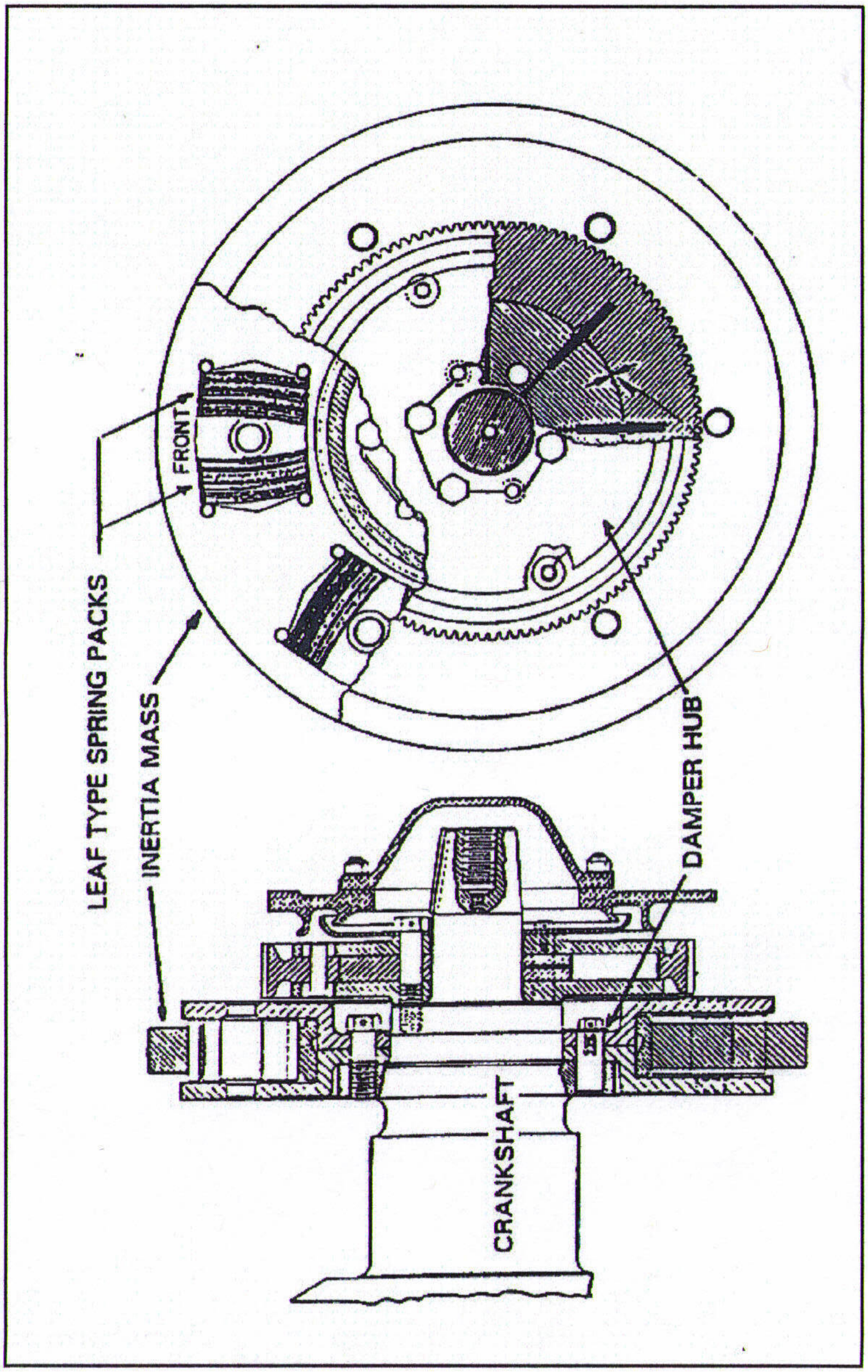


Figure 3-27 Spring Type vibration Damper

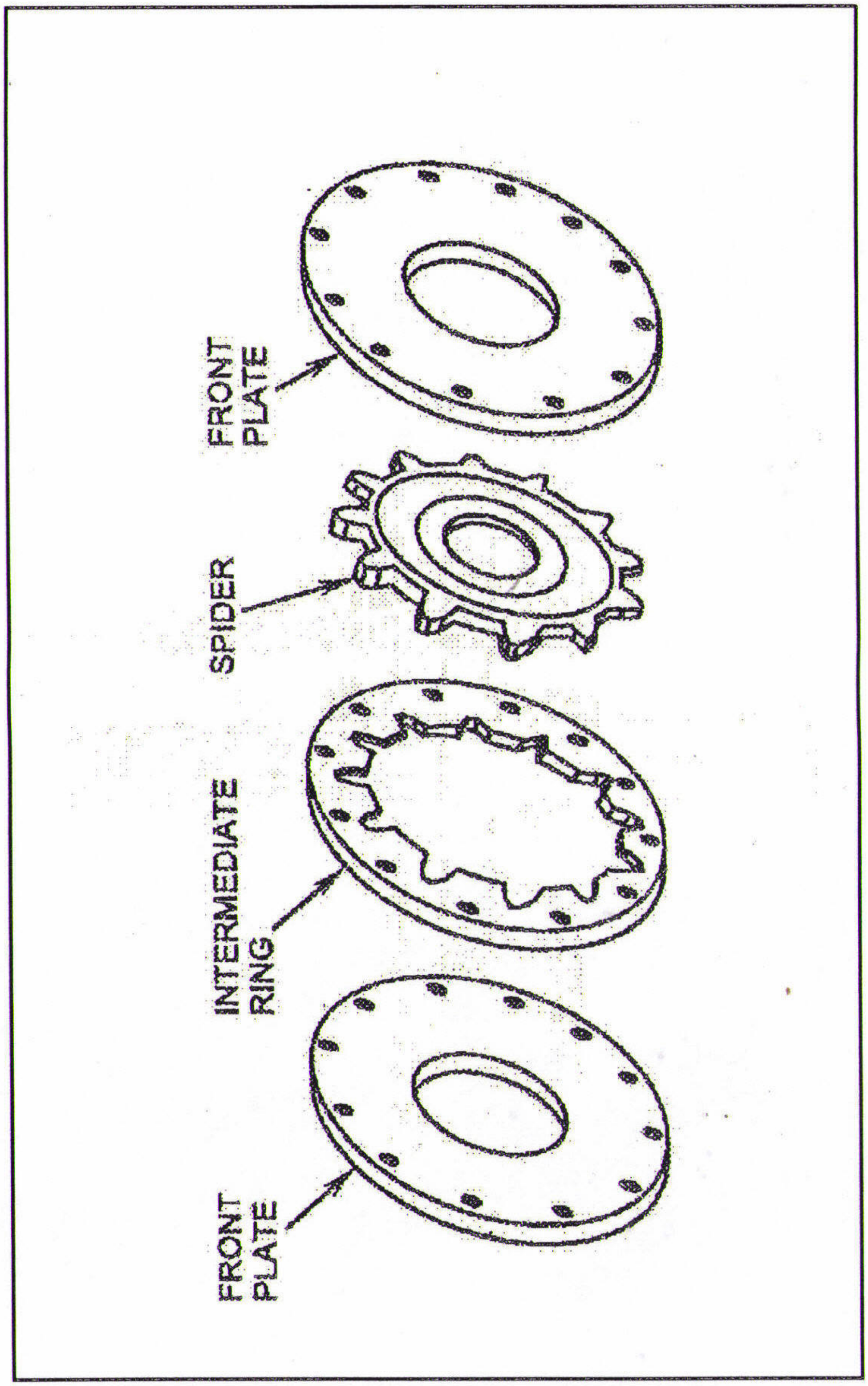


Figure 3-28 Gear Type viscous Damper

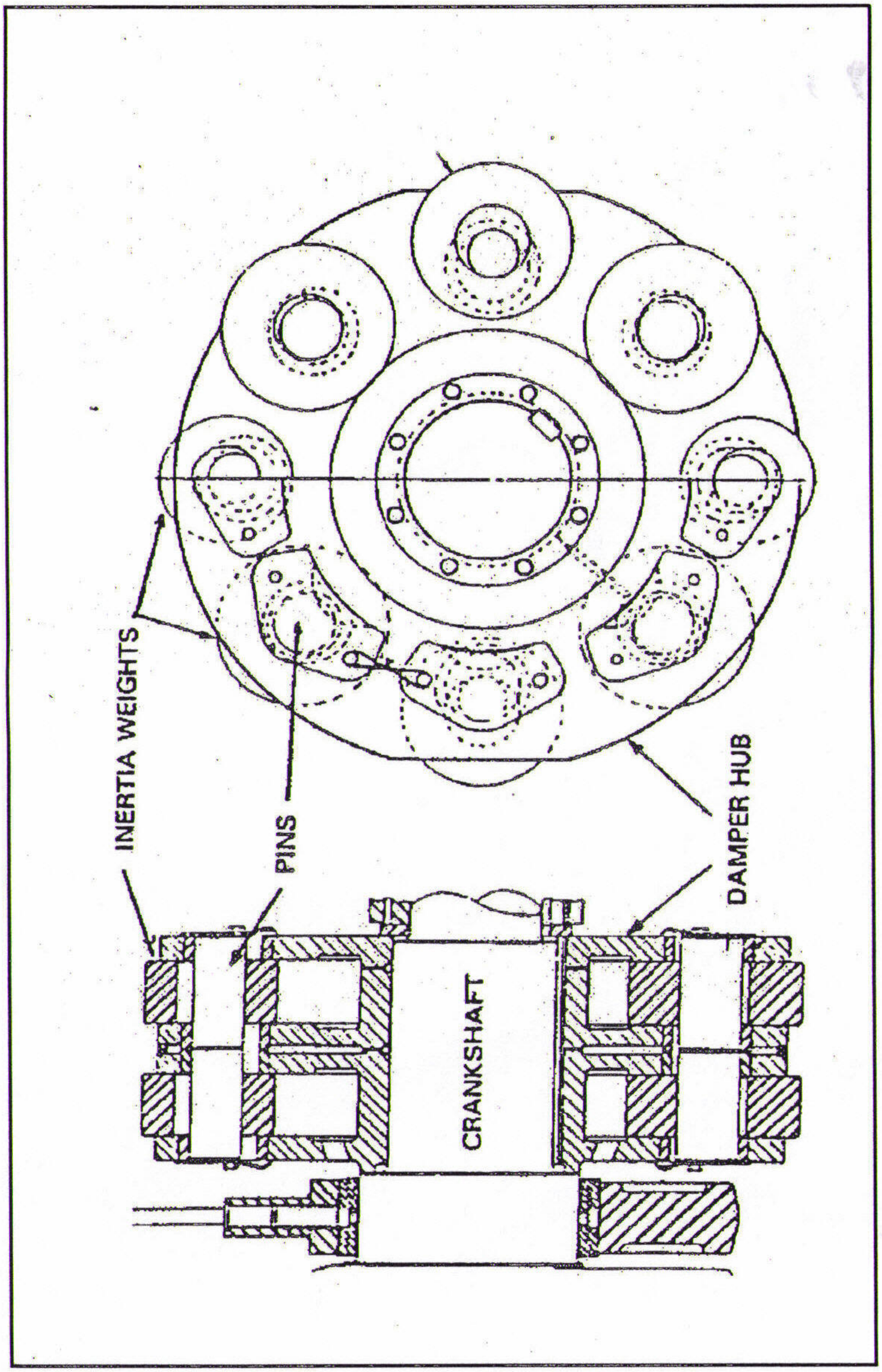


Figure 3-29 Bifiler Type vibration Damper

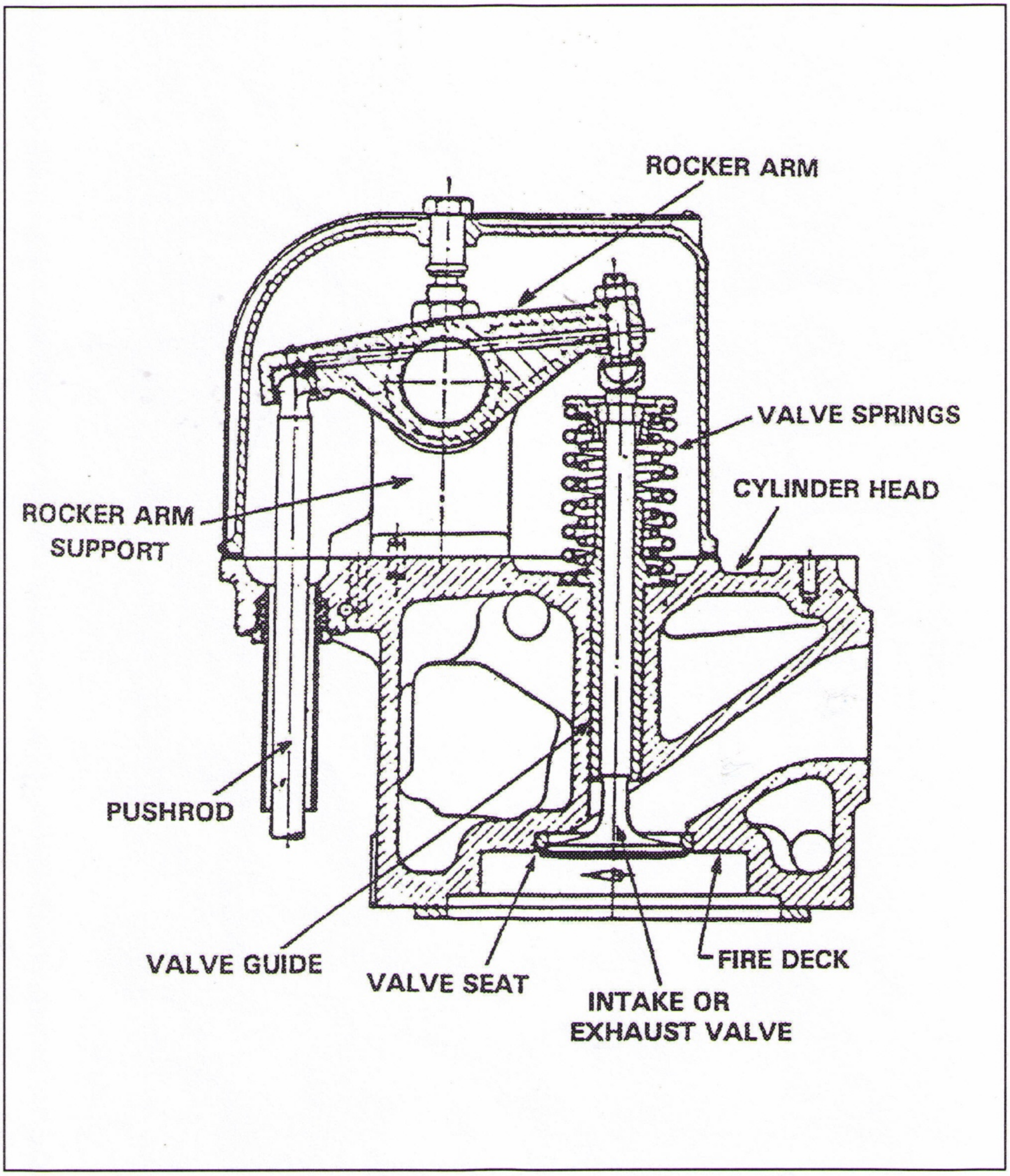


Figure 3-30 Cylinder Head Assembly

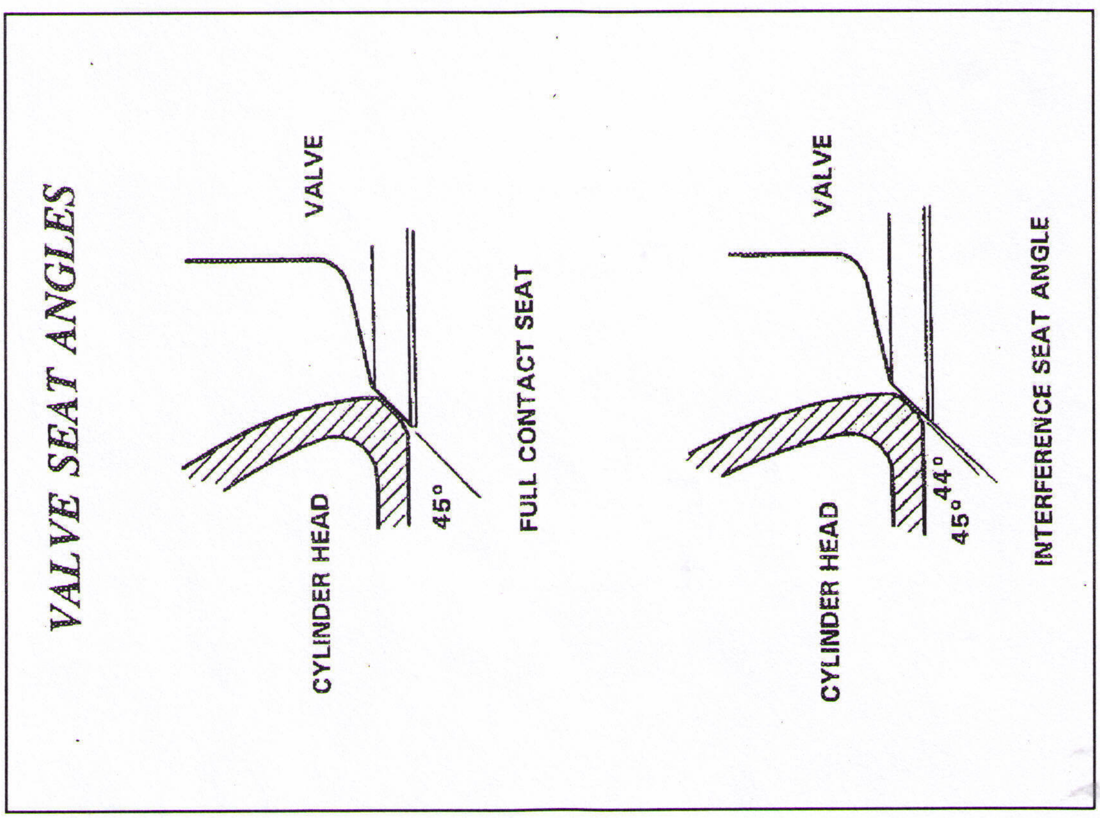


Figure 3-31 Valve Seat Angles

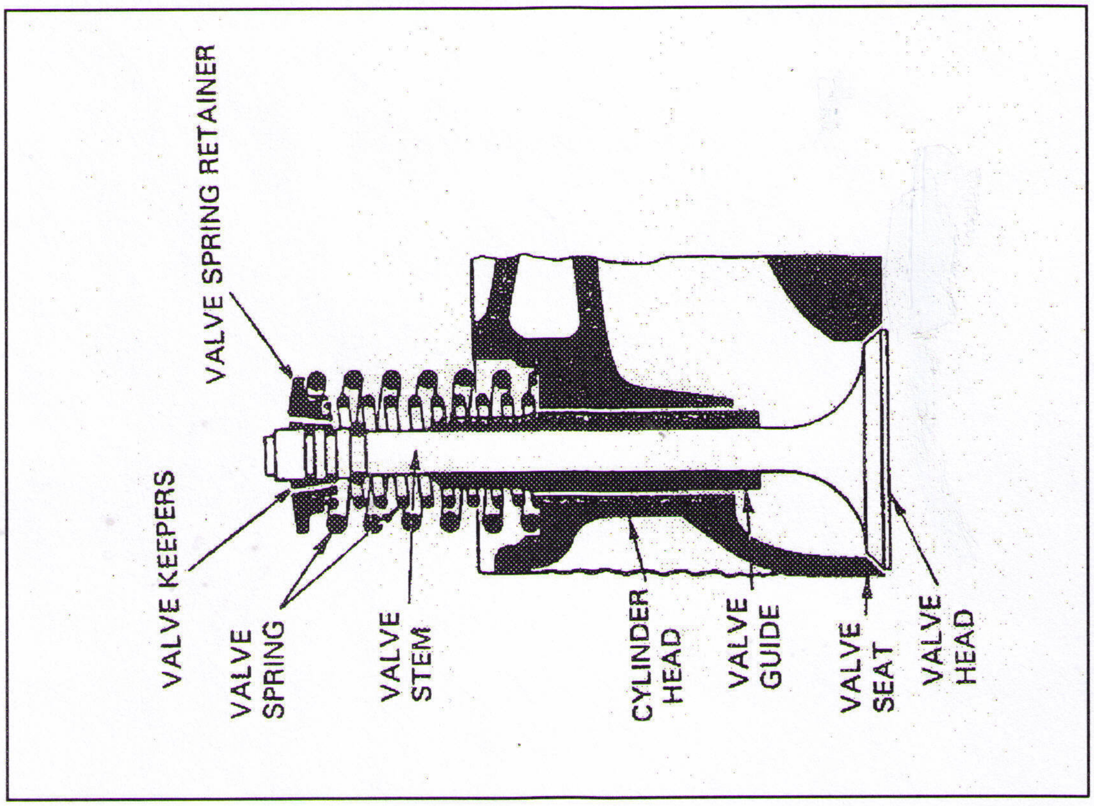


Figure 3-32 Valve Seat Assembly

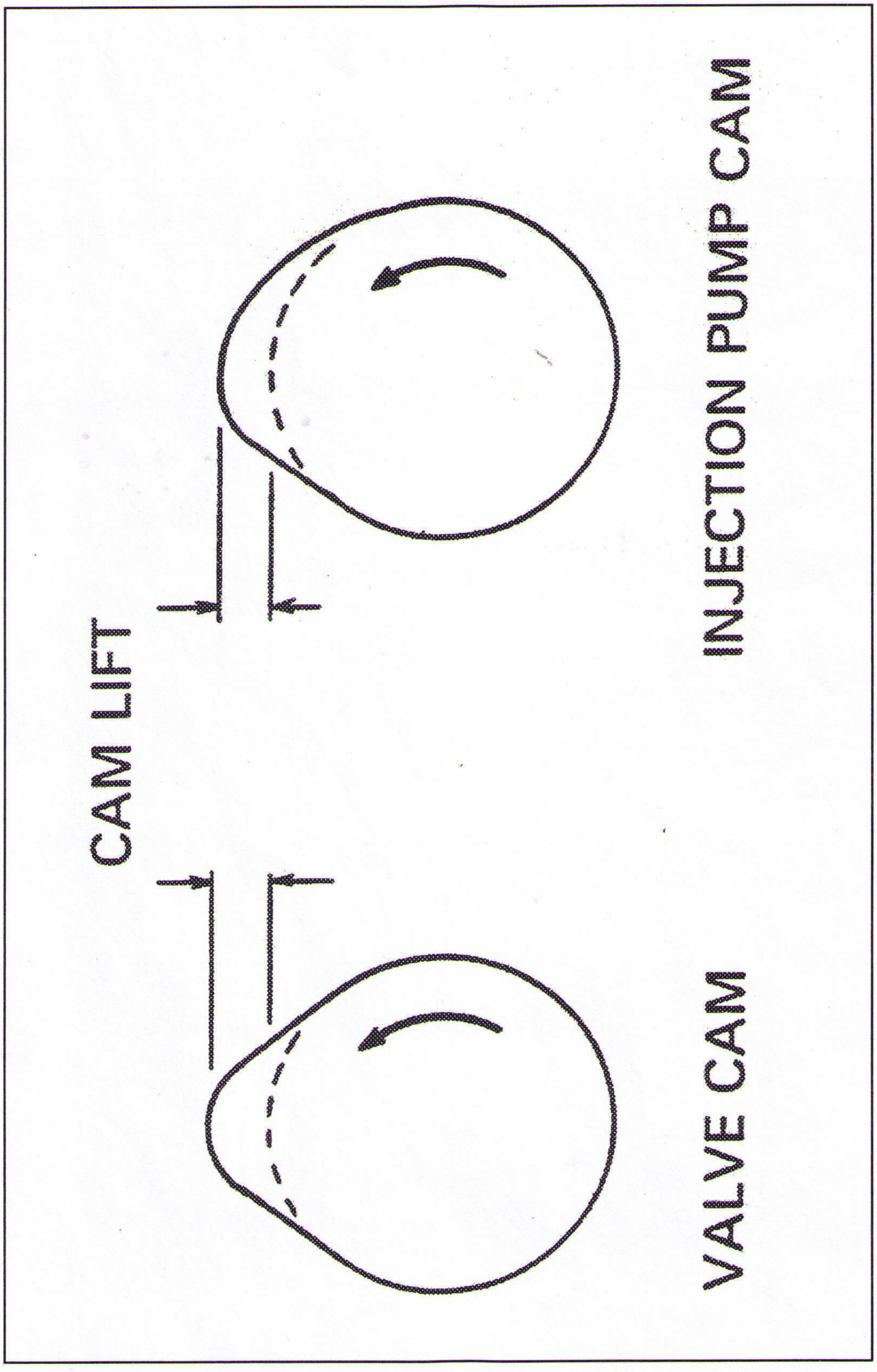


Figure 3-33 Camshaft Lobes

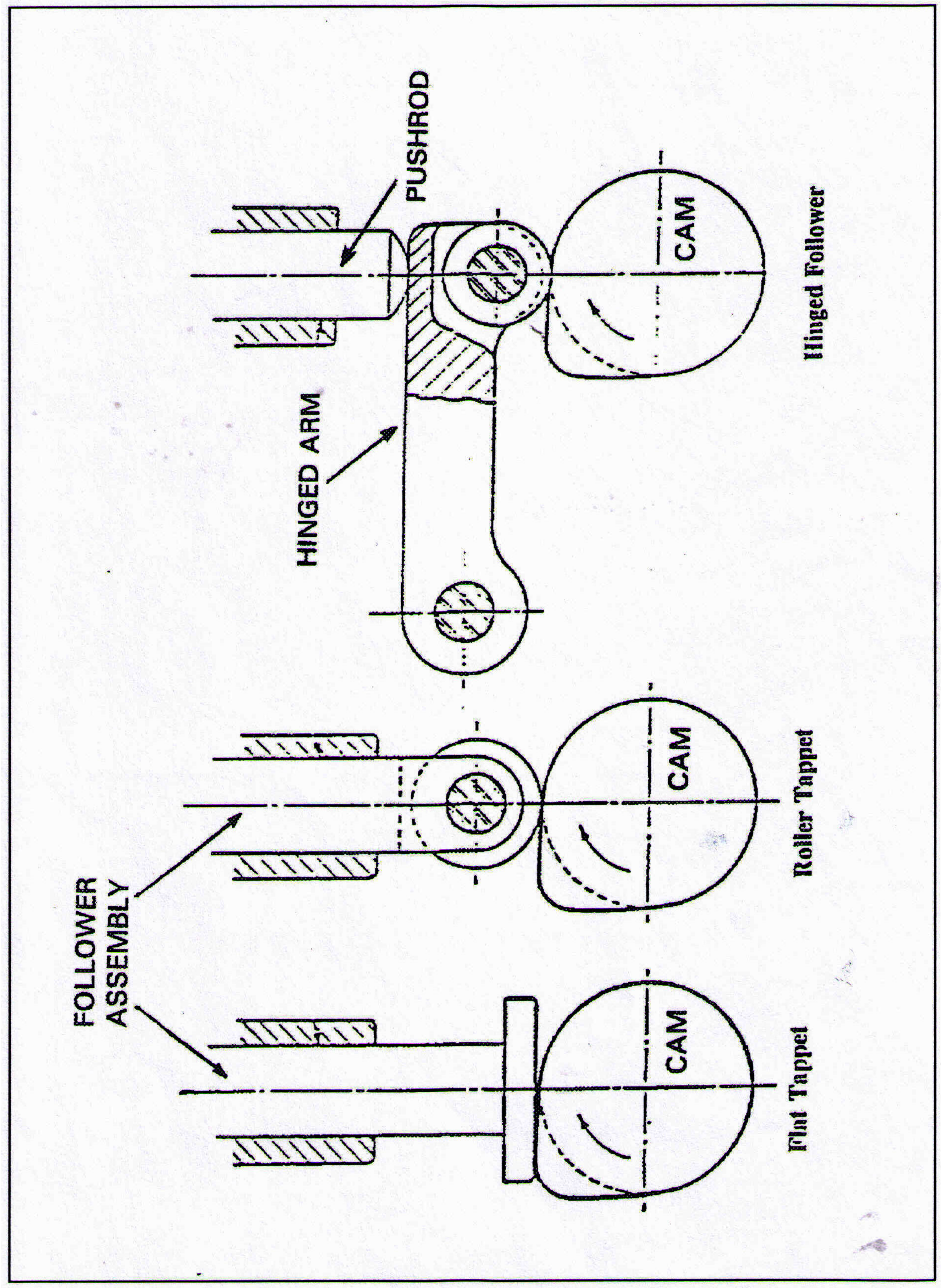
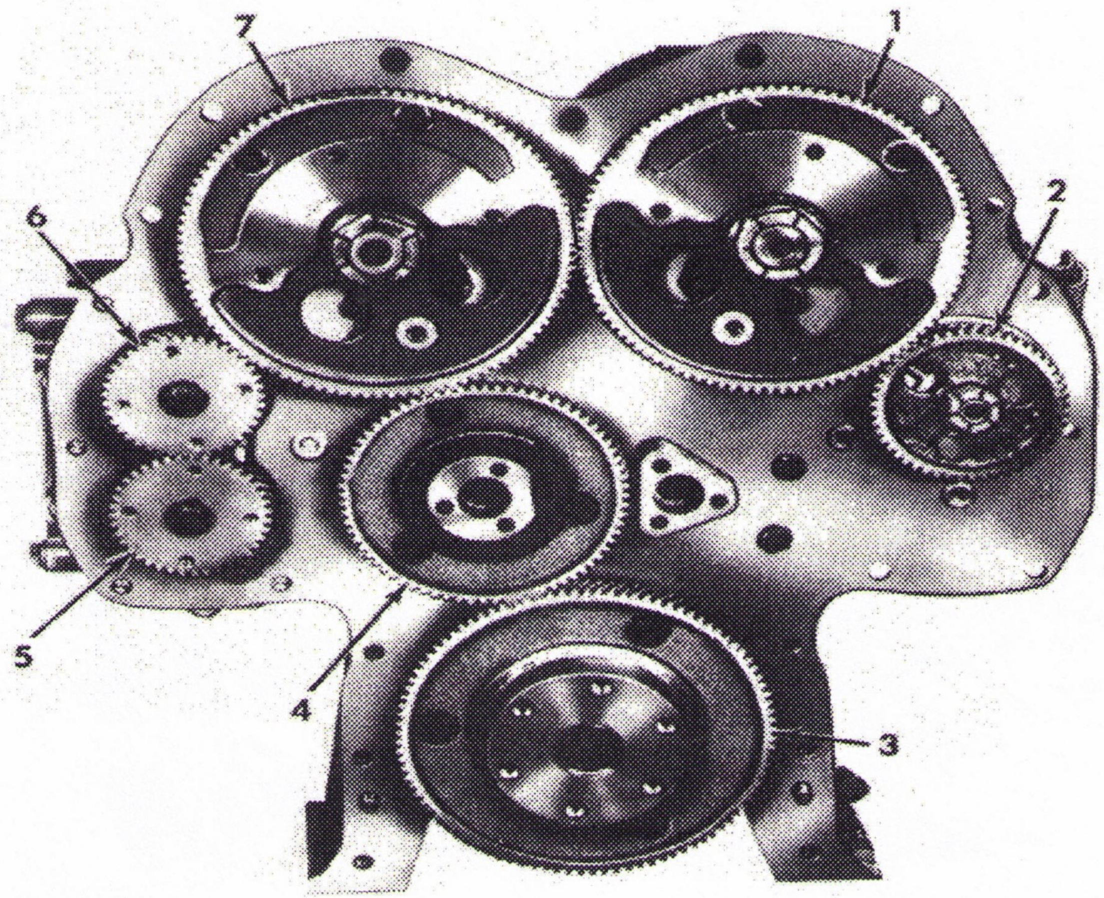


Figure 3-34 Cam Followers



1: Gear Balance Shaft
2: Governor Drive Gear
3: Crankshaft Gear
4: Idler Gear
5: Lower Blower Rotor Gear
6: Upper Blower Rotor Gear
7: Camshaft Gear

Figure 3-35 Gear Type Camshaft Drive Mechanism

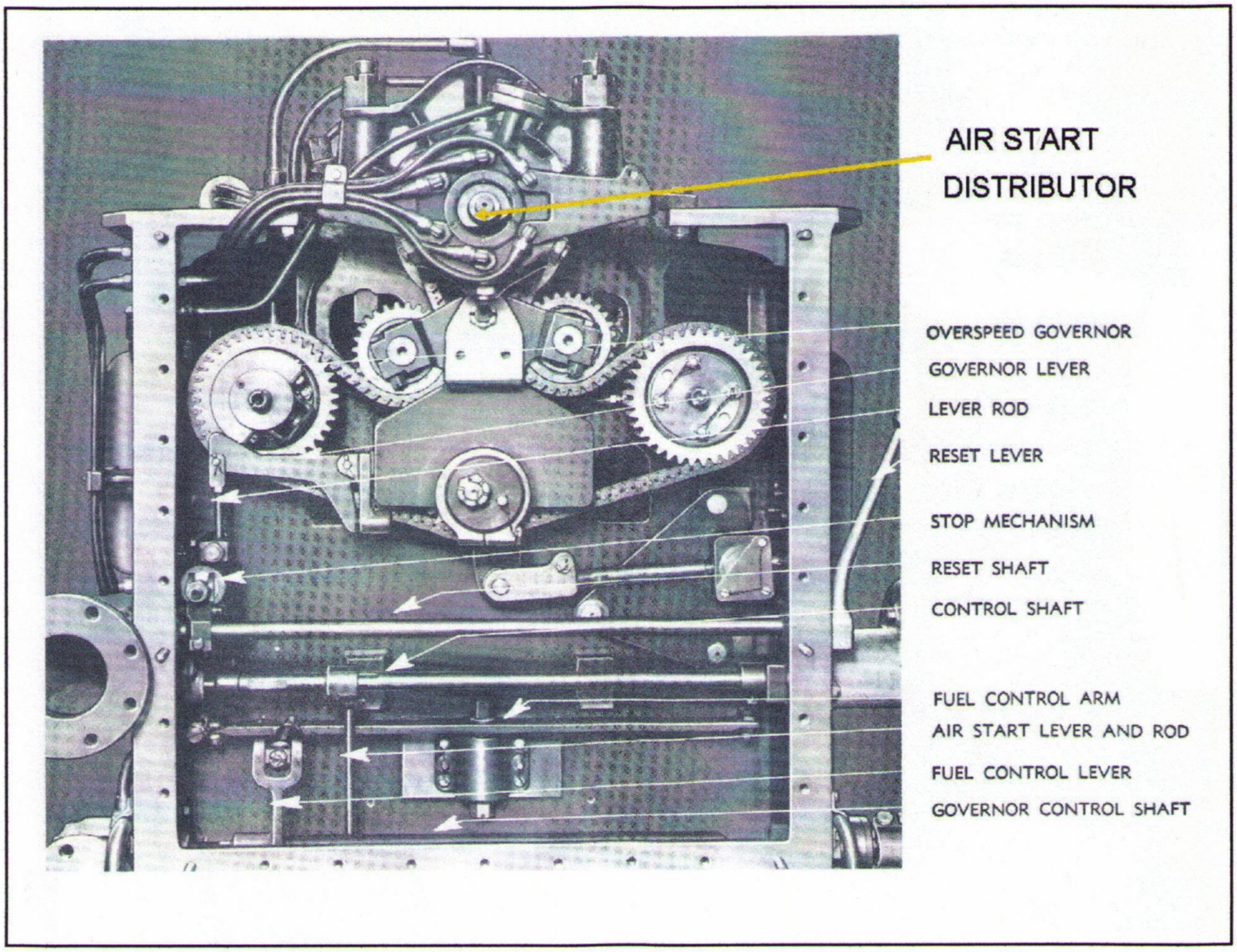


Figure 3-36 Chain Type Camshaft Drive Mechanism - OP

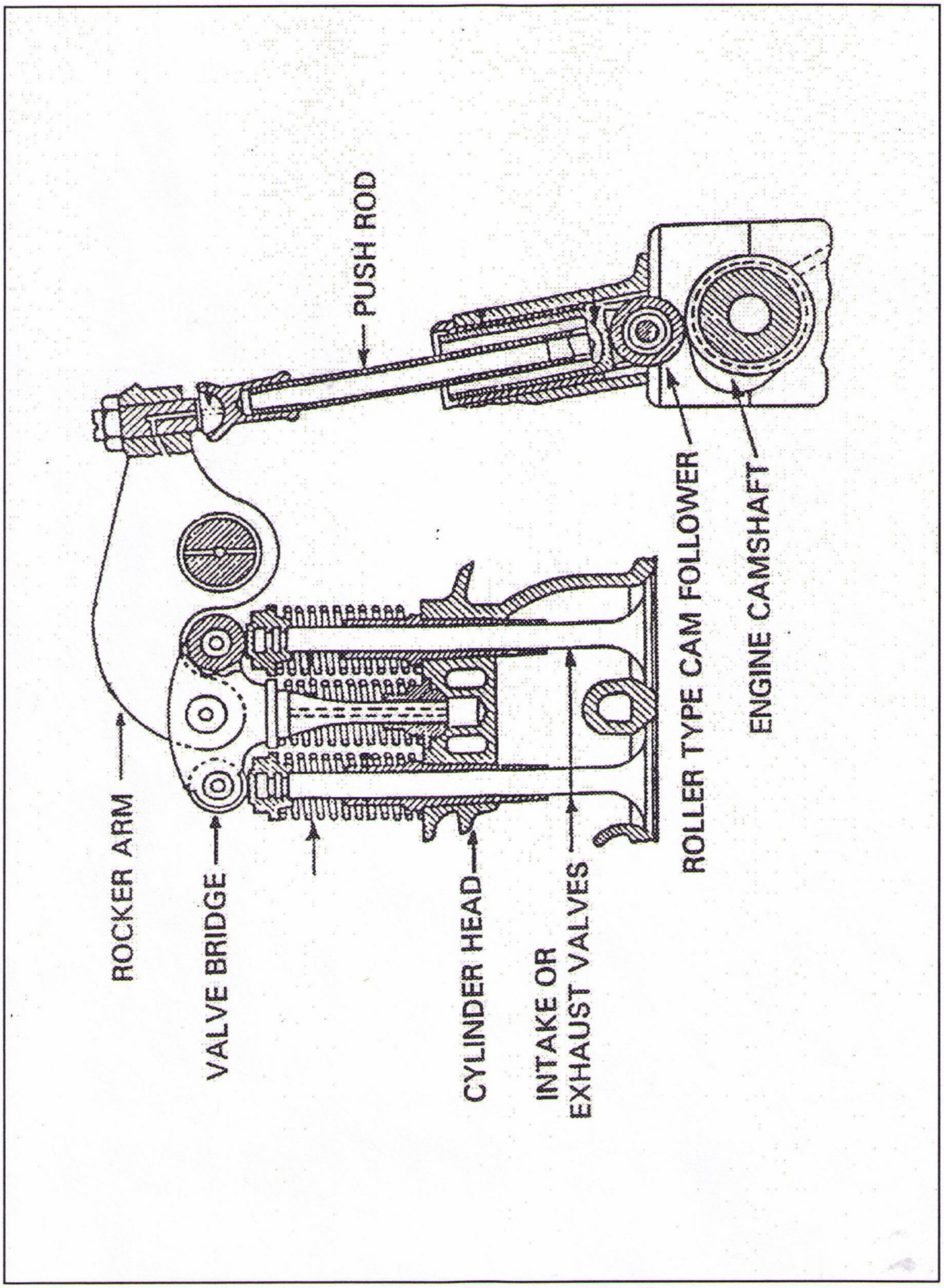


Figure 3-37 Rocker Arms and Pushrods

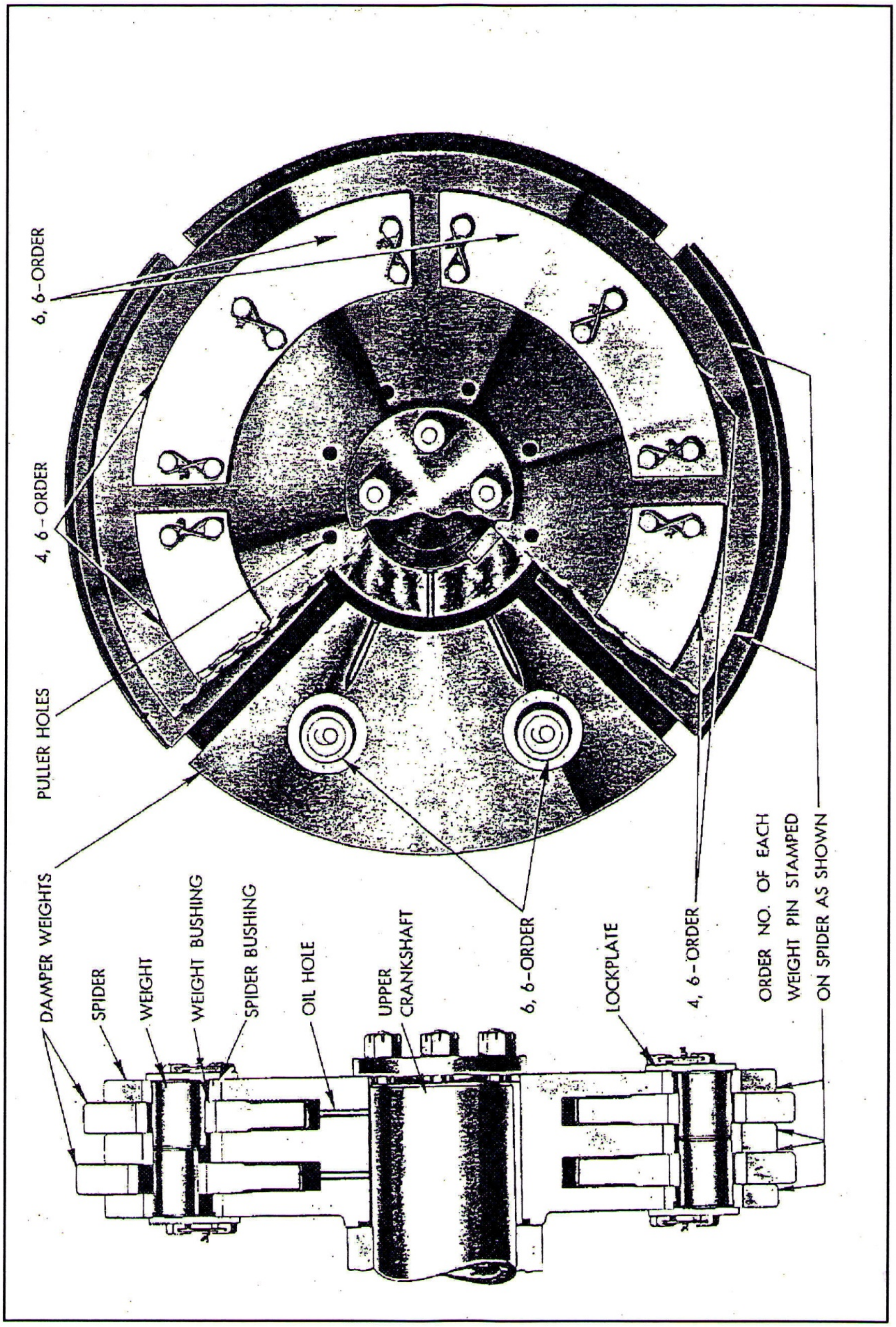


Figure 3-38 Pendulum Torsional Damper

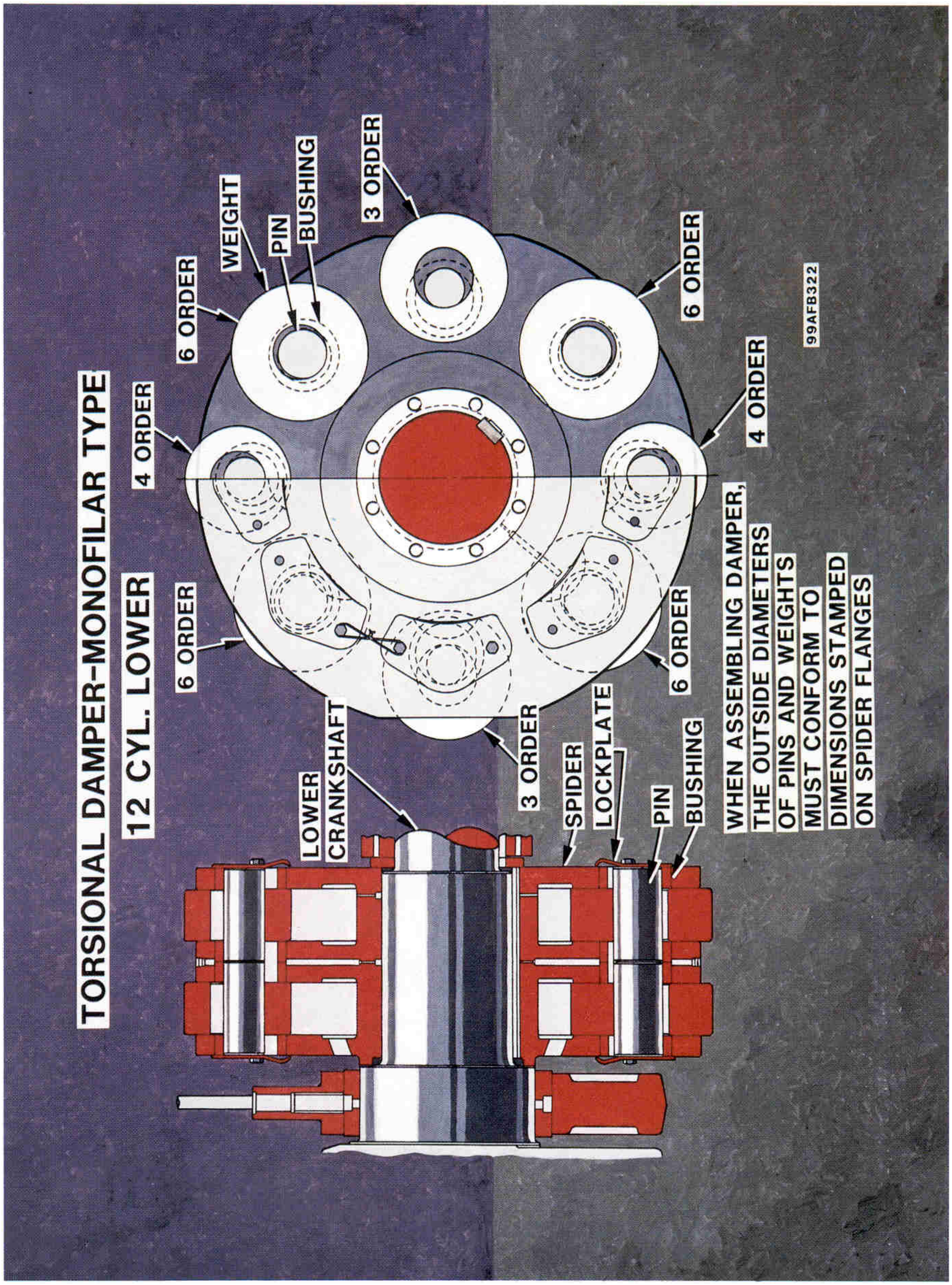


Figure 3-39 Monofilar Type Torsional Damper

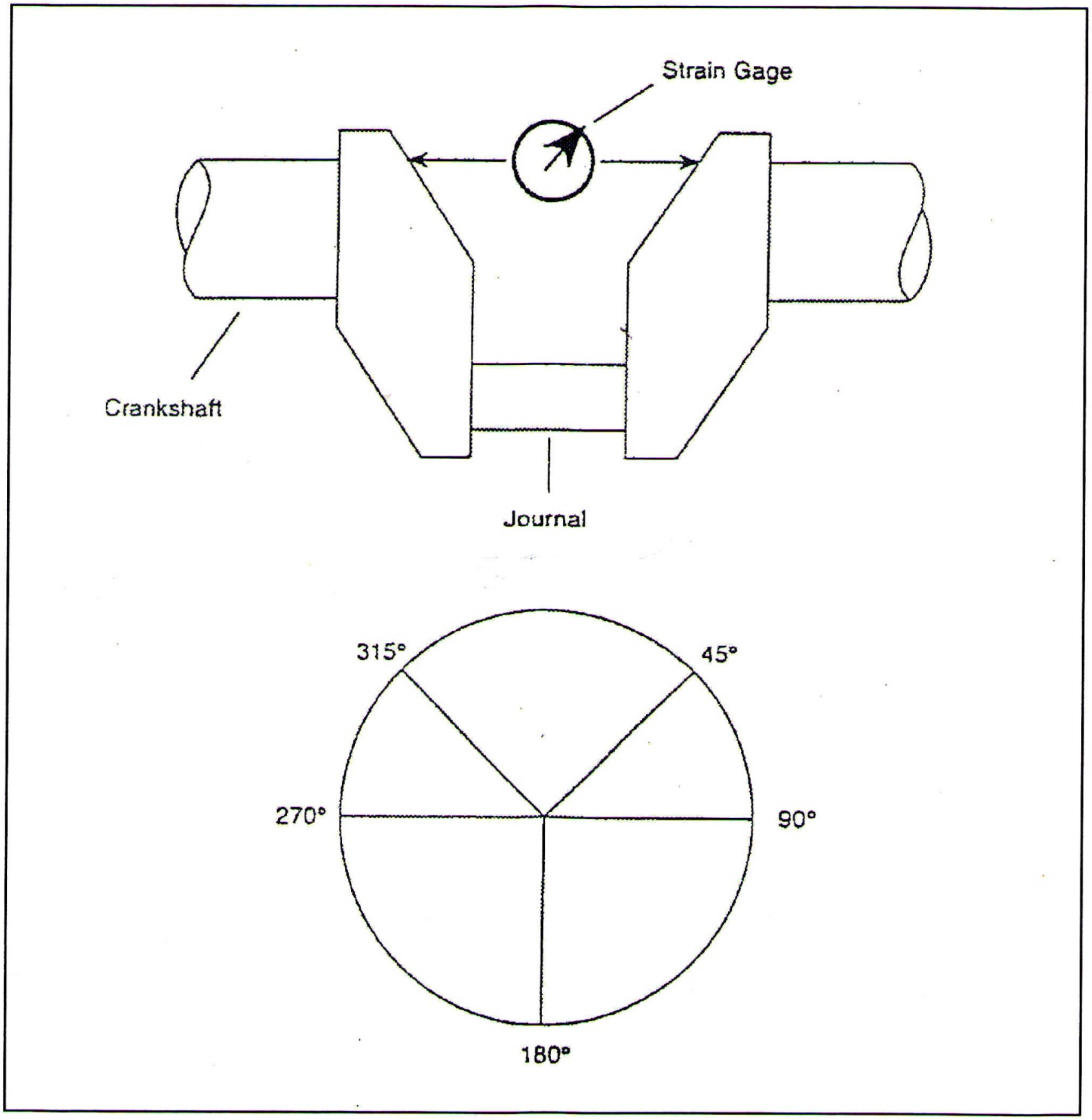


Figure 3-40 Crankshaft Strain Gauge Readings

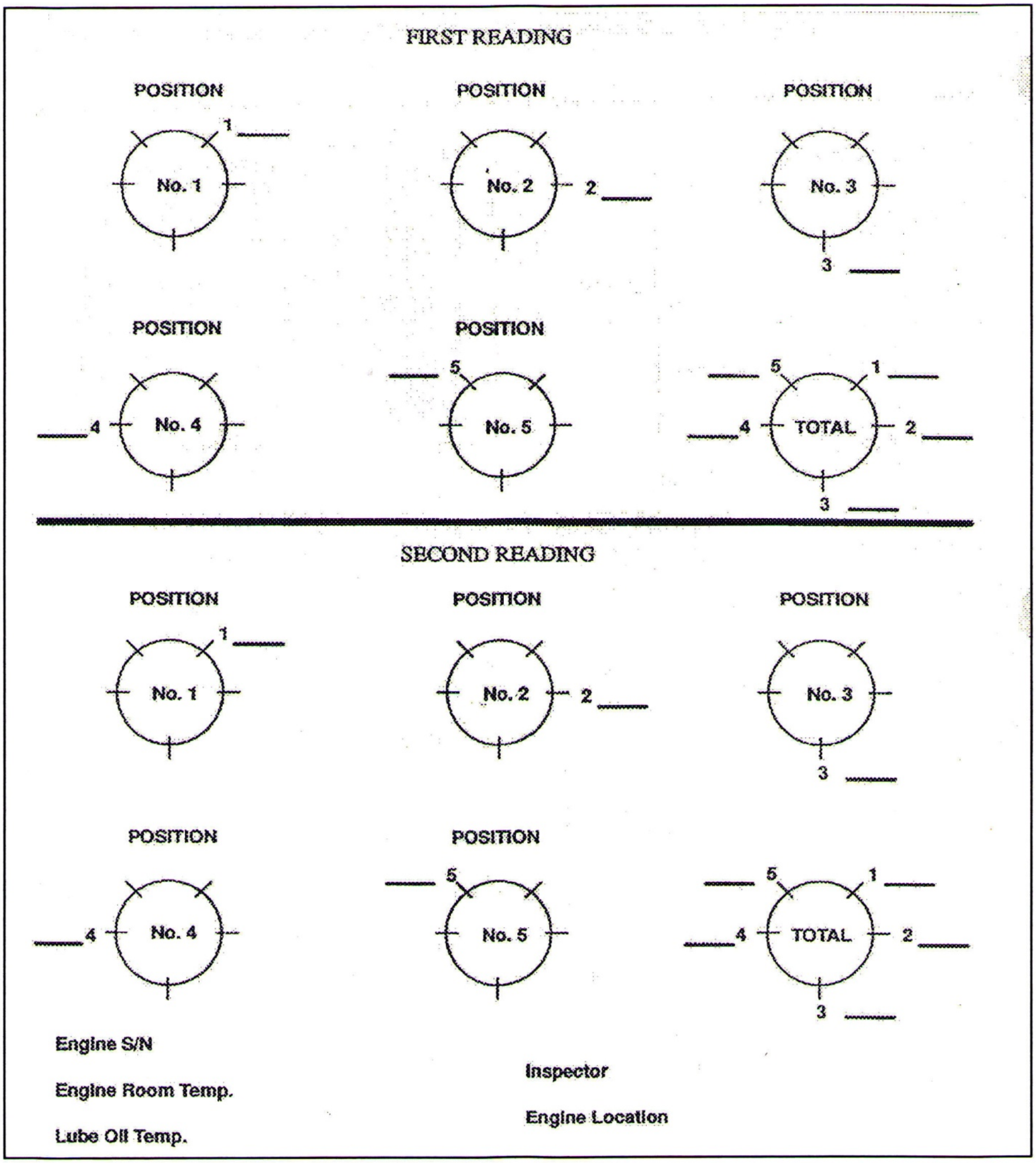


Figure 3-41 Crankshaft Strain Readings

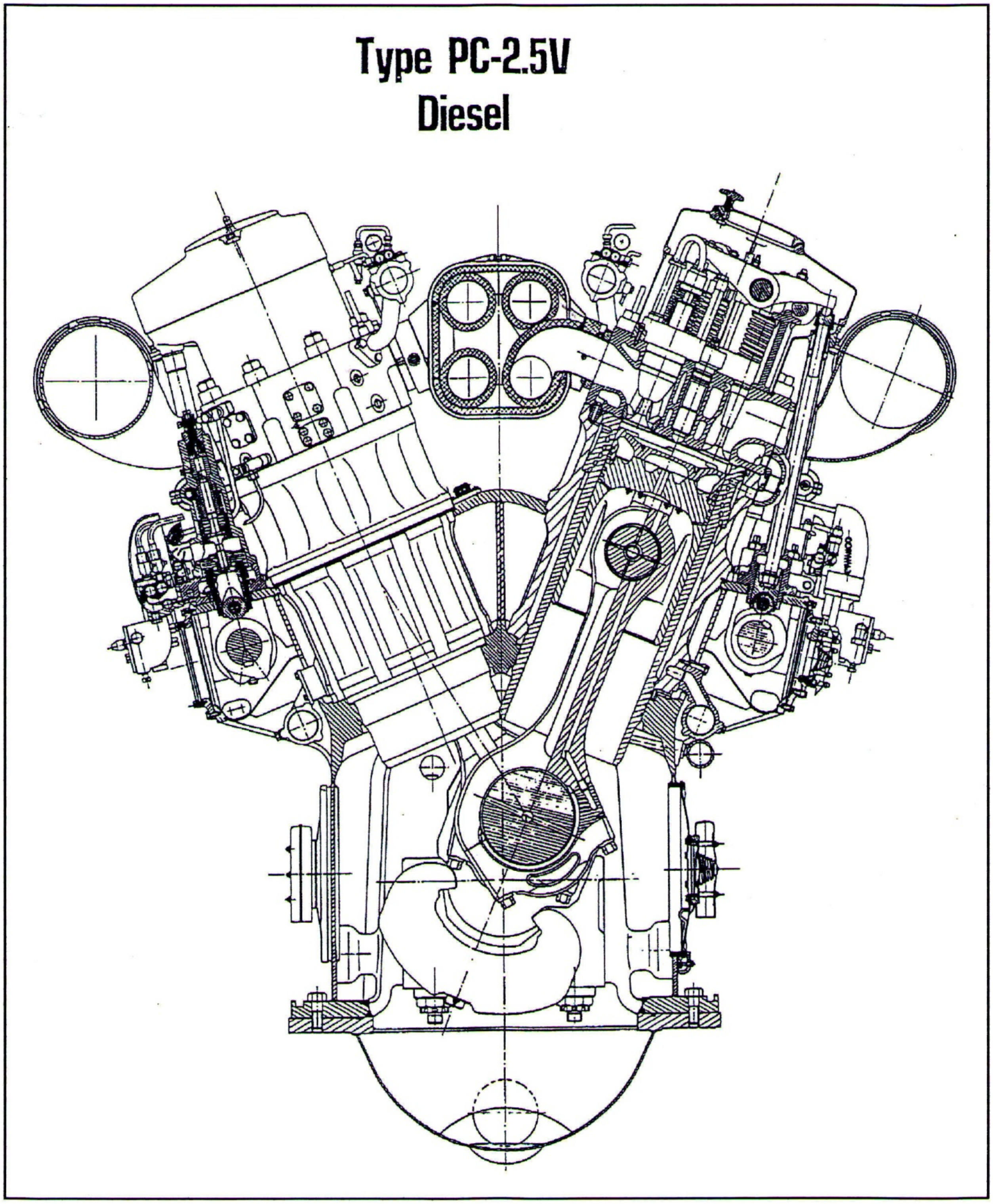


Figure 3-42 Pielstick Engine Cross Section

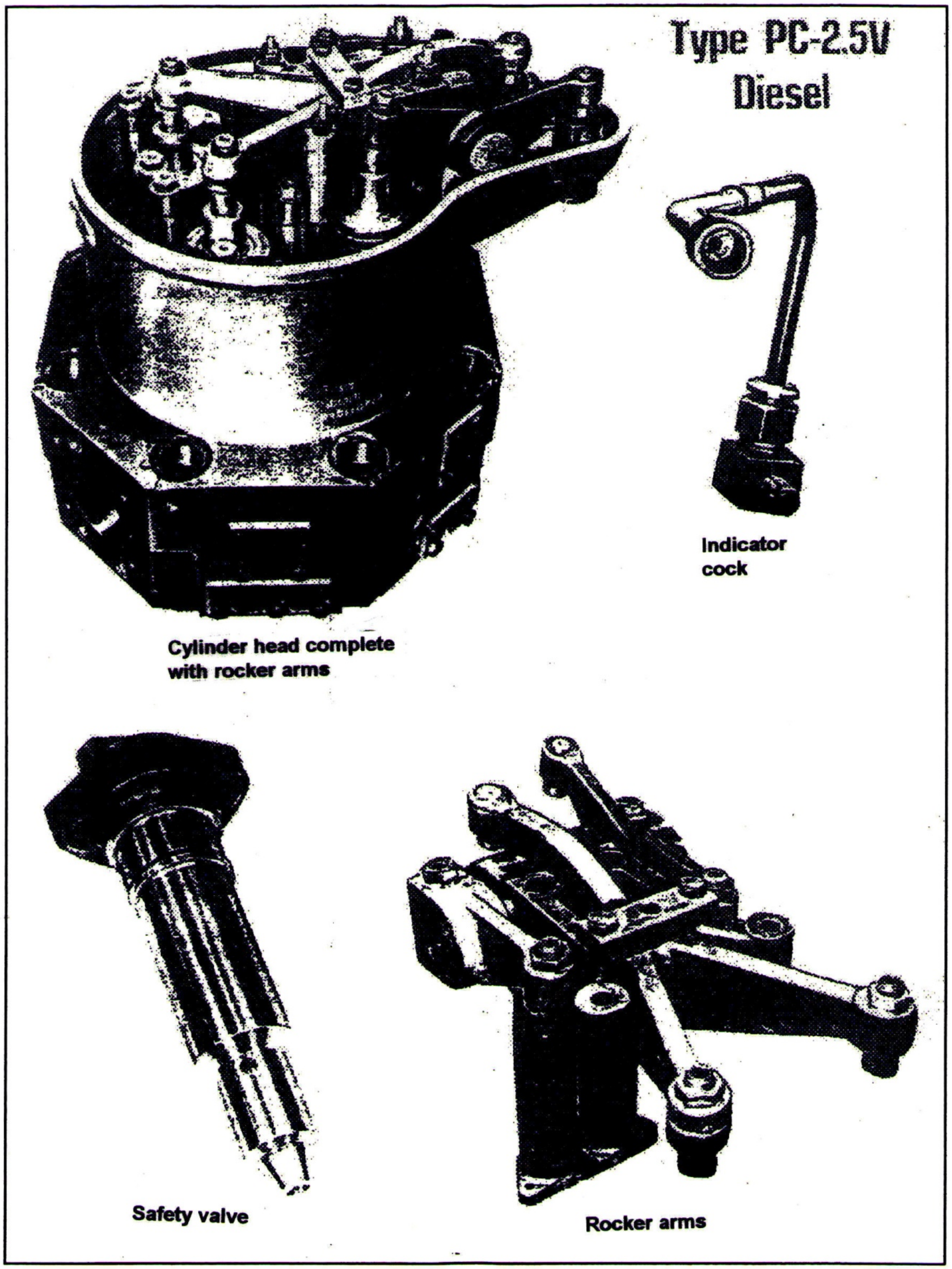


Figure 3-43 Cylinder Head with Rocker Arm Assembly

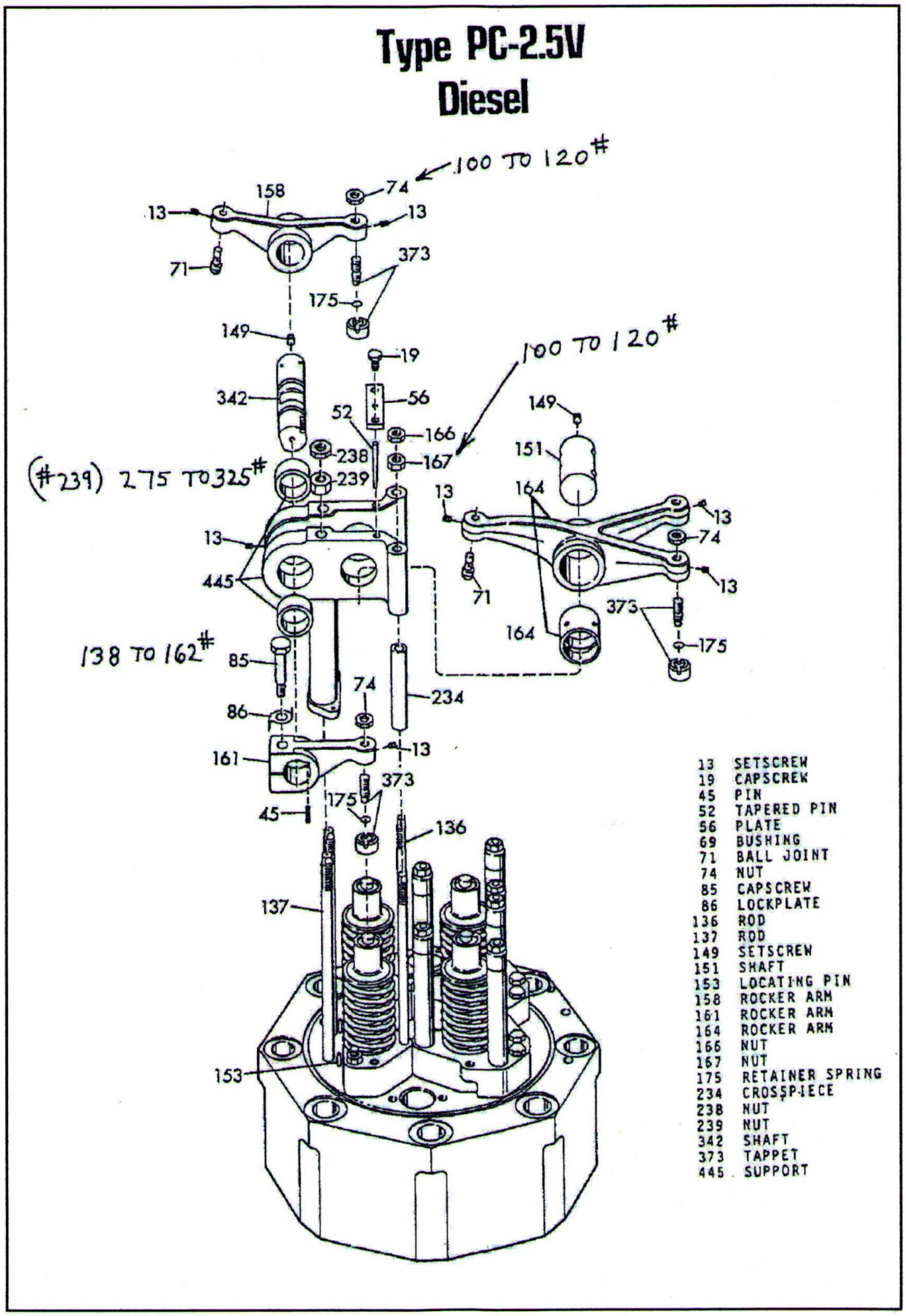


Figure 3-44 Rocker Arm Assembly

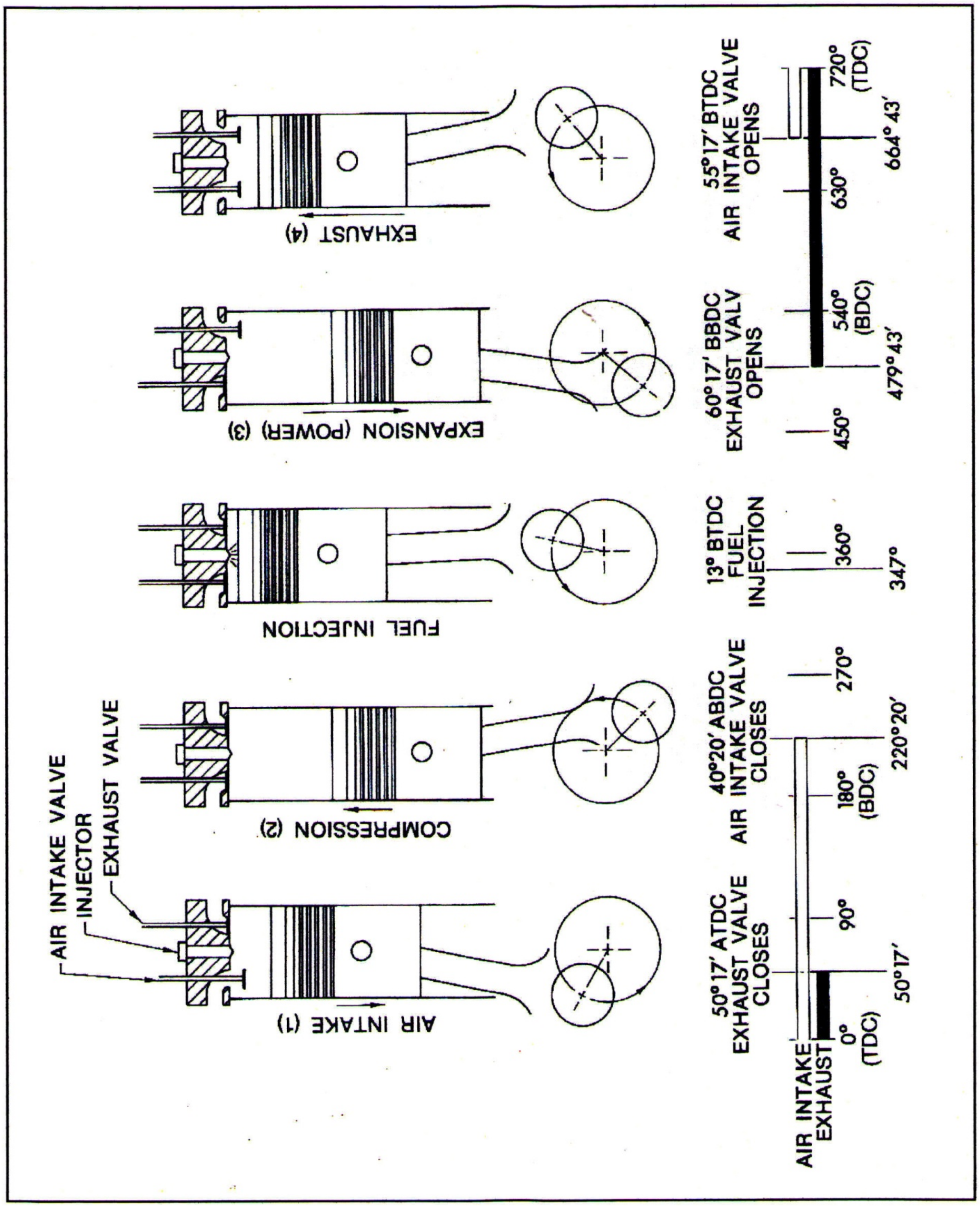
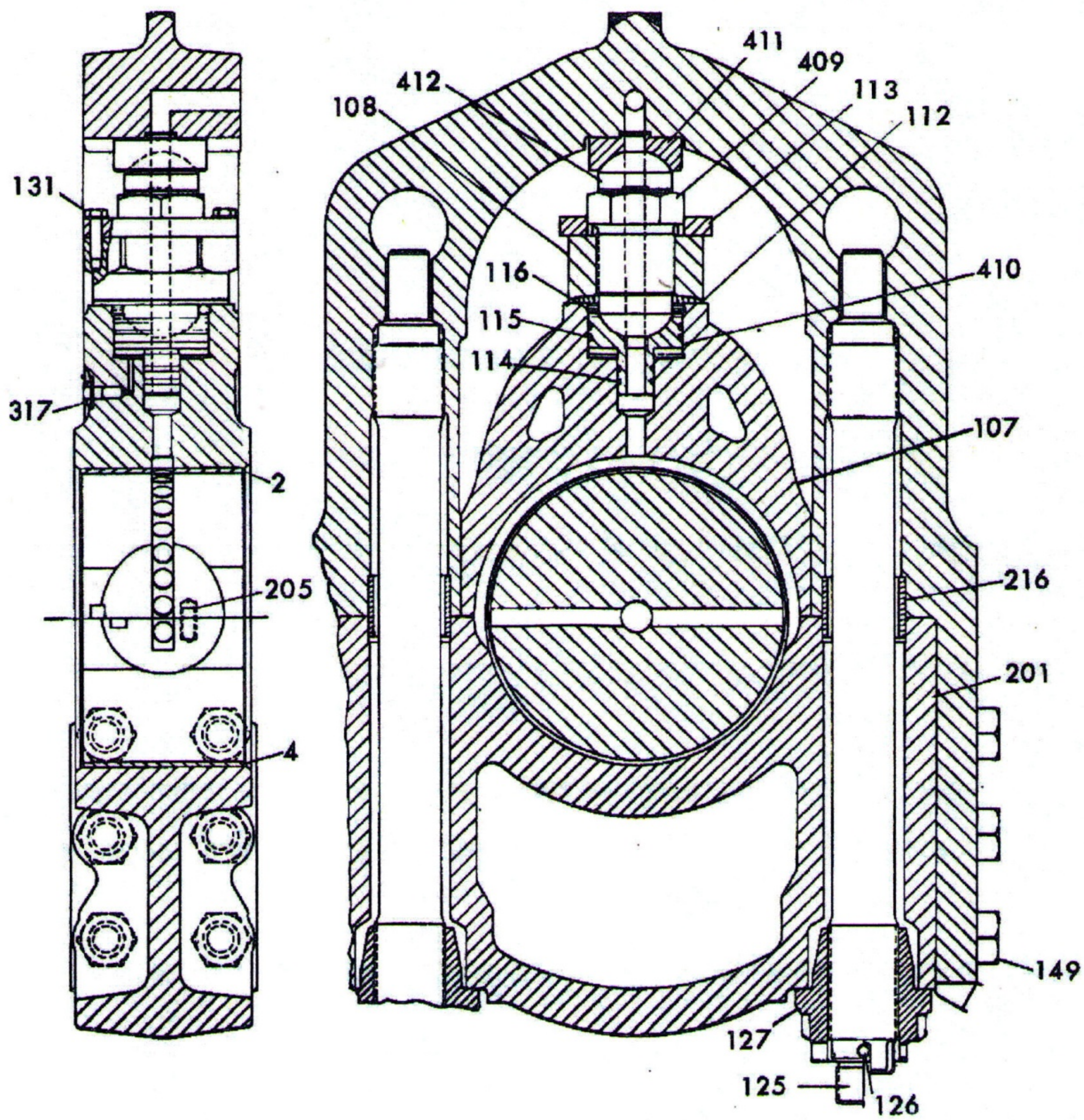


Figure 3-45 Sequence and Timing Events



2	BEARING SHELL - UPPER	116	SNAP RING	205	ROLL PIN
4	BEARING SHELL - LOWER	125	STUD, THREADED	216	RING DOWEL
107	BEARING CAP	126	COTTER PIN	317	PLUG
108	JACKSCREW BODY	127	NUT	409	SCREW, PRESSURE
112	WASHER - SPHERICAL	131	CAPSCREW	410	PISTON
113	LOCKWASHER	149	CAPSCREW	411	BLOCK - CONCAVE
114	O-RING	201	BEARING SADDLE	412	SEAT - CONVEX
115	O-RING				

Figure 3-46 Standard Main Bearing

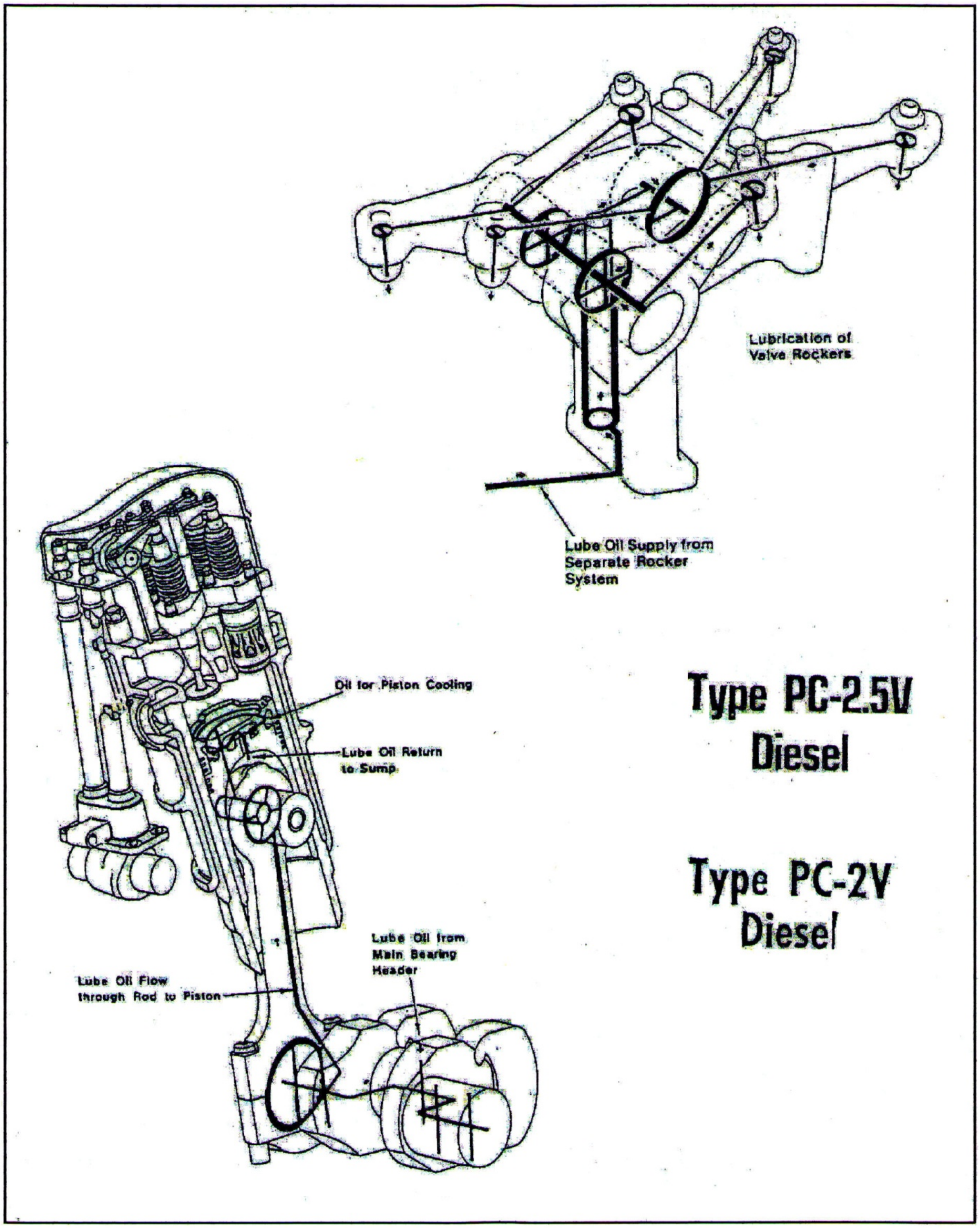


Figure 3-47 Lube Oil Distribution – Bearings, Rocker Arm, Piston Cooling

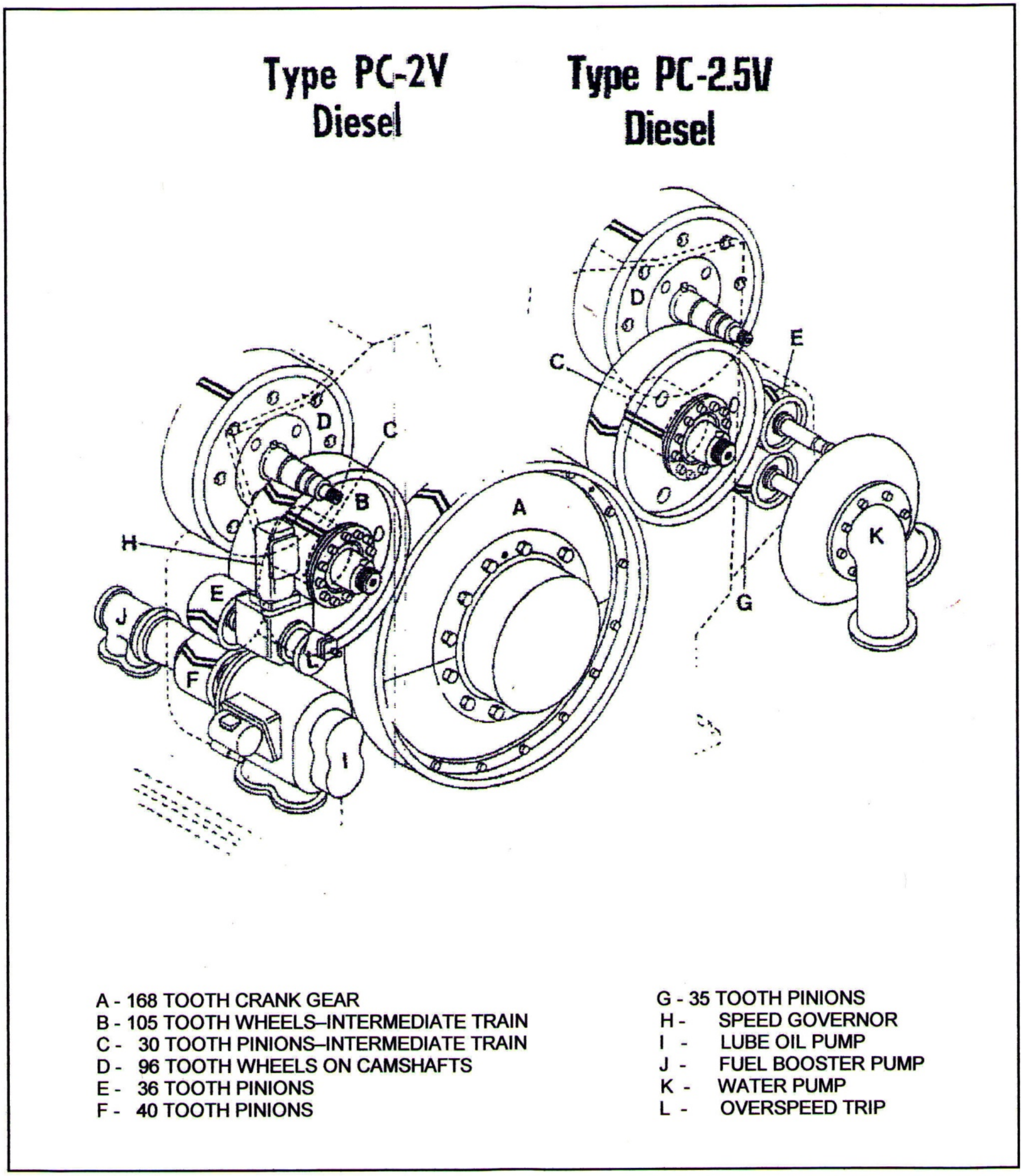


Figure 3-48 Timing Gear and Auxiliary Drives

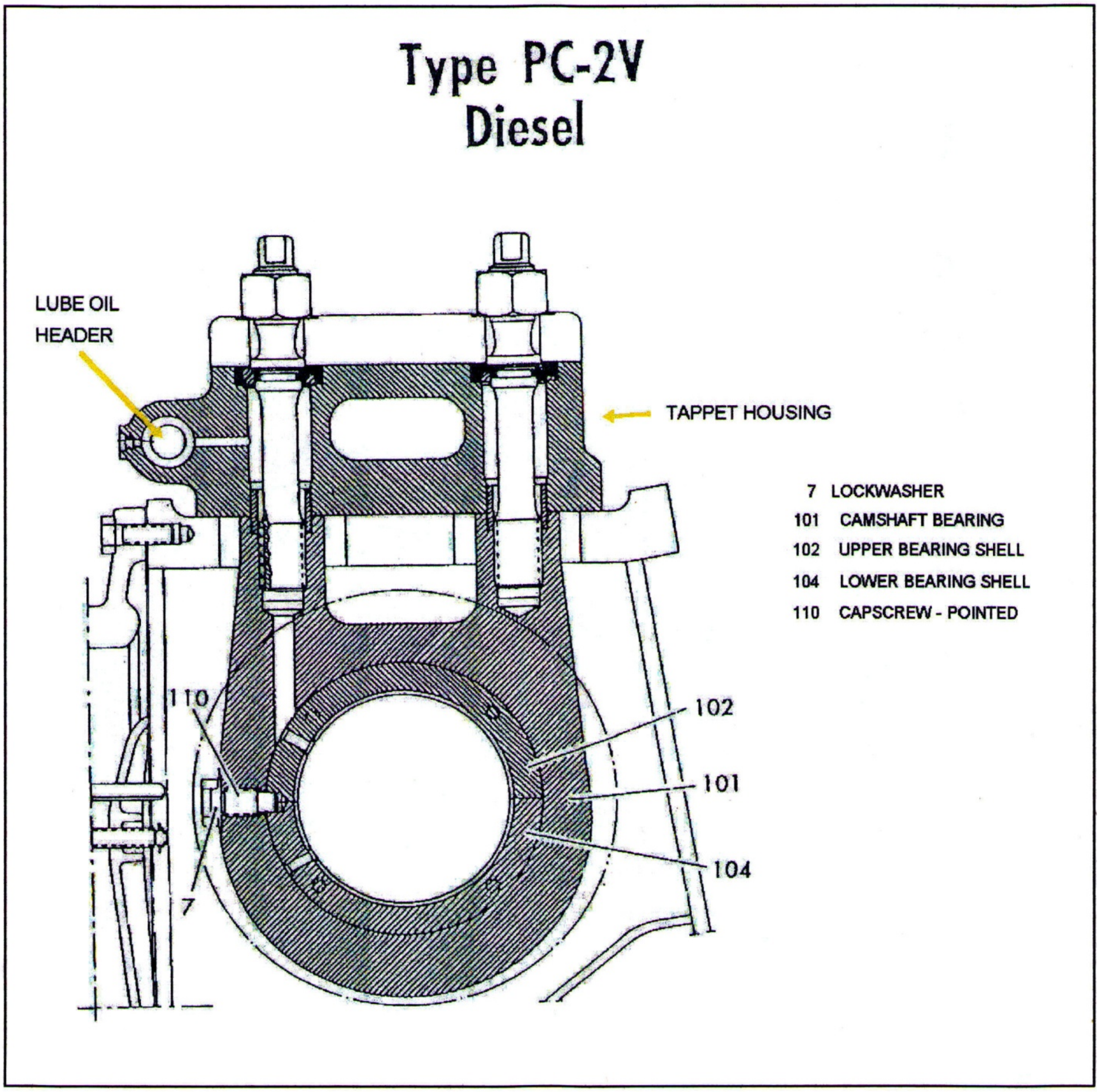


Figure 3-49 Camshaft Bearing Lubrication

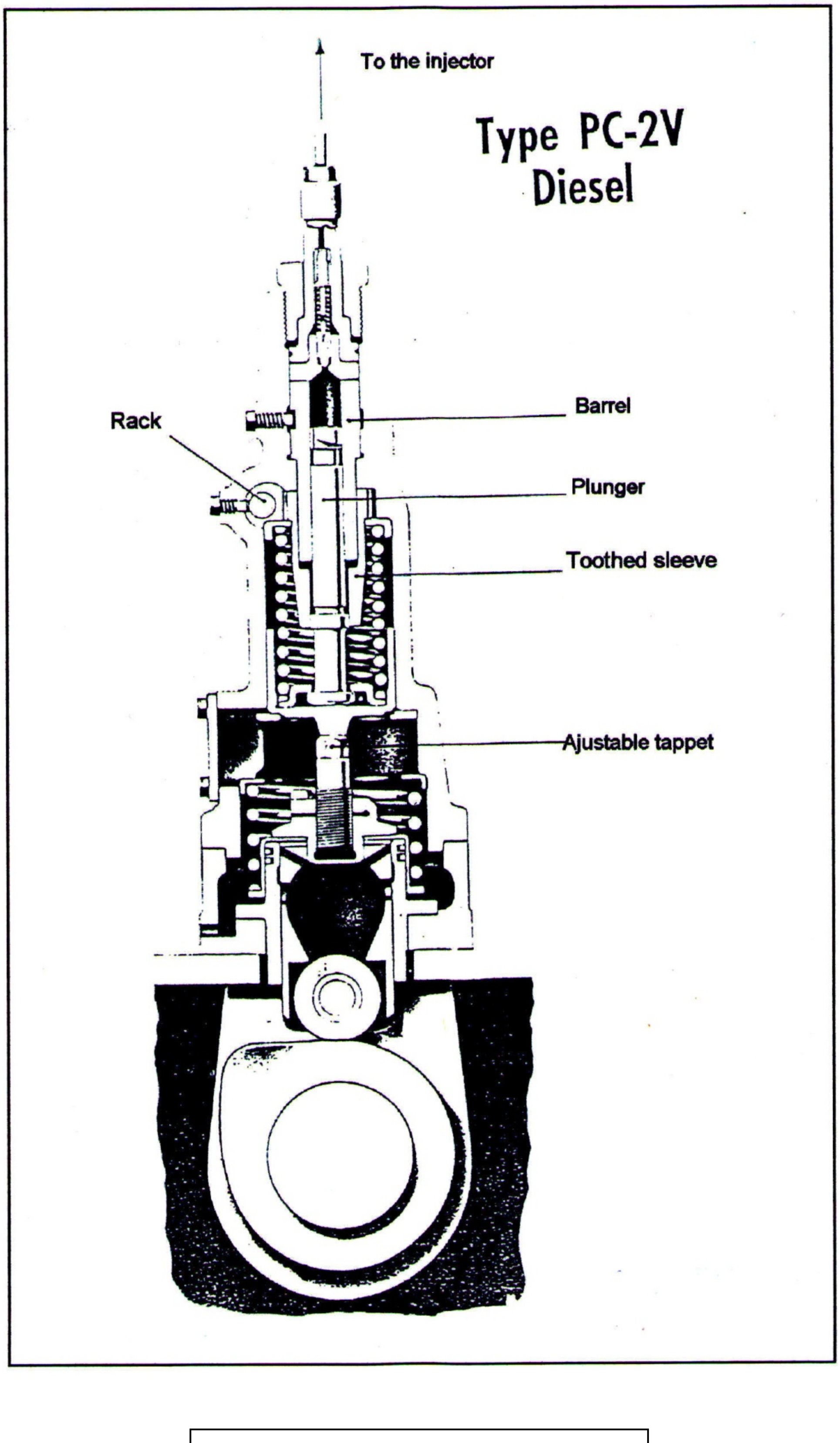


Figure 3-50 Fuel Injection Pump

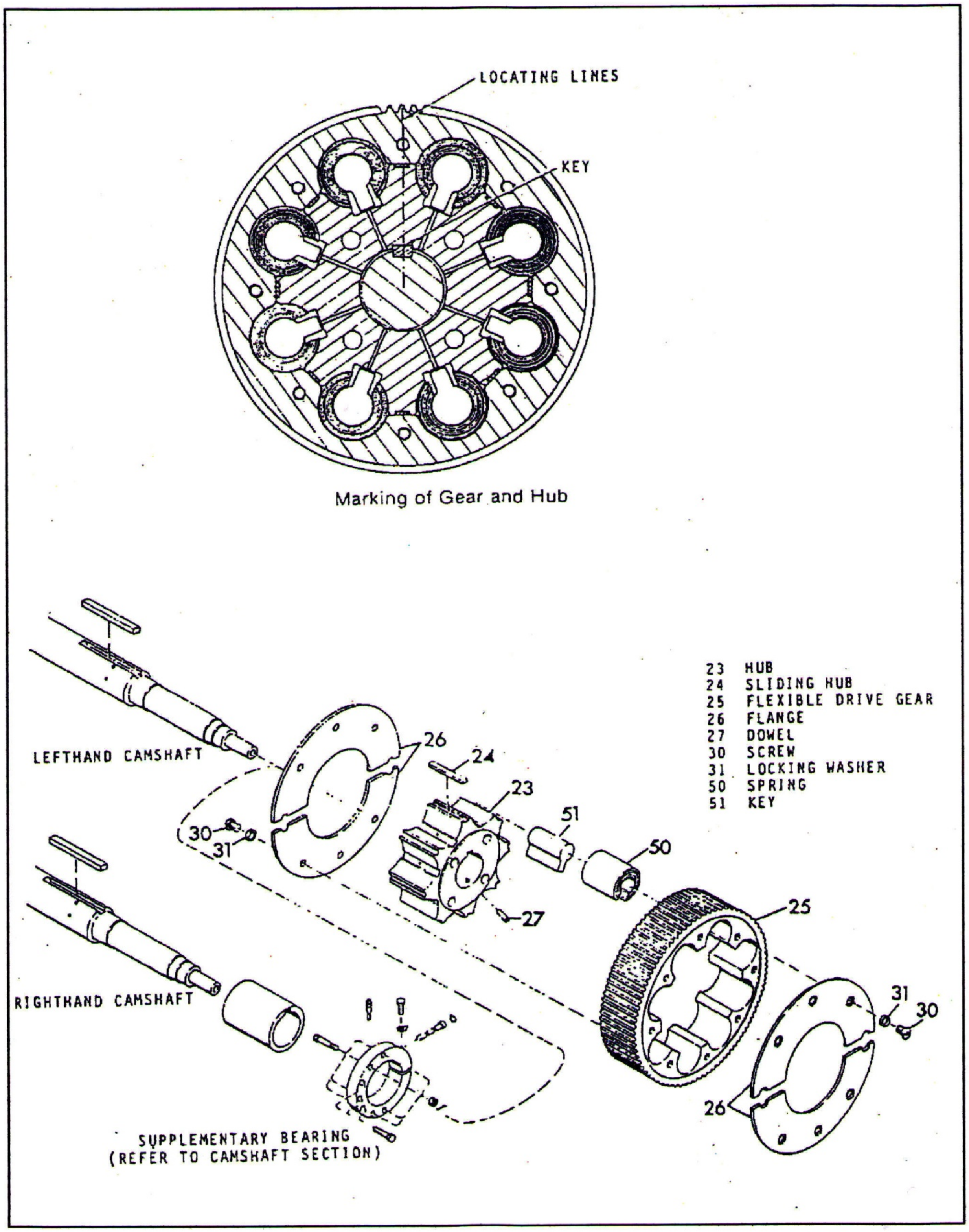


Figure 3-51 Flexible Drive Gear

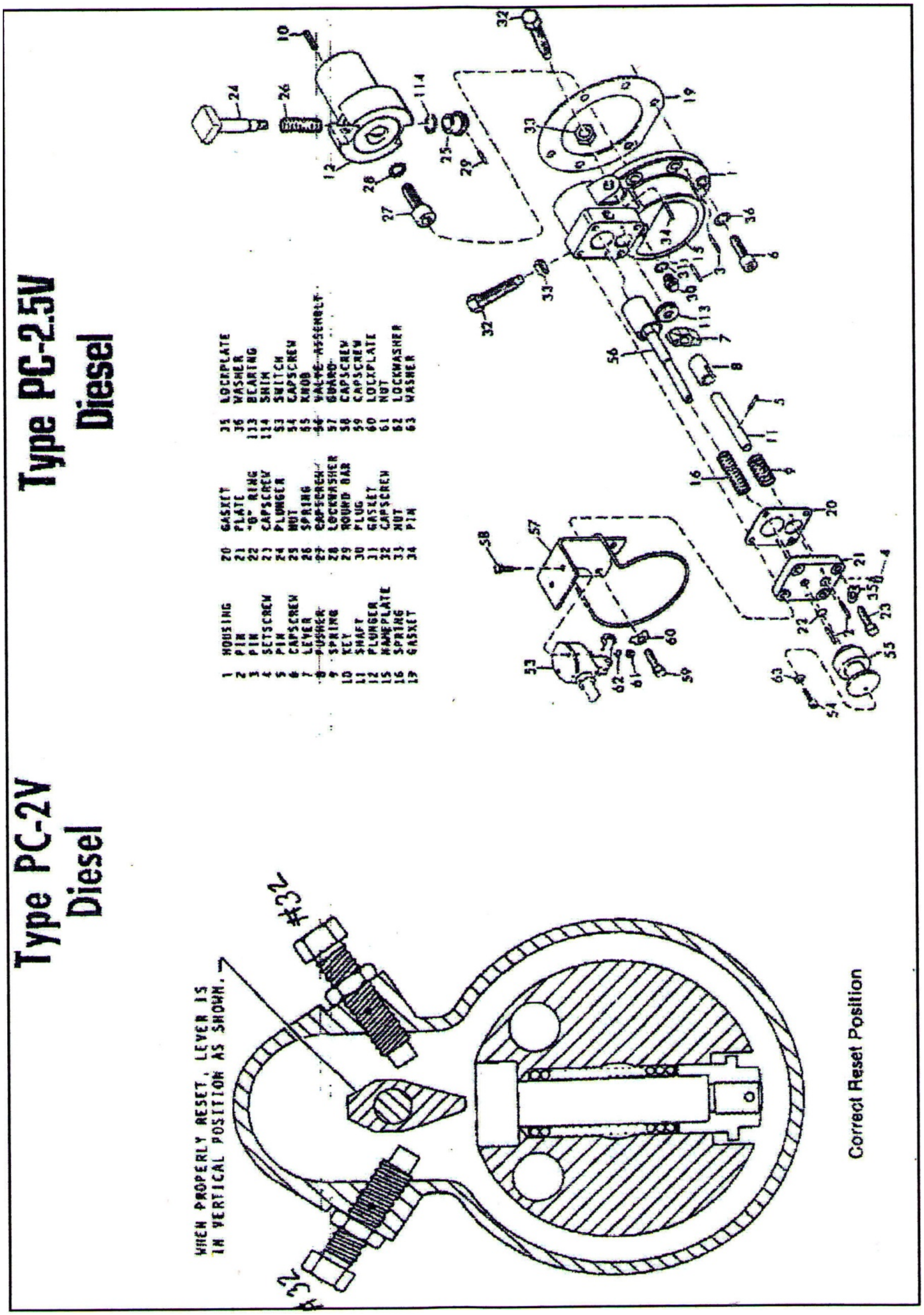


Figure 3-52 Overspeed Governor and Trip Mechanism

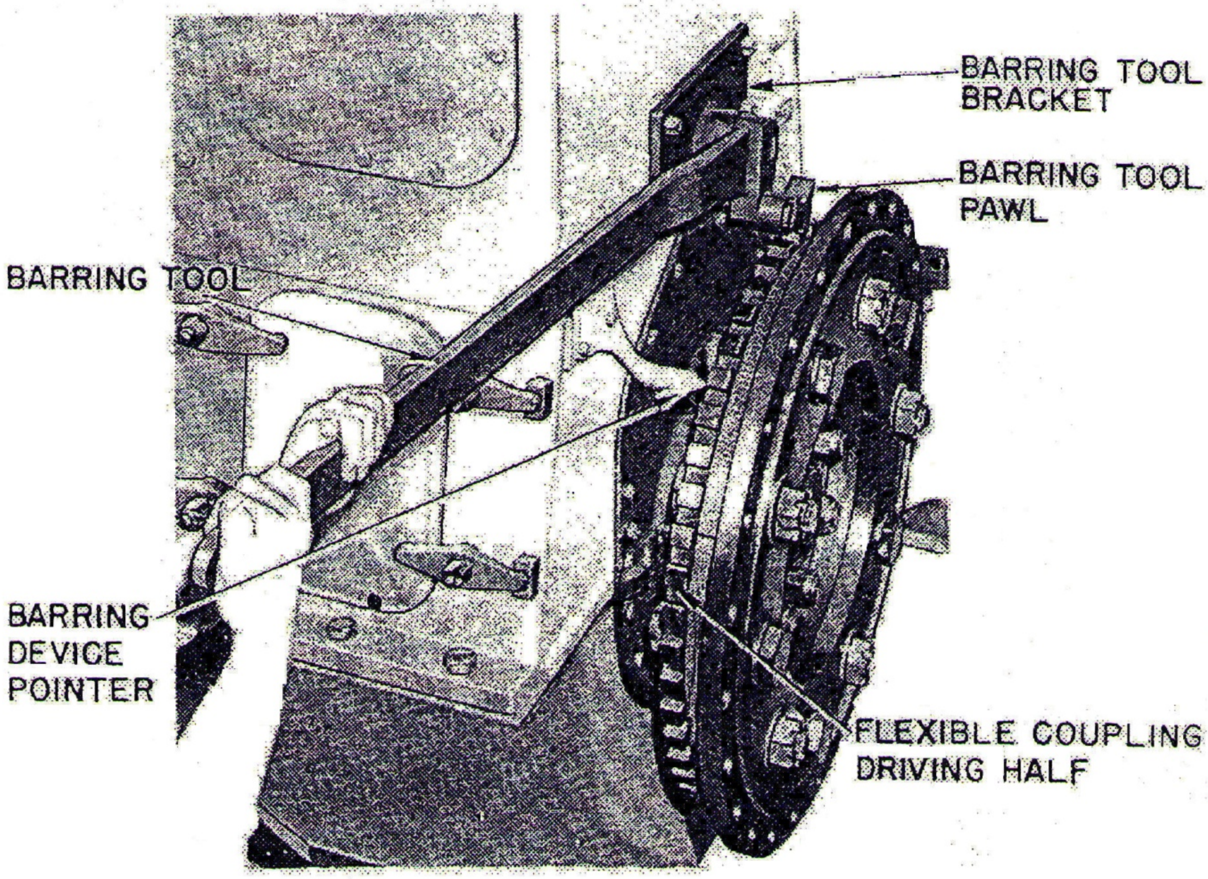


Figure 3-53 Manual Barring Device

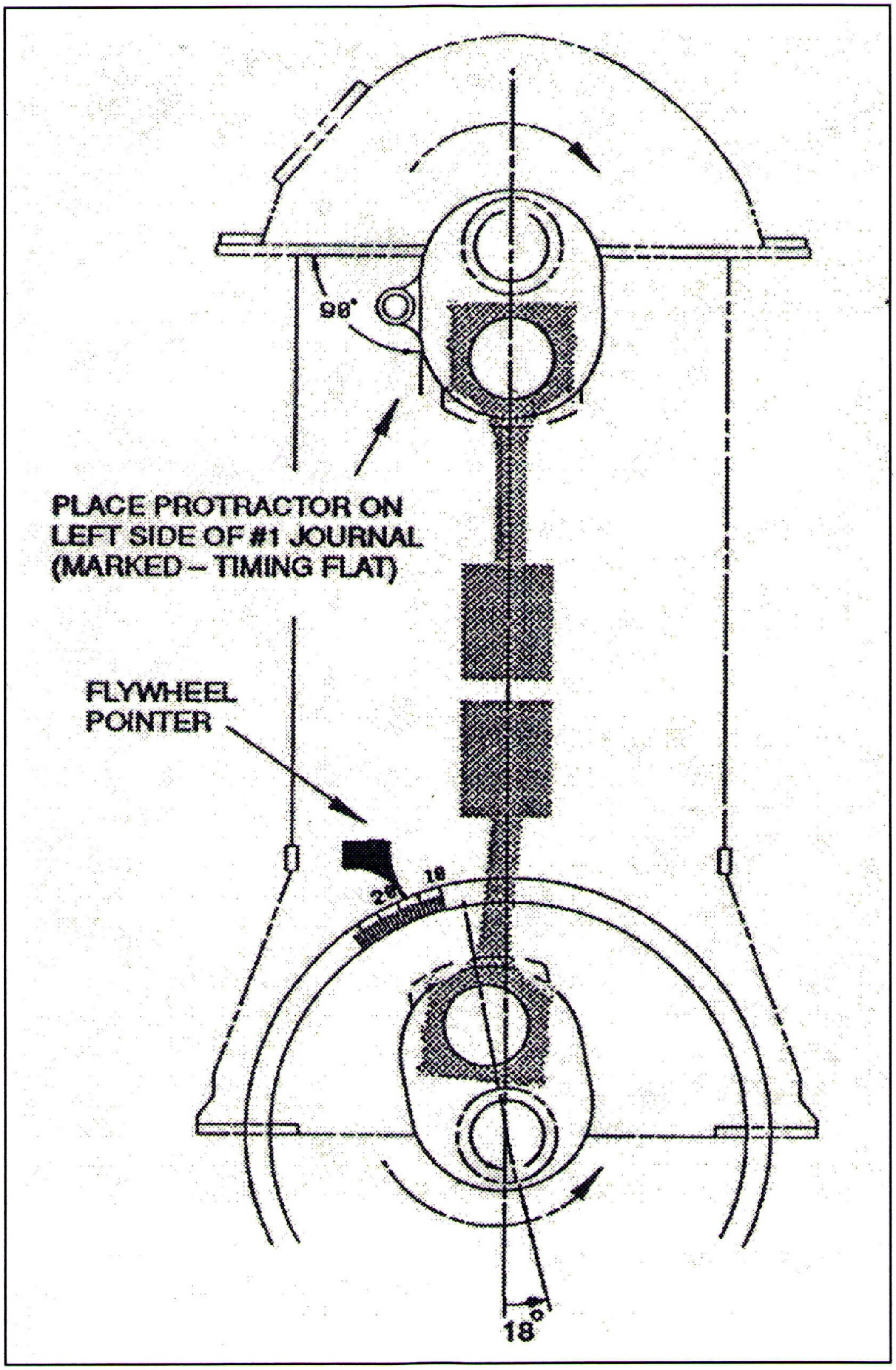


Figure 3-54 Crank-Lead Timing Viewed from Drive End

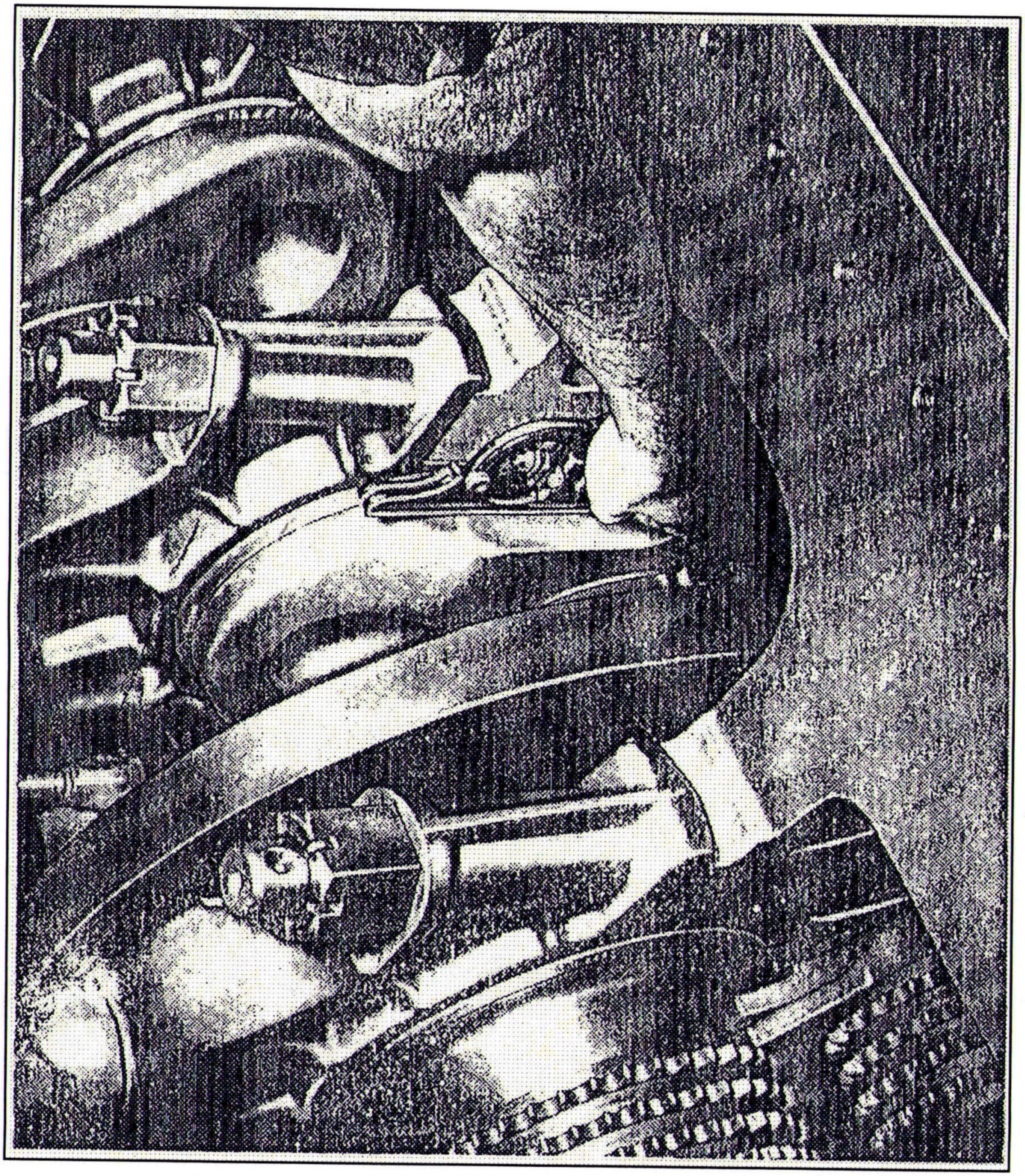


Figure 3-55 Crank-Lead Timing

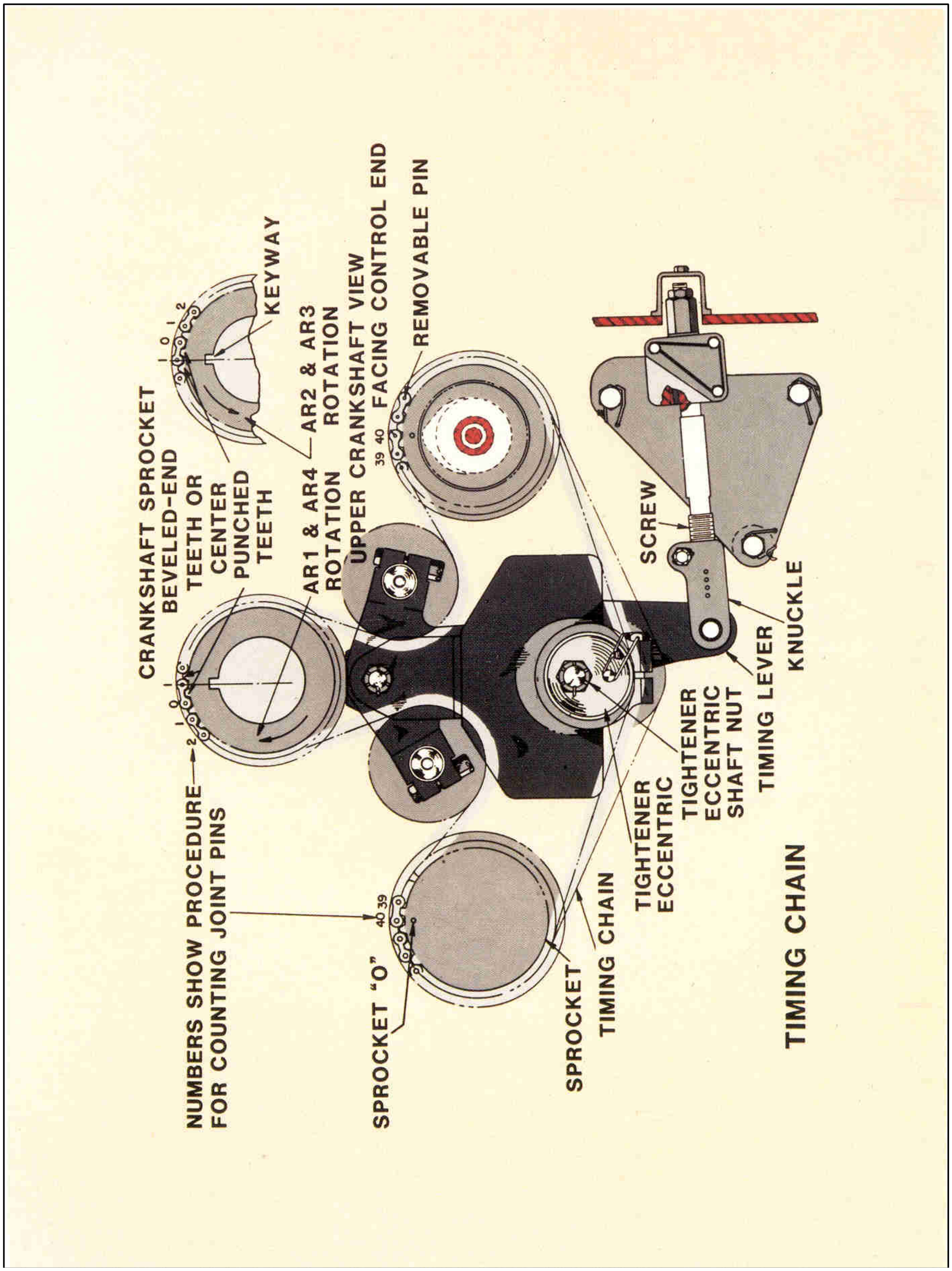


Figure 3-56 OP Engine Drive Gears and Timing Chain

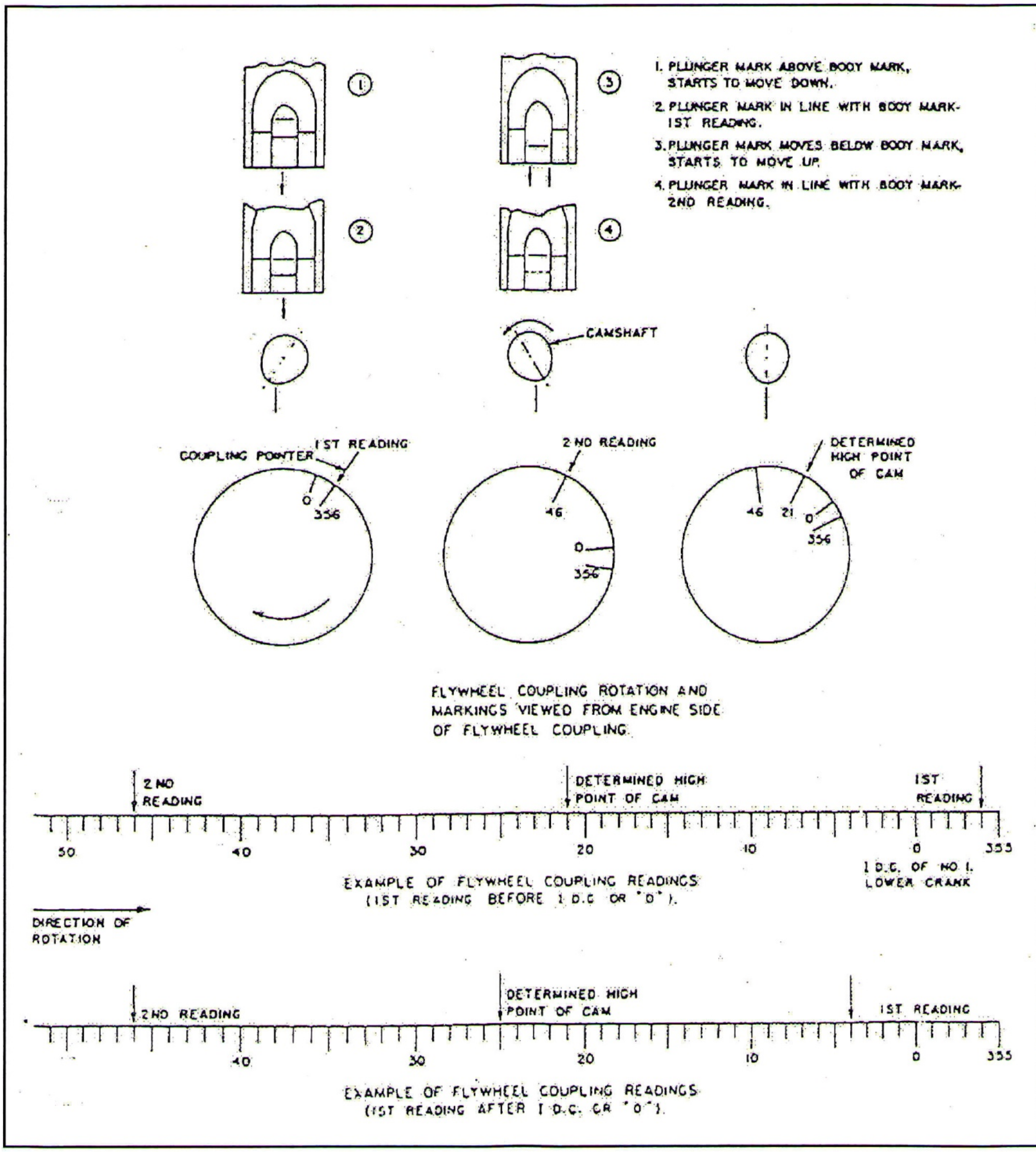


Figure 3-57 Flywheel Coupling Readings

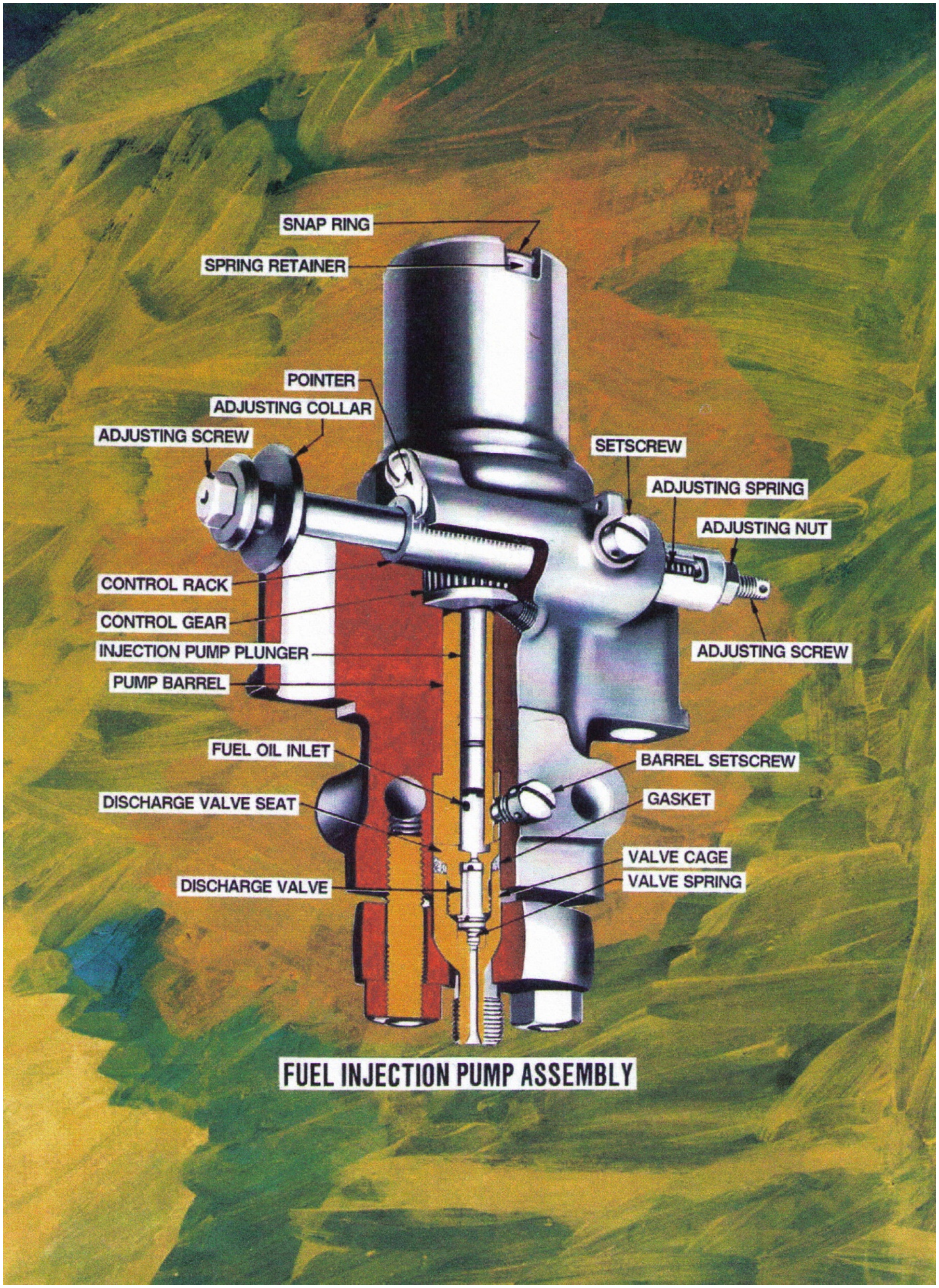


Figure 3-58 OP Engine Fuel injection Pump

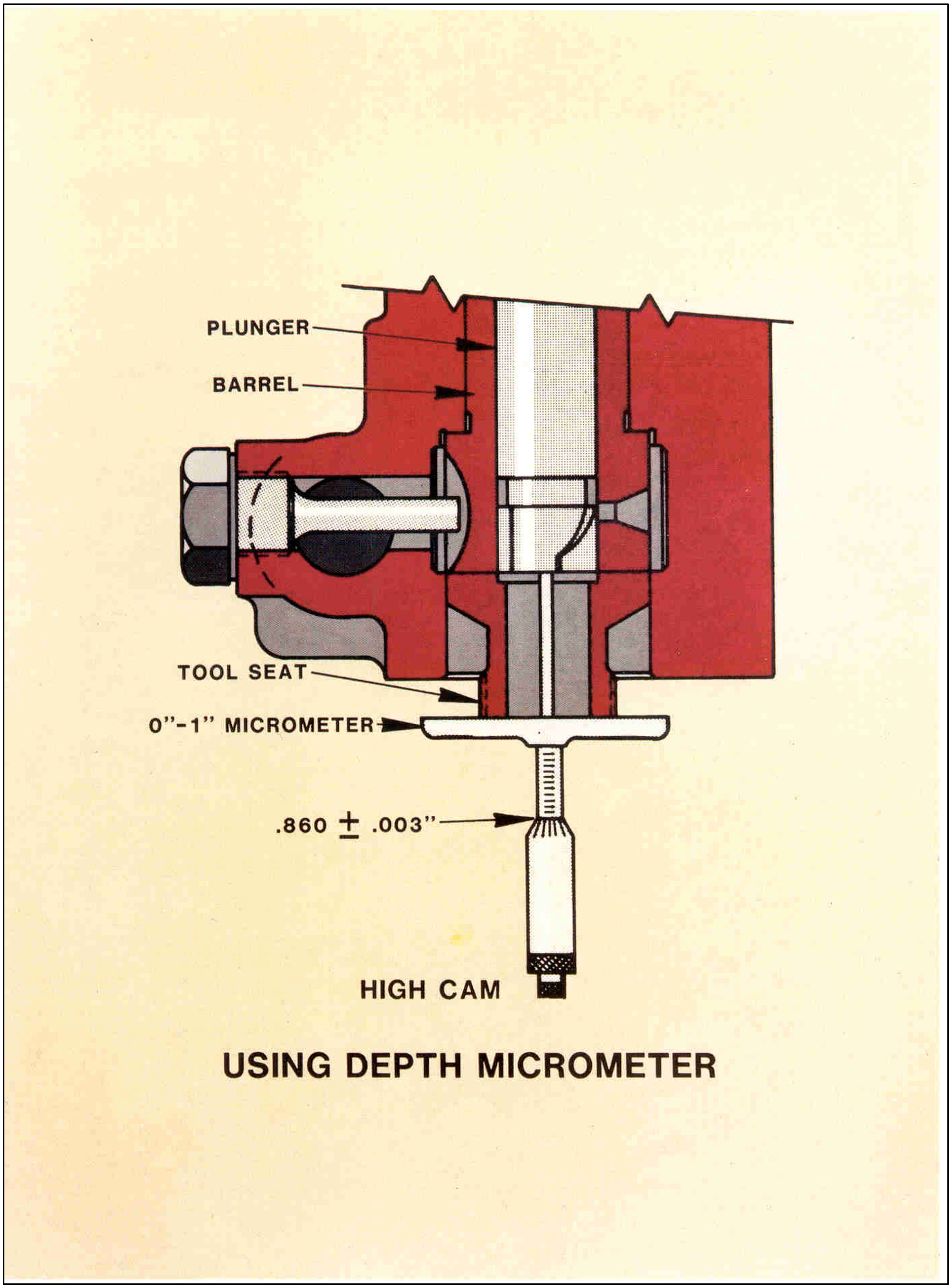


Figure 3-59 Depth Micrometer for Determining High Point of Cam

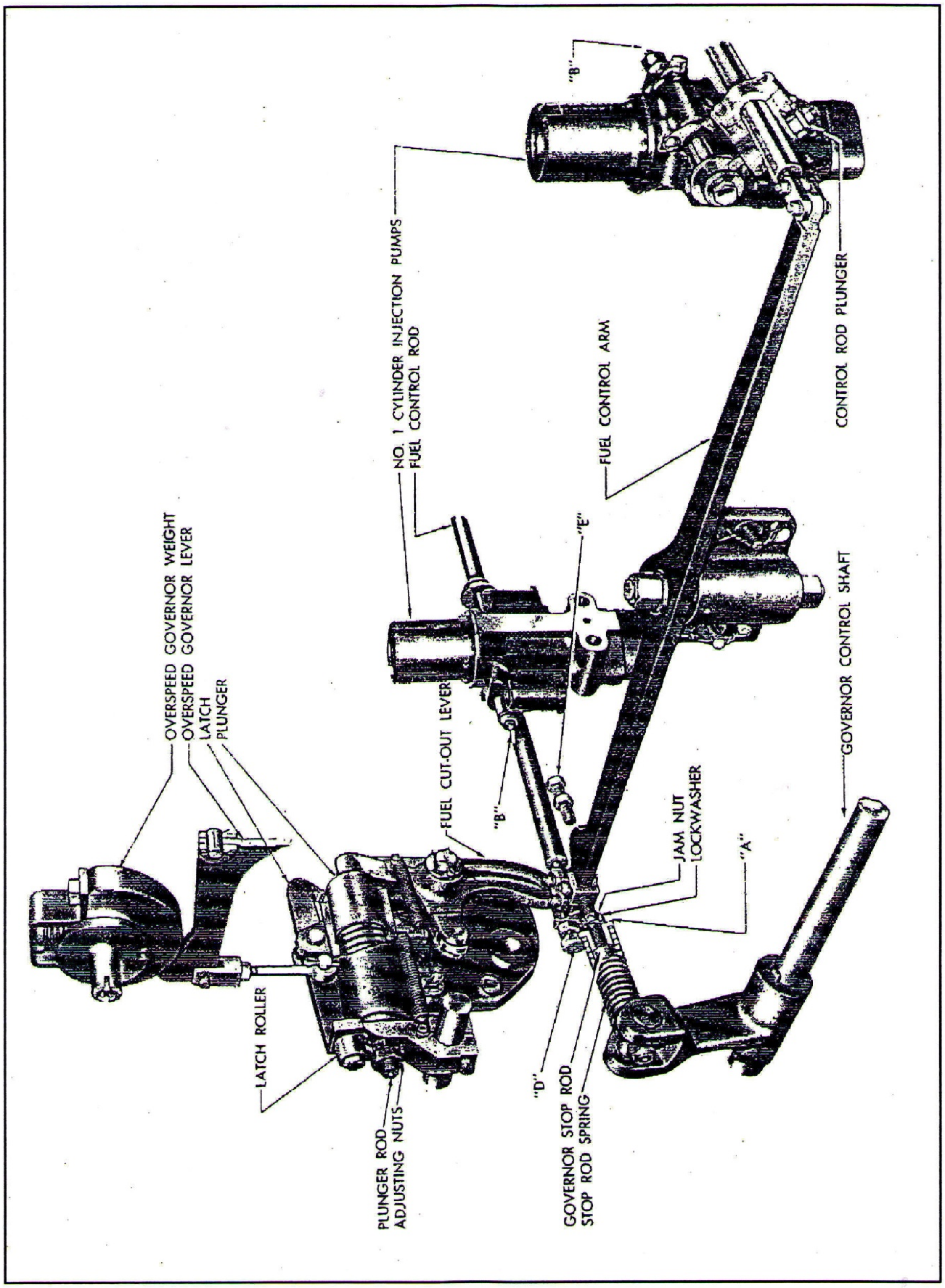


Figure 3-60 Fuel Control Linkage Adjustments

HANDS-ON SESSION 2

2.0 CRANKSHAFT(S)…VIBRATION DAMPER, BEARINGS, END FLOAT, AND WEB DEFLECTION

Purpose

The purpose of this session is to complement Chapter 3 by providing hands-on instruction supplement for better understanding.

Learning Objectives

Upon completion of this lesson you will be able to understand:

1. Where the crankshaft is located and how it is supported in the engine on its bearings and their support structures.

2. Functions of engine bearings including their assembly, disassembly, and measure-ments.

3. Crankshaft loading, motion, and proper alignment.

4. Torsional vibration and how vibration dampers work.

2.1 Vibration Damper

As each cylinder of the engine ‘fires’ it creates a pulse on the crankshaft. This pulse of torque causes the crankshaft to want to accelerate. In between these pulses, the crankshaft tends to decelerate as a result of the load from the generator (or whatever else the engine may be driving). These torque pulses result in a torsional vibration within the engine. This tends to twist and untwist the crankshaft, which puts it under stresses that over time, could cause the crankshaft to fail. To eliminate or attenuate this, torsional dampers are added to the front end of the crankshaft. There is usually no need to add mass to the drive end of the crankshaft as the generator or connected load usually adds a great deal of mass to that end of the system.

The torsional vibration damper could be thought of as a soft flywheel. The damper normally consists of a mass that is connected to a drive hub by springs, or rubber or viscous fluid or some other pliable element. As the engine accelerates (torsionally), the mass tends to lag the engine, and thus tends to cause the engine to slow down (not accelerate so rapidly). When the engine slows (between torque pulses), the mass tends to continue at its average speed and puts energy back into the crank in trying to keep it from slowing.

The engine tends to accelerate in the basis of once per revolution (called the first order), but since it has a multiple number of cylinders, it also has a frequency that is related to the number of cylinders and orders of frequency related to the primary (first order) and multiple of that. Therefore, the torsional vibration damper assembly needs to be able to take care of the primary (first order) frequency as well as the multiple orders of the primary frequency (usually the odd orders are of the most interest - 3^{rd}, 5^{th}, etc.).

There are a number of examples of torsional vibration dampers available in the work area. The instructor will point these out to the students. This exercise will involve primarily the damper system used on the Opposed Piston engines. There are basically three types of dampers. On older engines, the ‘pie’ damper was used, as shown in Figure 3-38. This damper was used on the lower crankshafts of the earlier 4- through 10-cylinder engines. On the newer engines, the monofiler damper is used, as shown in Figure 3-39. The lower damper on 12-cylinder engines is actually two sets of dampers on a single hub assembly and is called the ‘bifiler’ damper. The 12-cylinder uses a monofiler damper on the upper crankshaft as well as the bifiler on the lower crankshaft. We will disassemble and examine the parts of the monofiler damper.

The principle of the monofiler damper can be explained as follows: There are a series of doughnut (toroid) shaped parts that are suspended in the damper hub (spider) on pins. The diameter of the pin, in combination with the inside diameter of the doughnut determines the radius of gyration and thus the frequency at which the pendulum thus formed vibrates. The mass of the doughnut ring determines the magnitude of the oscillation. The two factors determine the energy that can be absorbed or given up.

In the damper assembly, there are pairs of weights with the same pin diameters and weight inside diameters and mass such that various frequencies can be handled. In operation, centrifugal force causes the pins and the weights to go to the most radially outward position in the spider. As the engine accelerates or decelerates, the pins and weights oscillate within the bore to absorb or give up energy to the spider, and thus to the crankshaft. This motion tends to hold the crankshaft speed constant, and thus attenuate the effect of the torque pulses from the cylinder firings.

Disassemble the damper by removing the lock wire and the bolts that hold the cover plates in place. Remove the cover plates on one side. This gives access to the pins. When the pins are removed, the weights may then be removed radially. Note that each set of weights is marked with its weight or position as are the pins and the locations on the hub.

Examine the pins, the bushings in the hub, the bushings in the weights, as well as the weights. There should not be any significant wear on the pins, and certainly no ridges, galling, or excessive scratches. There should be no wear in the bushings in the hub. Excessive wear occurs at the radial outside of these bushings if wear exists. These should be no wear in the bushings in the weights and no signs of galling on the edges of the weights, or other signs that the weights are binding in the hub, etc.

Reassemble the damper, including installing the cover plates, bolts and lock wire. Be certain that the proper pins and weights are installed in the proper locations in the hub. It is particularly important that the pins and weights on the opposite sides of the hub are matched as to weight and order. If this is not done, it can lead to vibration of the engine, as the damper is only physically balanced when the same order weights are opposite.

2.2 Engine Bearings, Crankshaft End Float and Web Deflection

The main bearings of the engine support

the crankshaft and control the longitudinal position of the crankshaft. Most of the main bearings in the engine are of the same design and may be interchanged. That is, any bottom half may be put in any bearing of the engine, as can any top half. However, the bottom and top halves may not be interchanged. There are also a number of special bearings which should not be interchanged or mixed with others of the main bearings. Although most main bearing halves may be interchanged, it is the custom to mark all main bearing halves as to their location in the engine. This is so that upon disassembling the engine for inspection or repair, it is evident where a failed bearing was located, and so forth.

The main bearings in the Opposed Piston engine are made of a special aluminum alloy. It has been observed that since having switched the engine to aluminum bearing, a bearing failure does not cause a failure of the crankshaft. After a failure, any aluminum material adhering to the crankshaft can be removed chemically and/or by lapping the crank journal.

A bearing failure is easily detected by either an opening up of the clearance/gap at the ends of the bearing halves, or by a pimpling of the bearing material usually evident on the edges of the bearing. There have been a number of incidence of bearings having failure, healed and run on for some time without a failure of the engine to operate.

The main bearings for the OP engine are located Figure 3-8. They are 3 inches wide by approximately 3/4 inches thick and the inside diameter, free, is 8.5075 inches. The bearing has a groove on the inside diameter that conduct oil from the oil inlet (at the top of the bearing) to the cross drilling in the crankshaft throw that takes oil to the connection rod bearing and on up to the piston. The connecting rod bearings are of the same material as the main bearings and are 4 inches wide by approximately 3/8 inches thick and 6 3/4 inches in inside diameter.

There are a number of special bearings in the engine, as described below:

1. Each crankshaft has a thrust bearing (in two halves) immediately in front of the vertical drive gear flange location on the crankshaft (see Figure 2-30). The vertical drive causes the crankshaft to thrust toward the forward end of the engine and the thrust bearing has a considerable area on the associated side of the bearing. The other thrust face is considerably smaller in area. The thrust bearing also limits the travel of the crankshaft longitudinally and positions the crankshaft within the engine assembly. It is important, when the unit is connected to a generator, that the bearing(s) in the generator have enough free travel that the engin thrust bearing retains control of the crankshaft position.

2. The last bearing in the engine is called upon to support about half of the load of the generator rotor assembly. For this reason, it is a special bearing with a section cutout to provide more clearance. Upon starting the engine, especially after it has sat still for some time, the bearings may not have much oil in them. This can cause excessive bearing wear. For that purpose, this bearing is provided with a bearing booster. This booster fills with oil while the engine is in operation and remains full when the engine is shut down. Upon the next start, starting air in put

into this booster cylinder, driving its piston toward the oil outlet end. This oil is forced into the last main bearing and helps lubricate that heavily loaded bearing as it begins to rotate as the engine is started. The oil enters the bearing with enough pressure to slightly lift the crankshaft.

3. As the engine fires, the main bearing on both crankshafts are forced away from the cylinders. In the case of the upper crankshaft, the crankshaft is forced upward. However, the blower end main bearing does not see this firing load and the crankshaft at that location would ride in the center of that bearing. This actually causes the crankshaft to be bent slightly at the last crank throw. To compensate for this effect, the blower end main bearing is intentionally bored and installed off center. For that reason This bearing can not be interchanged with other bearings

4. The forward end of the upper crankshaft on 12-cylinder engines supports the torsional damper. The damper is heavy and tends to bend the crankshaft downward at the first throw. Therefore, the 12-cylinder engines are provided with a special bearing, installed into the front cover of the engine to help support that end of the crankshaft.

The instructor may have students remove and reinstall the thrust bearing on the upper crank-line of the 6-cylinder engine unit.

After any main or connecting rod bearing is replaced in the engine, or after bearings are removed for inspection, the engine should be run through a 'run-in' procedure. This consists of gradually bringing the engine up to speed and load in several steps. In between the steps, the bearings are inspected for opening of the parting line, pimpling, or running hot.

2.3 Checking Crankshaft End Float

Particularly after the thrust bearings have been removed for inspection or replaced, it is necessary to check the end float of the crankshaft to ensure that the thrust bearings have been properly installed. This procedure is relatively simple but must be carried out to ensure proper assembly. The procedure consists of the following steps:

1. Install a dial indicator on the cylinder block with the stylus on either the end of the upper crankshaft or on the blower drive gear mounted on the crankshaft to measure longitudinal motion. In the case of the lower crankshaft, install the indicator between the cylinder block and the flywheel in the longitudinal direction.

2. Thrust the crankshaft forward using a bar between a crank cheek and the cylinder block bearing frame.
3. Set the dial indicator to 'zero.'

4. Thrust the crankshaft in the aft direction.

5. Read the dial indicator. This should be the thrust clearance. Repeat this procedure at least once more to be sure the number recorded is consistent.

2.4 Checking the Crank Web Deflection Crankshaft Alignment

Particularly when main bearings have been disturbed, replaced, etc., or the generator has been removed and replaced, it is necessary to check to see that the engine is properly aligned. This is down by measuring the crank web deflection. If the crank is straight, then as the crankshaft is rotated, a dial indicator located between the adjacent webs of the crank journal will not change the distance between them. If the crankshaft is bent at the throw, then as the crankshaft is rotated, the webs get closer together or further apart. This is due to the fact that the crank pin (journal for the connecting rod) does not change in length. If the crank is bent at the throw, the webs then wobble. This is detected by putting a dial indicator in the prick marks provided on the crank webs and rotating the crank. Since the connecting rods are in the way, it is only possible to take 5 readings. As shown in the diagram on Figure 3-40. Record the values on a chart similar to that shown in Figure 3-41.

It is normally only necessary to do this check on the last throw of the engine, as the block is rigid enough that the other bearings are normally well aligned. On the Pielstick engine, however, it is recommended that all the throws be checked periodically (at refueling periods, or every 5 years). Any time the generator is disturbed, the crankshaft alignment should be checked.

At the instructor's direction, place a dial indicator (strain gage) between the crank cheeks as shown in the figure, using the prick marks provided in the crank web. Do the following steps:

1. Rotate the crankshaft in the opposite normal direction until the dial indicator is almost touching the connecting rod. Take a reading or 'zero' the dial indicator at that point. Record the reading.
2. Rotate the crankshaft (in the direction of normal rotation) until the indicator is 90 degrees from the vertical position (horizontal position). Record the reading.

3. Rotate the crankshaft until the indicator is at the bottom (vertically down). Record the reading.

4. Rotate the crankshaft until the indicator is at the other horizontal position (opposite side to step 2). Record the reading.

5. Rotate the crankshaft until the indicator again approaches the connecting rod (on the opposite side). Record the reading.

6. The readings in step 1 and 5 should be very close to the same, if not the same. The difference between the reading at step 3 and steps 1 and/or 5 should fall within the limits set for crank strain given in the data book (or the instructor's direction). If they are not within the limits, it may be necessary to adjust the generator position as required to bring the strain within the limits.

7. The difference between the readings in steps 2 and 4 should also be within the lateral limits for strain. If they are not, it indicates that the generator needs to be moved sideways to bring the engine into alignment.

HANDS-ON SESSION 3

3.0 PIELSTICK ENGINE CYLINDER HEADS, VALVE OPERATING MECHANISMS, CYLINDER WATER JACKET, MAIN BEARINGS, PISTON, CONNECTING RODS

Purpose

The purpose of this session is to complement classroom instruction on 4-stroke cycle components and their functions with hands-on instruction utilizing the actual components.

Learning Objectives

Upon completion of this lesson you will be able to understand:

1. The 4-stroke cycle PC cylinder head assembly including its intake and exhaust valves.

2. The PC engine cylinder and water jacket assembly.

3. The PC main bearing assembly.

4. The PC piston and connecting rod assembly.

3.1 Pielstick Cylinder Heads, Valves and Valve Operating Mechanism

In the previous sessions, we have studied primarily the Opposed Piston engine. This engine is unique in that it has two crankshafts, two pistons in each cylinder, no cylinder head and no valves (the air is let in and the exhaust let out through ports). We will now look in some detail at parts used on the Pielstick 4-stroke cycle engine. It is also very similar to the ALCO engine design, such that much of the discussion and items observed are applicable in general to the typical 4-stroke cycle engines, regardless of manufacturer. Figure 3-42 shows a cross section of the Pielstick ‘V’ type engine, typical of that used in nuclear applications.

The cylinder head becomes a very important component of most diesel engines. It acts to close one end of the cylinder with the piston closing the other end. It usually contains the valves that admit combustion air into the cylinder and allow the exhaust to be expelled. The fuel injection nozzle is normally housed in the cylinder head. If the engine is ‘air over piston’ started, the air start admission/ check valve is also mounted in the cylinder head. Because the cylinder head is exposed to the pressures and temperatures of the combustion process, it must be strong enough to contain the high pressure and yet thin enough to quickly conduct the heat away from the surfaces subject to the high temperature. It is usually a rather intricate high strength cast iron part.

Figure 3-43 shows a view of the cylinder head complete with the valve operating mechanism and its housing, ready to be installed in the engine. The cylinder head is held down to the top of the cylinder liner and water jacket assembly by a number of studs with nuts. These studs are very strong and are ‘torqued’ to a very high value. In fact, it is impossible to manually torque the bolts properly; therefore, these studs are hydraulically stretched and then the nuts are tightened hand tight and then the hydraulic pressure relaxed. This ensures the studs are loaded uniformly and to the proper stretch required to hold the cylinder head tight to the cylinder liner to maintain the seal between these parts against the 1300 to 1500 psig pressure resulting from the combustion process.

Figure 3-44 shows an exploded view of the cylinder head assembly with the valve rocker mechanism. The valves of the engine must be operated at the proper time in the engine's cycle in order for the engine to operate properly. Figure 3-45 gives a quick review of the engine cycle and shows when the valves are operated during the engine's operation--taking two complete revolutions of the crankshaft to accomplish the 4-stroke engine cycle.

A mock up of the cylinder head with its valves and the associated section of the cam shaft will be used to demonstrate the operation of the valves and the injection pump during engine operation. Figure 3-46 shows a diagram of the relationship of the crankshaft, connecting rods, pistons, camshaft and valve operating mechanism of the engine, and how lube oil is supplied to these operating components.

The students will disassemble a cylinder head assembly at the direction of the instructor. This consists primarily of the following steps:

1. Remove the nuts on the studs that retain the valve rocker arm support. Remove the rocker arm support and its attached mechanism.

2. Remove the nuts on the studs that retain the exhaust valve cages and remove the exhaust valve assemblies.

3. Remove the spring keepers from the top of the intake valves using the spring compressor assembly. Remove the keepers, retainers and springs. Remove the intake valves from the cylinder head.

4. On the exhaust valve cages, use the spring compressor to depress the valve pushrods to the point that the keepers can be removed. Remove the keepers, retainers and springs. Remove the exhaust valves from the cage assemblies.

5. Inspect the parts as required/directed.

6. Reassemble the valves and valve cages to the cylinder head. Reassemble the valve rocker mechanism and torque the nuts and studs as required/directed.

The instructor will also cover valve lash adjustments and other checks using the operational display model of the cylinder head and valve mechanism.

3.2 Cylinder Liner-Jacket Assembly

Using the Pielstick 2-cylinder engine, the students will be shown how the cylinder liner and jacket assembly fits into the cylinder block and how cooling water enters the liner jacket at the bottom outside edge and proceeds up through the jacket and out into the cylinder head assembly through jumpers. The student will observe a cylinder liner and water jacket parts disassembled.

See the engine cross section shown in Figure 3-42. It should be noted that the liner jacket sits in a seat on the top of the cylinder block. The liner in turn sits in a seat at the top of the jacket. The cylinder head sits on top of the liner and the cylinder head studs, properly tightened holds all of these parts together in the engine cylinder block.

3.3 Main Bearing Assembly

Using the 2-cylinder Pielstick engine and a section of the crankcase, the student will observe how the main bearing are installed into the engine. The main bearing is an assembly of two parts, the upper and lower halves. Each half is a steel backed tri-metal unit. The steel backing has a layer of copper material plated onto the backing. The copper in turn has a layer of lead/tin material which is the bearing surface. Properly lubricated, there is no metal to metal contact between the crankshaft journal and the bearing surface. The softer lead/tin material helps the bearing 'wear in' and accommodate the crankshaft surfaces. The copper material is primarily there to conduct away the heat generated in the bearing and to become a bearing material should the lead/tin layer be worn away. The lube oil is vital not only to lubricate this and other bearings but also to conduct heat away from the bearings. See Figure 3-47.

The bearing bore is made such that it can be taken apart. Otherwise, there would be no way to install the crankshaft into the engine. The bearing bore in the block consists of two parts, as shown in Figure 3-46. The bottom half of the bearing bore is called the 'saddle'. The top half of the bearing bore is called the 'cap'. The saddle is held to the engine bearing saddle block by studs and nuts, as shown. These studs are very strong and are tightened to the point that they will not yield/deflect/stretch any further due to the firing loads from the cylinders plus the crush pressure from the loading of the bearing cap.

Each half of the main bearing is generally referred to as the bearing shell. In order for the main bearing shells to be retained in the bearing bore formed by the cap and saddle, they must be installed with a very high loading. The bearing shell is made 'too long' for the half of the bearing bore it is to occupy. When two shell are installed, if the cap and saddle were not tightly held together, there would be a gap between them due to the bearing shells being too long. To close the gap, the bearing cap is pressed down by a special cap nut assembly so that the clearance between the cap and saddle is closed. This creates enough stress in the bearing shells to cause them to adhere to the bore wall such that they will never turn in the bore.

The special cap nut assembly used to load the cap is a combination of a nut and stud which contains a piston. There is a port in the nut assembly that is connected to a hydraulic pump. Hydraulic pressure is pumped up to about 8000 to 10,000 psi. This causes the nut assembly, the cap and the cathedral section of the bearing cap to be compressed against the engine saddle block. A nut on the assembly is then tightened finger tight plus one flat. The hydraulic pressure is then relieved but, because the nut is now holding the assembly in the loaded condition, the load on the cap remains. Interestingly, this special nut assembly also acts to communicate lube oil from the lube oil header into the main bearings.

Because of the tremendous load on the cap assembly in the main bearing system, it has been noted that if a bearing fails, it usually results in a gap developing at either the bearing shell parting line or the parting line between the cap and the saddle. One method of bearing inspections is to determine that a .001 feeler gauge will not go into the parting line between the cap and saddle or between the saddle and the engine saddle block. If a feeler can be inserted, the bearing is probably failed and the assembly should be taken apart for further inspection.

3.4 Pielstick Piston and Connecting Rod Assembly – (See Figure 3-19)

The students, with the assistance and direction of the instructor, will disassemble a PC piston and connecting rod assembly. The following steps are involved: (With the piston crown sitting on the floor)

1. Remove the keeper rings from the ends of the wrist pin, in the piston wrist pin bore.

2. Remove the wrist pin and pull the connecting rod out of the piston.

3. Examine the wrist pin, the wrist pin bushings in the connecting rod and the wrist pin bores in the piston.

4. Remove the nuts from the studs that hold the piston skirt to the piston crown. Pull the piston skirt from the piston crown.

5. Examine the fits on the piston and in the crown. Examine the ‘O’ seal ring. Examine the oil feed holes in the piston to be sure they are clear.

6. Reassemble the piston to the crown and tighten and torque the nuts.

7. Reassemble the connecting rod into the piston and install the wrist pin and retaining clips. See that the piston moves freely on the connecting rod.

Note that the piston rings (piston ring grooves) on this piston are all at the top of the piston. The three compression rings install into grooves of the crown portion of the piston. The oil control rings install in the grooves on the piston skirt portion.

3.5 Pielstick Engine Power Output Shaft Gear-Drive Support Systems

The Pielstick engine power output shaft gearing provides power to engine support systems as shown in Figure 3-48. The camshafts are driven through the flexible drive gears t damper oscillations caused by engine cylinder firing and camshaft action of its loads. The camshaft bearing is illustrated in Figure 3-49.

The cam shaft is driven by a series of gears mounted at the rear of the engine (power take off end). The gear train for this engine is shown in Figure 3-48. The gear on the camshaft is a flexible drive gear intended to remove the torsional oscillations created both by the ‘firing’ of the cylinders and by the torque oscillations created by the operation of the injection pumps on the camshaft. The camshaft drive at full power is shown in Figure 3-50.

Figure 3-51 shows an exploded view of the parts of this flexible drive gear arrangement. The flexible drive gear assembly is hydraulically dampened by the entrance of engine lubricating oil in the assembly. The gear train of the engine not only drives the cam shaft, but also provides power to drive the water pump(s), lube oil pump, fuel pump, over-speed governor and the speed regulating governor.

Figure 3-52 shows the parts of the over-speed governor assembly. Similar to the OP engine over-speed governor, this governor/trip mechanism consists of a flyweight that is acted upon by centrifugal force. When the engine is at normal operating speed, a spring holds the flyweight against the shaft to which it is mounted. If the engine experiences an over speed condition, the centrifugal force on the flyweight overcomes the spring force and the flyweight moves out and hits a pawl. When the pawl moves off center, it allows a spring to push a plunger which operate a switch and/or a hydraulic valve which then causes the shutdown control cylinder to operate, shutting off the fuel to the cylinders.

HANDS-ON SESSION 4

4.0 ENGINE CRANK-LEAD AND FUEL INJECTION TIMING FOR THE OP ENGINE

Purpose

This session will complement classroom instruction of Chapter 3 and 4 by providing hands-on instruction for measuring and setting crank-lead in the OP engine thereby proper intake combustion and exhaust timing and providing hands-on instruction for measuring and setting fuel injection pump timing.

Learning Objectives

Upon completion of this lesson you will be able to:

1. Understand the reason for crank-lead in the OP engine.

2. Understand how crank-lead is measured and reset by means of the vertical drive gears.

3. Check and set fuel injection pump height for proper fuel injection timing (applicable to all engines).

4.1 Checking/Setting the Crank-lead

These exercises use the 6-cylinder OP engine unit in the work area. This engine assembly is complete with the crankshafts, connecting rods, pistons, cylinders, camshaft with its gear drive mechanism, and injection pumps.

The crank-lead establishes the point at which the air intake ports open with respect to the lower crankshaft position by changing the angular relationship between the upper and lower crankshaft. The connecting vertical drive gear coupling hub assembly can be used to change their relationship between the two crankshafts. Refer to Figure 2-30.

The vertical drive is connected to the crankshaft by sets of bevel (miter) gears at each end. Large changes in the crank-lead can be made by changing the tooth of the pinion gear that is engaged with the gear on the crankshaft, but this does not allow for small changes (less than about 5 degrees). Therefore, the joint at the coupling hub is used to allow the vertical drive to be adjusted.

On some vertical drive designs, this is done by having a cone on the mating parts, the cone being locked up by bolts that hold the parts of the cone tightly together. On another design, there are 23 bolts in the lower coupling joint. By a combination of the number of teeth on the vertical drive pinions and the number of bolts, it is possible to find a position within one-half degree, where the 23 bolts can be installed when the crank-lead is as desired.

With directions from the instructor, students will check or set the crank-lead by using the following procedure:

1. Locate the flywheel and flywheel pointer at the rear of the engine block. Locate the barring drive and use the ratchet wrench provided to turn it. See Figure 3-53.

2. If not already removed, remove the top

cover from the upper crank-line (or remove the inspection covers from the control side of the top cover). Remove the lower crankcase inspection covers from both sides of the engine (at least for the No. 1 cylinder).

3. Locate the timing flats on the crankshaft throw counterweights. See Figures 3-54 and 3-55. These should be evident when the crankshaft is rotated to a position where the flywheel pointer reads (or is near) zero.

4. Using a bubble type protractor, determine that the crankcase is level by placing the protractor on one of the air receiver compartment flanges. If not level, set the protractor so that the bubble is 'level' when the protractor is flat on the flange (vertical surface). Remember the direction in which the protractor is being used for reference in future use.

5. Rotate the engine until the protractor on the timing flat on the lower crankshaft shows the lower crankshaft is at the inner dead center position (IDC).

6. Read the flywheel pointer. It should read 'zero'. If not, recheck the bubble protractor to be certain it is set properly (per Step 4 above) and that the crankshaft is in the correct position. If the pointer still reads other than 'zero', then loosen and reset the pointer to read exactly 'zero'.

7. Rotate the engine in normal direction of operation (counterclockwise on the lower crankshaft as viewed from the flywheel end), until the timing flat on the number one throw of the upper crankshaft (aft web) is vertical using the bubble protractor. Reference Figure 3-55.

8. Read the position of the flywheel pointer (on the lower crankshaft) when the upper crankshaft is so positioned. The pointer should read 12 degrees (or a number set by the instructor).

9. If the flywheel pointer is not at the correct reading, then the crank-lead is not correct. If not correct, depending on the type of vertical drive coupling, do one of the following:

   a. Loosen the bolts that hold the taper cone together and using the bar provided to break the cone loose, OR,
   b. Undo and remove the 23 cap-screws on the lower hub flange coupling.

10. Once the coupling is loose, continue to turn the lower crankshaft until the flywheel pointer is at the correct crank-lead. If it was necessary to turn the crankshaft clockwise, then turn it too far and come back to the correct position in the counter-clockwise direction.

11. Once the lower crankshaft is in the correct crank-lead position, lock up the vertical drive coupling by either:
    a. Tightening and torquing the bolts on the ring that locks the taper cones together, OR.
    b. Installing the 23 bolts in the lower coupling hub flange.

NOTE: It may be necessary to turn the lower crankshaft through several rotations (always CCW) in order to find the position at which the 23 bolts can be inserted at the correct crank-lead (plus or minus ½ degree). Tighten and torque the bolts.

This completes the check and/or setting of the crank-lead.

4.2 Checking High Point of CAM

It is necessary to complete the crank-lead check before this procedure. The injection timing is always referenced back to the lower crankshaft, but the camshafts are driven off the upper crankshaft. Therefore, any change in the crank-lead will result in a change in the injection timing.

The injection timing consists of two steps. First, the camshaft must be properly timed. Then the point at which injection starts as the injector plunger moves up the cam flank must be set properly. Before the injection timing can be set, the cam position must be checked/set.

The cam has two flanks which are symmetrical about the center of the high point of the cam. By tramming the cam, the location of the high point of the cam can be found. This high point is used to set the cam to the correct position with respect to the crankshaft. Only the cams for the No. 1 cylinder are used for this. The other cams are located, during manufacture and assembly of the camshaft, to align properly with the cam for the No. 1 cylinder.

The following steps are required to check/set the high point of cam. Refer to Figures 3-56 through 3-59.

1. If not already removed, remove the high pressure tubing line between the injection pumps and the nozzles on the No. 1 cylinder (both sides).

2. Remove the discharge fitting, check valve and spring on the No. 1 injection pumps (both sides).

3. Install the stroke gage on the #1 OCS pump. In some cases, the stroke gage may be equipped with a dial indicator. In the following steps, the gage will be aligned or matched when the dial indicator reading is the same as the previous reading. Refer to Figure 3-58.

4. Turn the flywheel in the normal direction of rotation until the stroke gage ‘lines’ align with the plunger line going in a downward stroke. STOP when the lines are aligned.

5. Record the flywheel pointer reading at which alignment was found.

6. Continue to turn the engine (in direction of normal rotation) until the stroke gage goes all the way down and comes back up until the lines are again aligned. STOP when the lines are aligned.

7. Record the flywheel pointer reading at which this second alignment was found.

8. If the first number is between say 340 and 360 degrees, first subtract the number of degrees between 360 and the first reading from the second reading. Then divide the resulting number by 2 to obtain the high point of the cam. If the first number is greater than zero, then add the two numbers

together and divide the result by 2 to find the average, which will be the high point of cam. See the charts at the bottom of Figure 3-57.

9. Move the stroke gage to the No.1 Control Side (CS) pump and repeat steps 1 through 8 above.

10. If the CS cam does not match the OCS cam, slip the CS cam sprocket the number of degrees to match up with the OCS cam. If the CS cam is 'too far advanced', this means that the CS high cam figure is a lower number than the OCS high cam figure. To change, loosen the four (4) nuts or capscrews one turn on the CS sprocket and turn the flywheel in rotation to number of degrees change desired. Re-tighten the nuts or capscrews.

11. Repeat Steps 4 through 8 as required to match the figures.

12. If the CS cam is 'too far retarded', this means the CS high cam number reads higher than the OCS high cam figure. To change, loosen the four (4) nuts or capscrews one turn on the CS sprocket, and turn the flywheel against rotation the number of degrees change desired. Re-tighten the capscrews or nuts.

13. Repeat Steps 4 through 8 as required to match the figures.

14. With both camshafts reading the same high cam number, you now have to set the high cam to agree with the technical manual setting. To do this, rotate the external timing device to get 43 degrees high cam after Inner Dead Center (IDC). Turn the nut counterclockwise to advance timing, (making the high cam number lower). Turn the nut clockwise to retard the timing, (making the high cam number higher). NOTE: One turn on the timing nut equals 1.5 degrees of rotation.

4.3 Setting the Injection Pump Timing

The above steps put the high point of cam in the correct position, which influences the timing on all of the cylinders. It is also necessary to check the point of port closure on the injection pumps to time each cylinder as follows:

1. Using the same stroke gage as used in the steps above, turn the engine in rotation to the point of high cam for the respective cylinder in its firing order.

2. With the cam for that cylinder at high point, the end of the stroke gage plunger should be flush with the end of the gage.

3. Measure the amount of protrusion or amount of recess of the gage plunger. If there is a protrusion, then additional fuel pump shimming is required. If the gage plunger is recesses, then shims must be removed.

4. Remove the injection pump assembly from the tappet assembly.

5. Determine the thickness of the present shim pack and add or subtract the shims as determined in Step 3. Always try to obtain the minimum number of shims that will result in the desired shim pack thickness. Refer to Figure 2-39.

6. Reinstall the injection pump and again check the stroke gage. If the exact number of shims can not be obtained, it is better that the plunger be slightly recessed at high cam.

Since this is an exercise only, it is only necessary to demonstrate this technique on one injection pump. In actual practice, this must be done for each injection pump on both sides of each cylinder on the OP engine.

Similar procedures are applicable to other engines. First, the cam must be timed to the crankshaft and then the pump must be timed to the individual cylinder cam.

One other setting on the injection system needs to be check/set. On the Control Side (CS) injection pump of the number one (1) cylinder, set the distance from the injection pump control rod collar to the pump body to 2-3/16 inches, as shown on Figure 2-36. Figure 3-60 shows the fuel control system from the governor output shaft to the fuel pumps' pinion gear for each cylinder. Once No. 1 CS pump is set as shown, set all other pumps on both sides of the each cylinder so that they read the same rack reading on the each pump. These settings provide for each cylinder receiving the same amount of fuel during each injection to produce equal balanced power output.