WAR DEPARTMENT TECHNICAL MANUAL

TM 55-1105

ENGINE, DIESEL, MARINE, ENTERPRISE MODELS DMQ-36 and DMQ-38

Property of
R. Desrumeaux

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This manual covers the DMQ-36 model engine supplied under Contract W-2789-tc-233, of which the lowest serial number is 42277.

This manual also covers the DMQ-38 engines supplied under Contract W-1311-qm-342, of which the lowest serial number is 42003.

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SECTION I
GENERAL DESCRIPTION

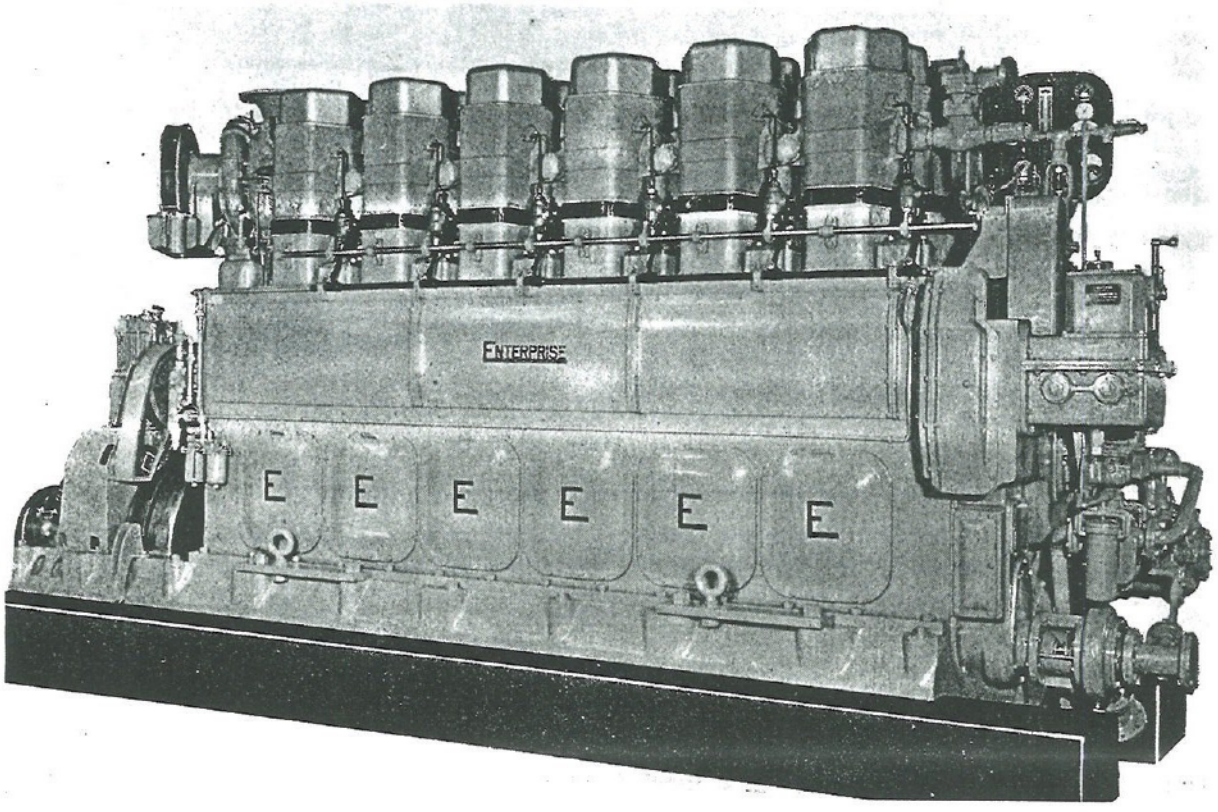

FIG. 1. ENTERPRISE DMQ-36 DIESEL ENGINE

This is an Enterprise DMQ-36 Diesel Engine, one of the two engines whose operation, maintenance, and repair are explained in this manual. It is a six-cylinder, four-cycle engine with 16″ pistons and a 20″ stroke.

1. SCOPE OF MANUAL. Instructions in this manual cover the operation and maintenance of both a six-cylinder and an eight-cylinder Enterprise engine of the DMQ class. Both engines are turbocharged with Buchi-type gas turbine turbochargers. Since both engines are in the same class, they use the same cylinder sizes. With slight differences, operation and maintenance of the engines are the same. In each section of this manual up to Sect. XXI, instructions pertain to the six-cylinder model. In Sect. XXI the differences found in the eight-cylinder engine are explained. In using this manual for the operation of an eight-cylinder engine, instructions given for the six-cylinder model will be followed, referring to Sect. XXI for differences in construction, operation, or maintenance. The Turbochargers are integral parts of the engines.

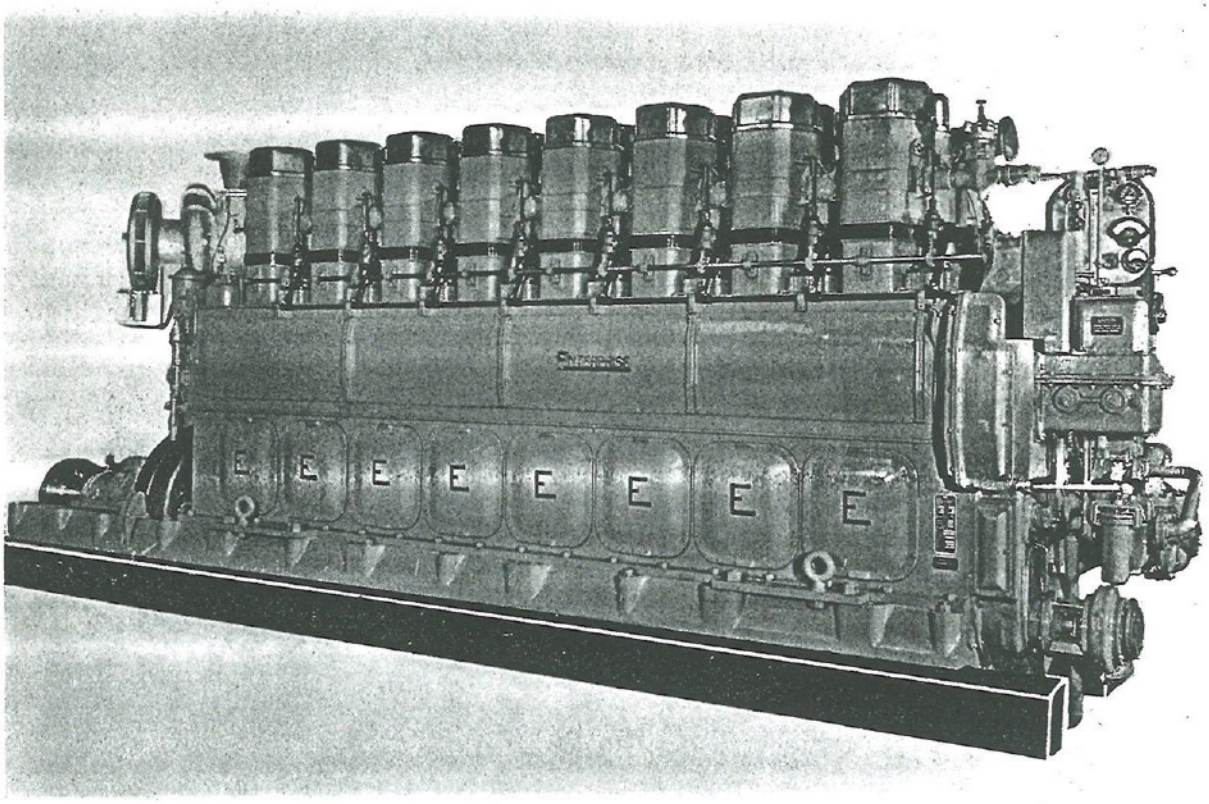

FIG. 2. ENTERPRISE DMQ-38 DIESEL ENGINE

This is an Enterprise DMQ-38 Diesel Engine, whose operation, maintenance, and repair are also explained in this manual. The two engines are practically identical except that this engine has eight cylinders. The differences between the two engines are explained in this manual.

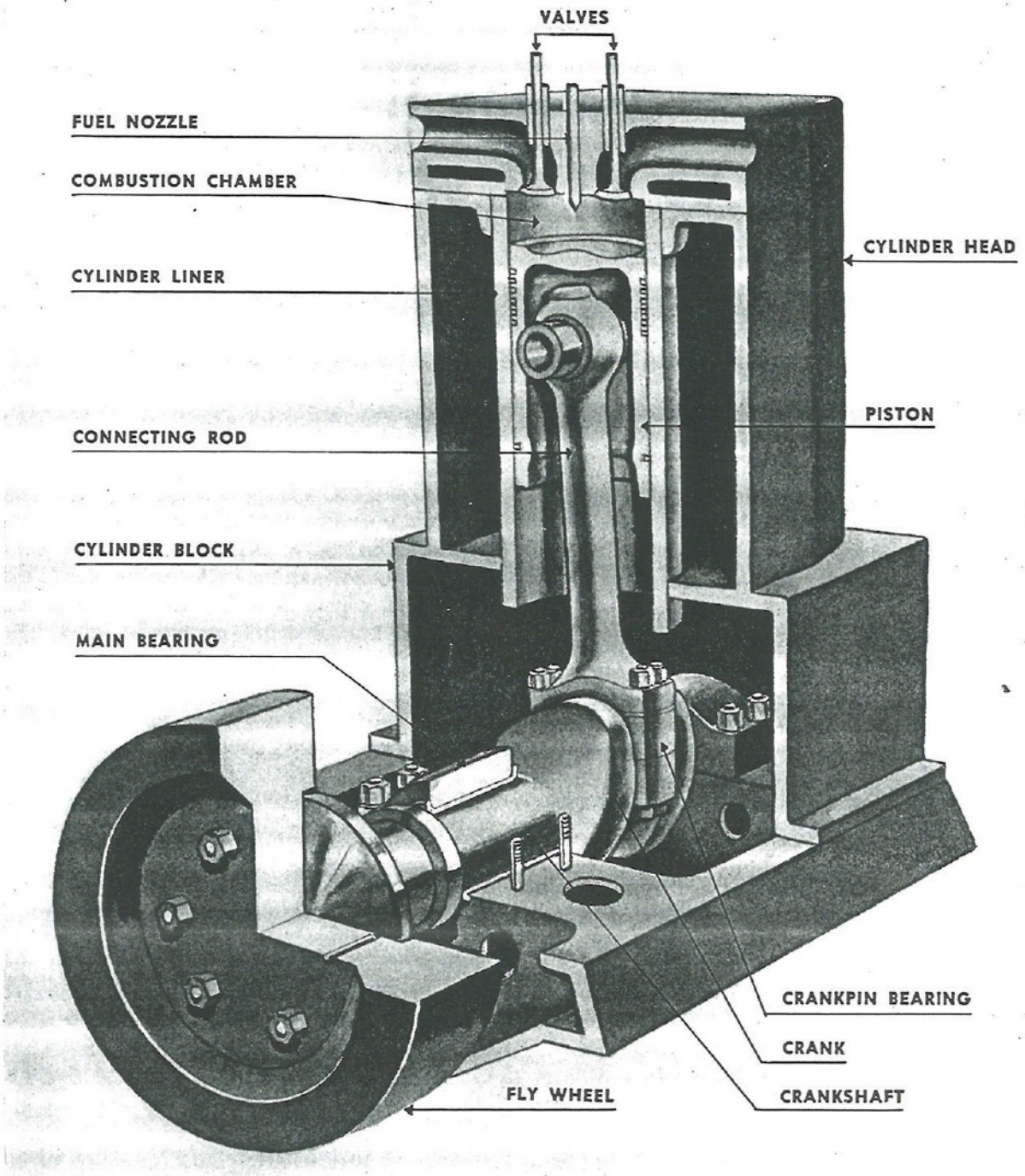

Fig. 3. One-Cylinder Engine

SECTION II
PRINCIPLES OF DIESEL OPERATION

2. BASIC PRINCIPLES. ***a.*** Like other internal combustion engines, the Diesel converts heat into mechanical force by burning fuel in its cylinders. Diesel fuel is an oil similar to kerosene, but heavier and usually darker in color. When Diesel oil burns, it unites with the oxygen and new substances are formed. They are carbon dioxide, water vapor, nitrogen and any oxygen not needed to burn the oil. After they have cooled down, the gases formed by the burning of fuel will fill about the same space as the air and fuel originally filled. But at the time of burning the gases generate tremendous heat. Heating any gas will cause it to expand, and this natural action is often referred to as the energy of heat. If the burning process takes place in the open, the expanded gases spread out. If the combustion is in a closed chamber, the heated gases will exert pressure against the chamber walls.

b. In the Diesel engine, expansion of the hot gases is controlled and made to produce motion which performs work. In Fig. 3 a simple engine is shown cut away to show the parts. The round cylinder is closed at one end by the cylinder head. Inside the cylinder a piston, sometimes called a power piston to distinguish it from pistons used in auxiliary equipment, is free to slide up and down the cylinder. The piston is hollow, but closed at the top by the piston crown. The cylinder head, cylinder, piston and piston crown enclose a space called the combustion chamber. The cylinder head and the piston head are solid. The cylinder head cannot move, but the piston working up and down can make the compression chamber larger or smaller. When the piston is up as far as it can go, it is said to be at top dead center and the combustion chamber is at its smallest size. The movement of the piston is controlled because it is connected to a crank which is part of a crankshaft. The connecting rod is fastened at the lower end to the crankshaft by a bearing, while the top end of the connecting rod is fastened to the piston by a piston pin. This piston pin can be seen in about the middle of the piston. Steel rubbing against steel will tend to stick fast, so bushings and bearings are built into the engine illustrated in Fig. 3. All of these parts move fast. A bronze bushing encloses the piston pin and, since bronze is softer than steel, it will not cause the steel piston pin to stick. The crankshaft and the connecting rod also move. Therefore, bearings of soft Babbitt metal are used to surround these parts where they connect to prevent steel from rubbing on steel.

c. The movement of the piston from the top to the bottom, or from the bottom to the top, of the cylinder, is called a stroke. In Fig. 3 the piston has just come to the top of its stroke. The combustion chamber was filled with air at high pressure—about 400 pounds per square inch. When air is compressed it becomes hot. Into this hot air a small amount of Diesel fuel has been sprayed. The Diesel fuel starts to burn. Immediately the hot gases produced by this burning increase the pressure in the combustion chamber to about 600 pounds per square inch. The piston on the Enterprise engine is 16 inches across the top. This means that the total area of the piston top is 201 square inches. Multiply this area by 600 pounds per square inch, and the total pressure against the piston becomes 120,600 pounds. This pressure pushes against the cylinder head, but the cylinder head is solid and will not move. The expanding gases are prevented from escaping between the piston and the cylinder by rings on the piston which seal any

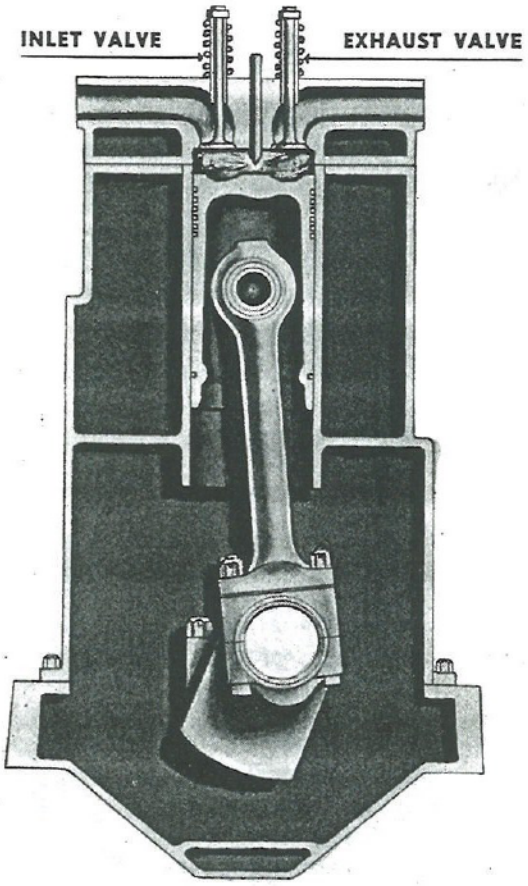

Fig. 6. Piston on Power Stroke

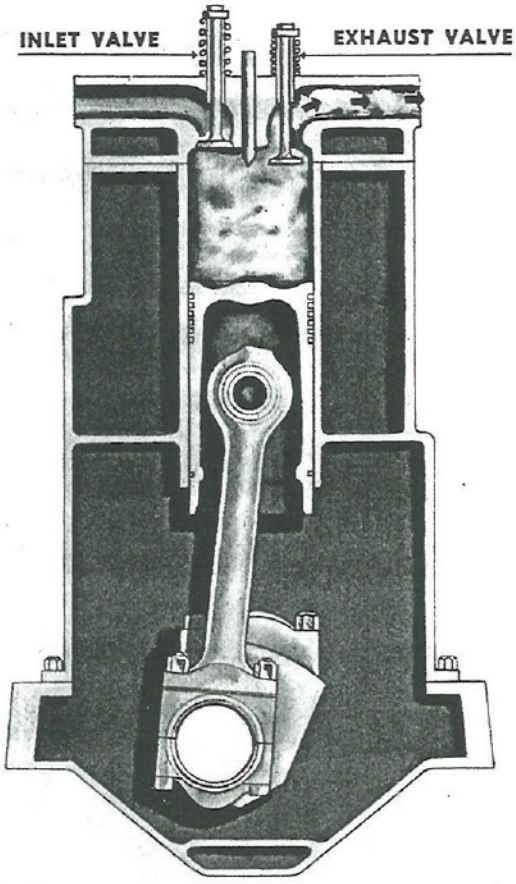

Fig. 7. Piston on Exhaust Stroke

shut. The piston now starts upward on the compression stroke. As it moves upward it forces the fresh air into a space that continually grows smaller until the air reaches a pressure of about 400 pounds per square inch. The more the air is compressed, the hotter it becomes until it reaches a temperature of about 1000 degrees Fahrenheit.

c. Power Stroke. When the piston nearly reaches the top of the cylinder, as shown in Fig. 6, both the intake and exhaust valves remain closed. However, another valve, called the spray valve, opens to admit a fine spray of Diesel fuel. This is forced into the hot compressed air under high pressure. As soon as this spray hits the hot air it is set on fire. The burning of the fuel creates an expansion of hot gases, and this expansion forces the piston down.

d. Exhaust Stroke. As the piston moves down, the exhaust valve, which had remained closed during the other three strokes, opens when the piston is almost at bottom dead center, as shown in Fig. 7. The compressed gases rush out of the opened exhaust valve and all the remaining gases are forced out as the piston travels up in what is called the exhaust stroke, or sometimes the scavenging stroke. When the piston reaches the top again, the combustion chamber is cleaned of the combustion gases and ready to draw in fresh air when it repeats the intake stroke on the next downward movement. The cycle of four strokes starts over again.

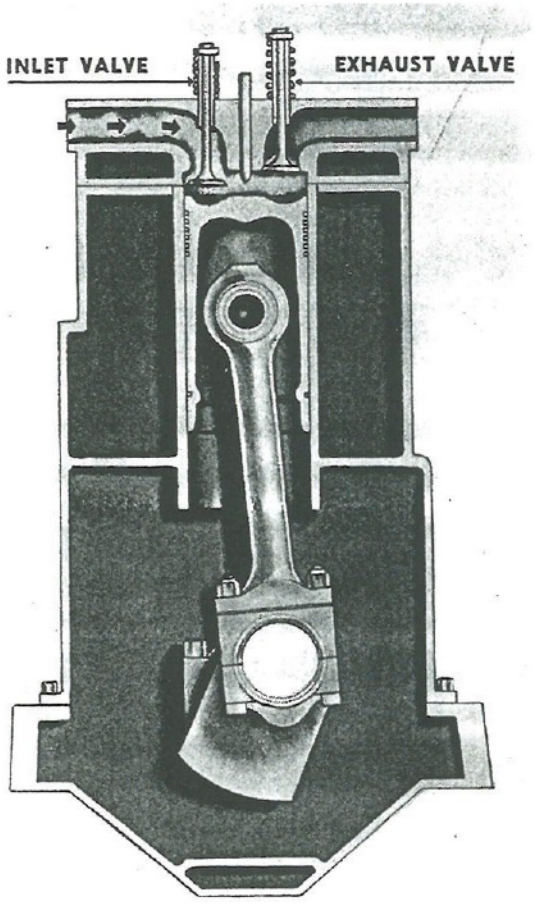

Fig. 4. Piston on Intake Stroke

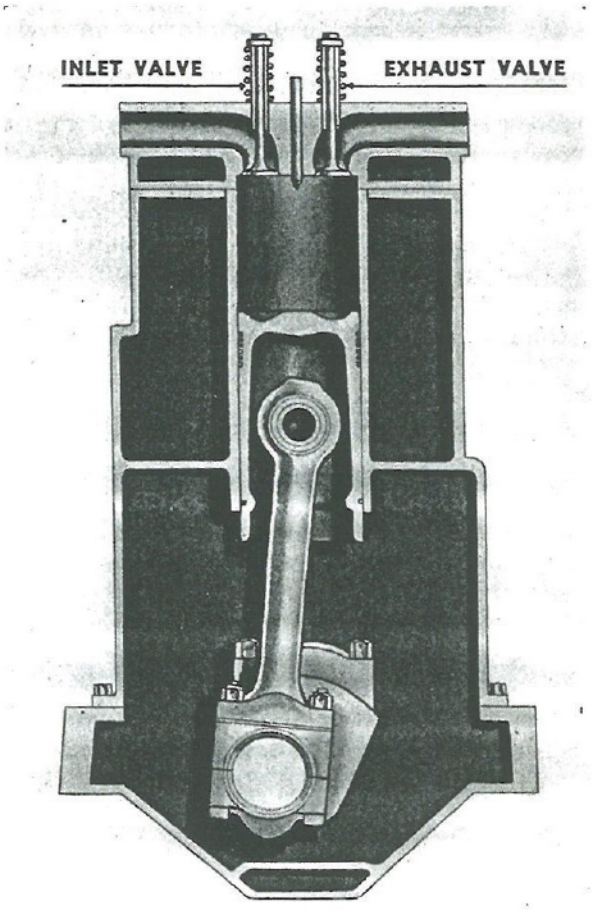

Fig. 5. Piston on Compression Stroke

possible opening at that point. However, the piston will move downward. As the piston is forced down, it places pressure on the connecting rod, and this, in turn, forces the crankshaft to turn. Thus, the heat energy created by the burning of Diesel fuel has been forced to turn a crankshaft, with great motion and force. How the air was compressed to 400 pounds per square inch before the combustion, what happens to the gases when the piston reaches bottom dead center, where more fresh air will come from, and how the fuel got into the combustion chamber at the proper time are explained in subsequent paragraphs.

3. FOUR CYCLES. The Enterprise engine is called a four-cycle engine. This means that as the piston moves up and down in the cylinder it enters four different phases or strokes. These four strokes, intake, compression, power and exhaust comprise the four cycles.

a. Intake Stroke. The piston shown in Fig. 4 is at top dead center. The exhaust valve is closed but the intake, or inlet, valve is opened. As the piston starts downward it draws in fresh air through the opened intake valve. Sometimes this stroke is called the suction stroke, because a large quantity of air is sucked into the cylinder.

b. Compression Stroke. When the piston reaches the bottom, as shown in Fig. 5, it has drawn in a large amount of air, and the intake valve closes while the exhaust valve remains

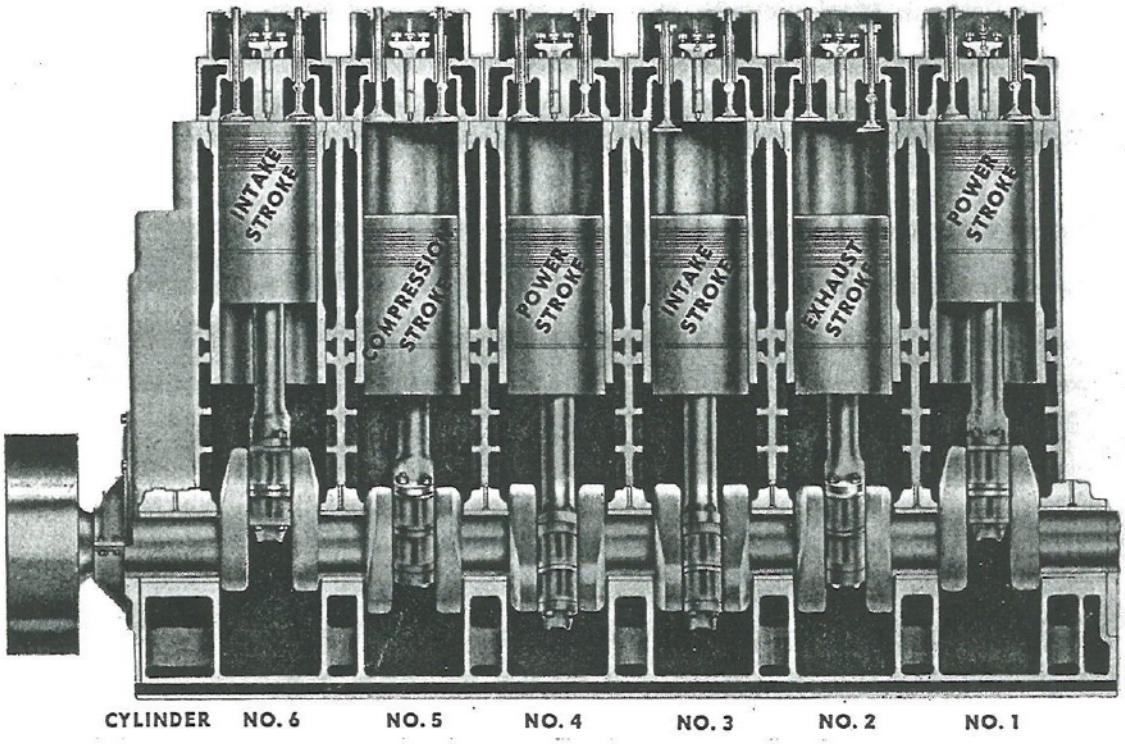

Fig. 8. Pistons in Position

4. THE FLYWHEEL. Only one of the four piston strokes produces power. The other three, especially the compression stroke require power. This power is supplied by the flywheel. The engine has a heavy flywheel which operates on the principle of momentum. Momentum is a term used to describe the fact that a heavy body, once put into motion, will continue moving for an extended period. The flywheel on the engine is speeded up, on the power stroke of the cylinder, and more than enough power is available for the operation of the other three strokes.

5. ADVANTAGES OF MANY CYLINDERS. One-cylinder engines will not produce an even flow of power because the flywheel slows down too much between power strokes of the piston. However, on engines having many cylinders, the power stroke in each cylinder occurs at close intervals so that the flywheel is being continually turned. In a six-cylinder four-cycle engine one piston is on a power stroke at every one-third of a turn. In an eight-cylinder engine the power strokes are spaced for every one-fourth of a turn.

Fig. 8 illustrates what is taking place in a six-cylinder engine at the exact moment the fuel is ignited in the combustion chamber of the No. 1 cylinder. The action is as follows:

No. 1 cylinder is just starting the power stroke with both valves closed.

No. 2 cylinder is on the exhaust stroke with the exhaust valve fully open.

No. 3 cylinder is on the intake stroke with the intake valve fully open.

No. 4 cylinder is on the latter part of the power stroke with both valves closed.

No. 5 cylinder is on the compression stroke with both valves closed.

No. 6 cylinder is on the first part of the intake stroke with the intake valve just opening.

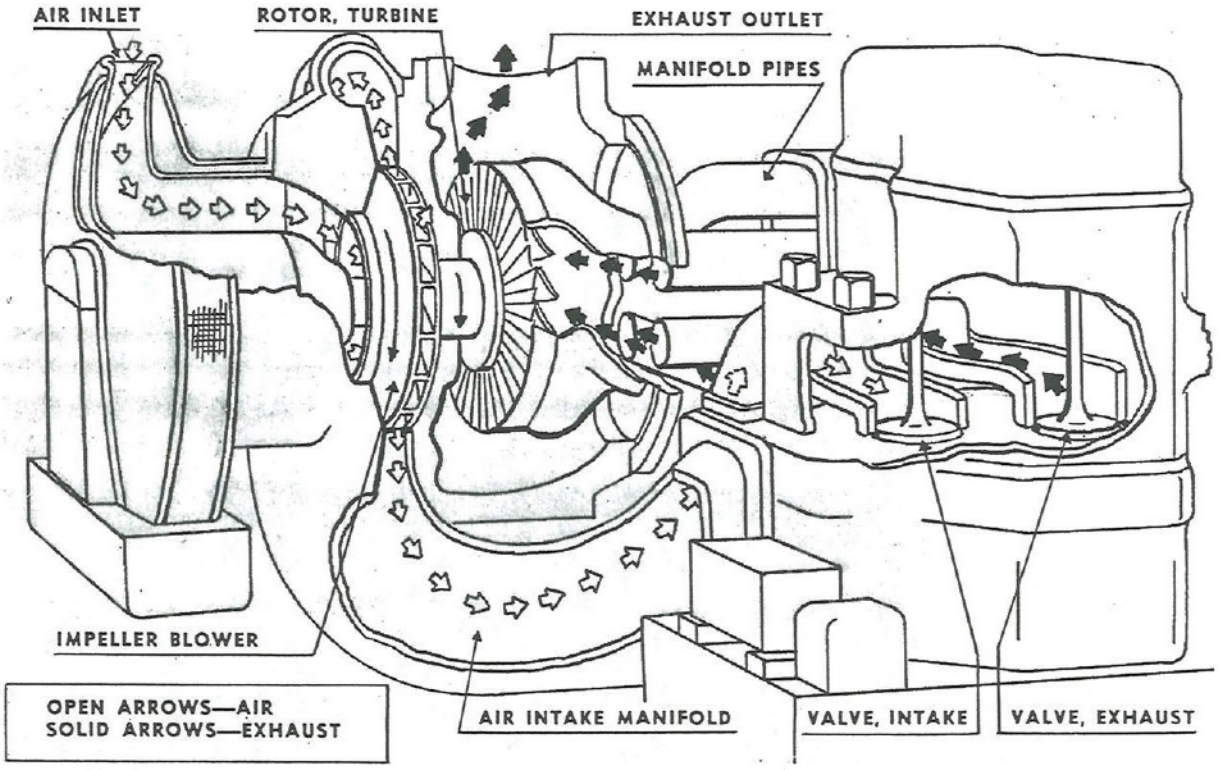

Fig. 9. Operation of Turbocharger

The flywheel on a six-cylinder engine may be lighter in weight than one on a one-cylinder engine because not as much momentum is required due to the frequency of the power strokes. This results in a smoother running engine.

6. TURBOCHARGING. *a.* As explained in par. 3 d, the intake or suction stroke of the cylinders draws in the air which supplies the oxygen that combines with the fuel oil to form an explosive mixture. Turbocharging increases the quantity of air that is taken into the cylinders and therefore increases the amount of fuel that can be burned on the power stroke. This results in the engine producing more power. This process is often called supercharging.

b. Operation of the turbocharger on the Enterprise engines is shown in Fig. 9. The exhaust gases leave the cylinders with great force. Because their expulsion from the cylinders is staggered the gases do not come out in a steady stream, but on impulses. In addition, the gases are hot. This combination of heat and pressure creates impulses which contain a large amount of energy. In order to harness these exhaust gases for useful work, they are conducted through manifold pipes to the rotor of a gas-turbine. There the forces of the exhaust gases turn the rotor at high speed before escaping out of the exhaust.

c. This rotor is directly connected by a shaft to an impeller blower enclosed in a separate housing. The force of the exhaust gases which spin the rotor drive the impeller blower which draws in air from the atmosphere and forces it under low pressure into the engine air intake manifold.

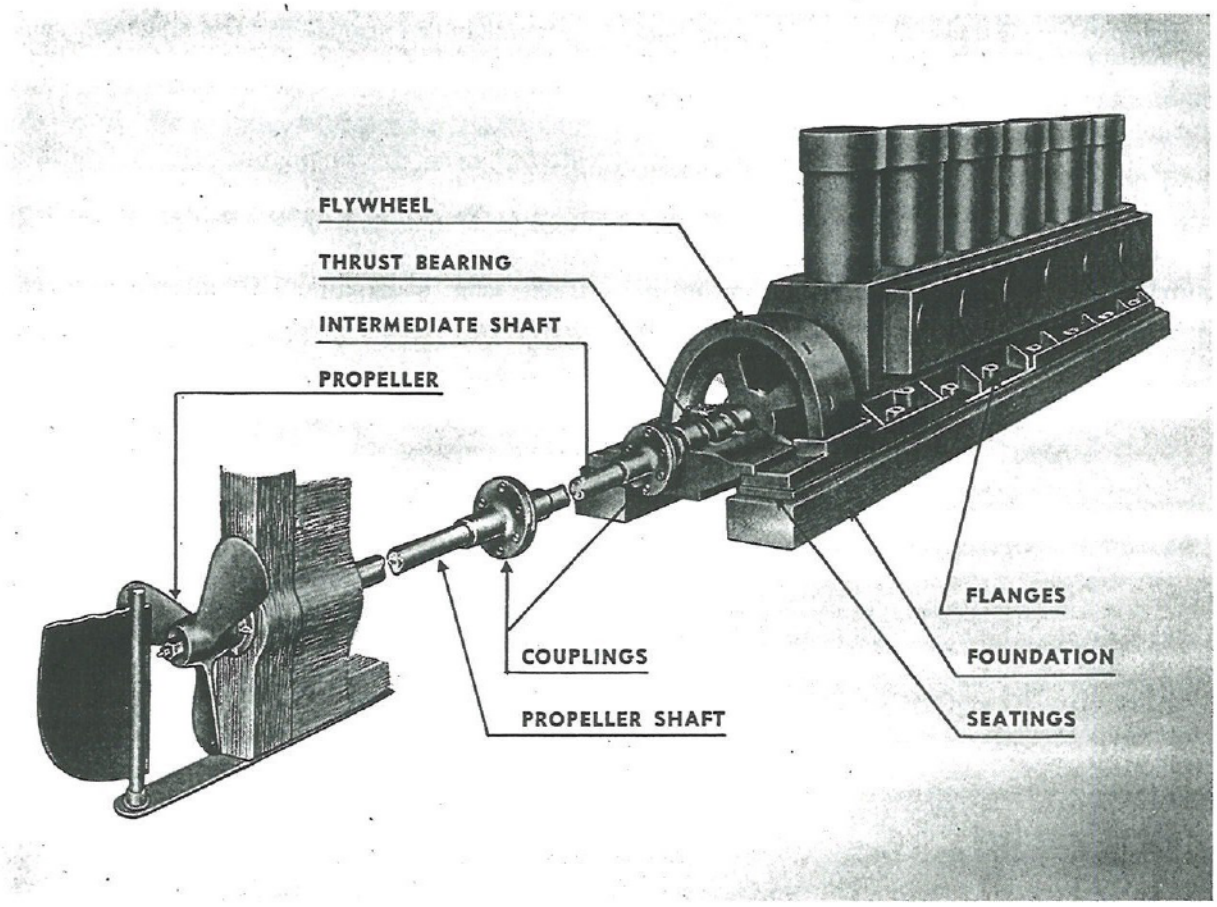

Fig. 10. Engine Installed in Vessel

d. When the pistons are on the intake strokes, they draw from this supply of air instead of taking in air at the normal atmospheric pressure. This results in a larger quantity of air entering the cylinders, enabling them to burn larger charges of fuel. This increases the pressure on the top of the pistons and creates more power without any increase in the speed of the engine.

e. The operation of the turbocharger is automatic. When the engine needs more power, the fuel system sends more fuel into the cylinders. The burning of this additional fuel results in a heavier volume of exhaust gases. The increased volume of the exhaust gases turns the rotor fan at a faster speed and thus the speed of the impeller blower is increased. More air at higher pressures is delivered to the air intake manifold and the cylinders can draw in more air to burn the additional amount of fuel.

7. FOUNDATION AND SEATING. In Fig. 10 a Diesel engine is shown installed in a ship. Each side of the engine base has a flange. These flanges are secured to the engine seating built on the top surfaces of the foundation, and they are a part of the ship's construction. The weight of the engine is spread over a large area.

8. MAIN BEARINGS AND JOURNALS. Fig. 3 shows that the crankshaft is supported by, and rotates in, main bearings. Each bearing is made up of two halves. The part of the crankshaft enclosed in a main bearing is called a main journal. Any part of a shaft that works inside a bearing is called a journal.

9. PORT AND STARBOARD ENGINES. Sometimes two engines are installed in one ship. If each engine turns a separate propeller, the ship is called a twin-screw ship. The engine on the left side of the ship when facing the front end or bow is called the port engine, and the starboard engine is on the right side. The engines are built or installed so that, for ahead propulsion, the propellers turn outboard when looked at from above.

10. AUXILIARY EQUIPMENT AND MECHANISM. In order for the piston to develop power, auxiliary equipment and mechanism, and systems, are installed in the engine to furnish fuel, air, lubrication, cooling, and other needs. Each item is explained in subsequent paragraphs of this manual.

SECTION III
LUBRICATION OF ENGINE

11. NEED FOR LUBRICATION. In every moving part of an engine two pieces of metal rub together. This friction produces heat. If this heat is developed over even a short period, it may rise to a point where the metal will melt and cause the parts to fuse together. This is known as "freezing." To prevent metal from rubbing against metal, all working parts in an engine are fitted so that a small space, or clearance, is left between them. This is done so that oil can be forced into the space. This oil, which is constantly supplied, serves as a "cushion" which keeps parts from grinding. At the same time, it carries away part of the heat generated by the engine. The lubrication system and the engine cooling system (discussed in Section IV) are the only means of keeping the engine at proper working temperatures. Neither can do the work alone; the two must work together. If the engine fails to receive proper lubrication serious trouble results.

12. LUBRICATION SYSTEM. Basic parts of the engine lubrication system are:

a. A storage tank to hold oil needed to replace lubricating oil consumed in operation.

b. A service tank to supply lubricating oil needed in the system.

c. A pump to force oil into the engine.

d. A pump to recover oil from the engine after it is used.

e. A filter to clean recovered oil for re-use.

f. A cooler to cool recovered oil for re-use.

g. Necessary piping and tubing to connect these parts with valves needed to control the supply of oil.

h. Gauges and thermometers that indicate pressures and temperatures for the guidance of the operator.

13. HOW THE SYSTEM WORKS. Lubricating oil passes through the engine many times before it becomes too thin or "breaks down" to a point where it does not possess sufficient body to provide the proper cushion between the working parts. The oil travels in a circuit described as follows:

a. The moment the engine starts, the lubrication oil pumps begin operating. Oil is drawn from the lubricating oil service tank, is forced through a fine mesh screen, and enters the engine. There it circulates under pressure to all the working parts, and then drains down into the sump, or base, of the engine. Once in the sump, the oil is recovered from the lowest point by another pump called a sump, or scavenger pump. This pump draws the lubricating oil through a coarse metal strainer which removes any large pieces of foreign material.

b. Since the recovered oil usually contains small particles of dirt, water, and other foreign matter which would injure the wearing surfaces of the engine, the oil is forced through filters. The recovered oil emerges from the filters with these foreign elements removed. The oil still contains the heat it drew off from the engine. To lower its temperature, the oil must pass through a lubrication oil cooler before it returns to the service tank for recirculation through the engine. When the lubricating oil "breaks down" after repeated circulations through the engine, it no longer is adequate to protect the engine and it must be changed. The proper time to change lubricating oil is explained in Section VII.

14. PARTS OF SYSTEM. The various parts of the lubricating oil system, with the exception of the oil storage tank and the service tank, are shown in Fig. 11. Operators will become familiar with the location of the parts illustrated.

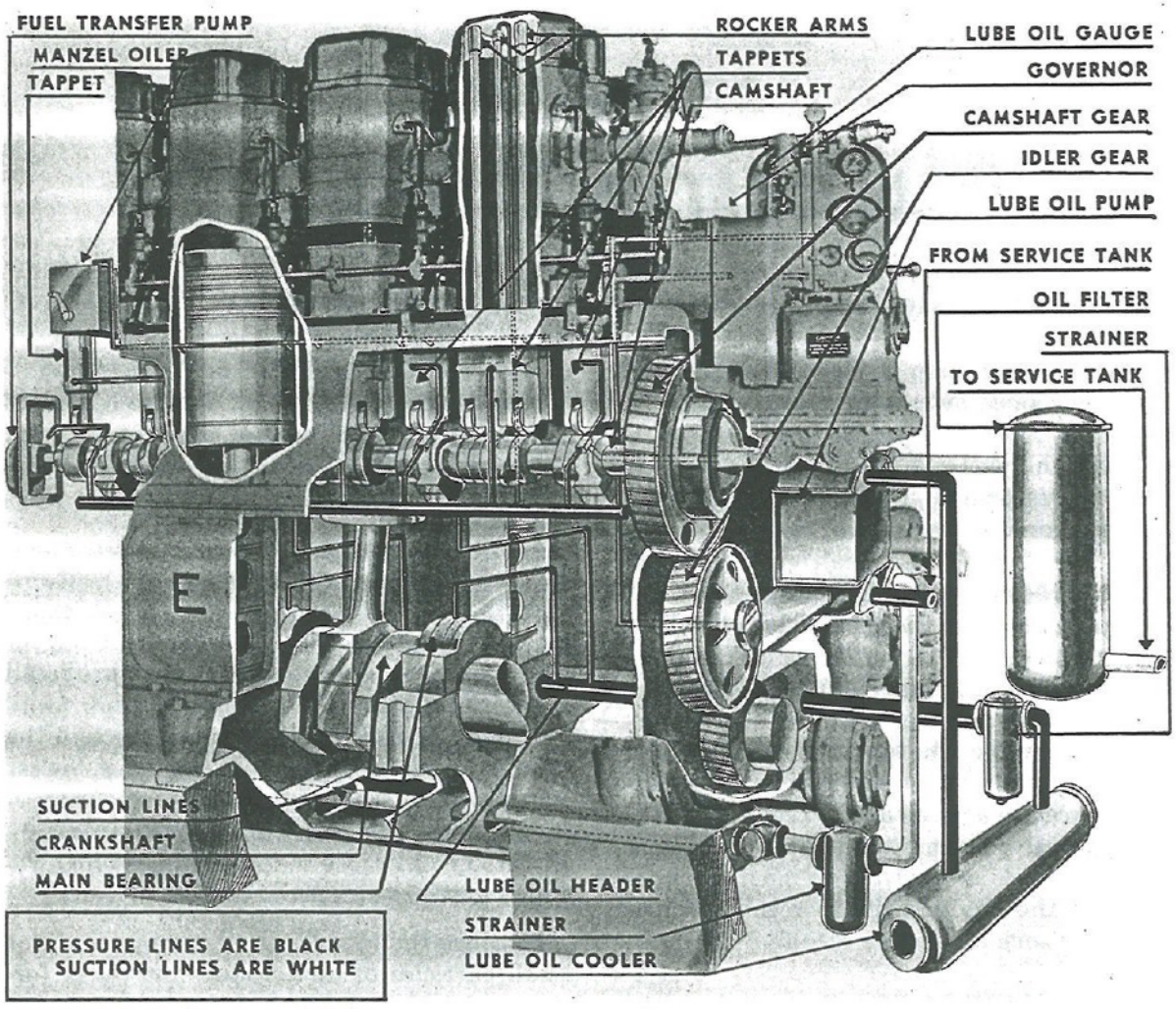

Fig. 11. Lubrication of Engine

a. Lubrication Oil Storage Tank. The oil storage tank holds a supply of fresh new oil that is used to replenish the system when necessary, or to supply new oil when the old oil wears out. The oil storage tank is connected to the lubrication oil service tank with piping and valves.

b. Lubrication Oil Service Tank. (1) The oil used in the system is held in the tank between the reconditioning process and the return to the engine. At the bottom of the tank a flanged connection leads into a pipe to the lubricating oil pressure pump so that the pump can draw oil from the tank as the engine requires it. There is a removable cover on the top of the lubricating oil service tank, and below this cover is a strainer. The tank can be cleaned by removing the cover and strainer. At other times the strainer should be left in position. New oil, when added, should go through this strainer. By removing the cover, the operator can check on the circulation of oil through the system. Either a sight glass is mounted on the side of the tank, or a float gauge is provided. The level of the oil in this glass, or the float level, indicates the amount of oil in the service tank. The gauge must be inspected frequently, and additional oil must be added when the gauge shows that such a step is necessary. The

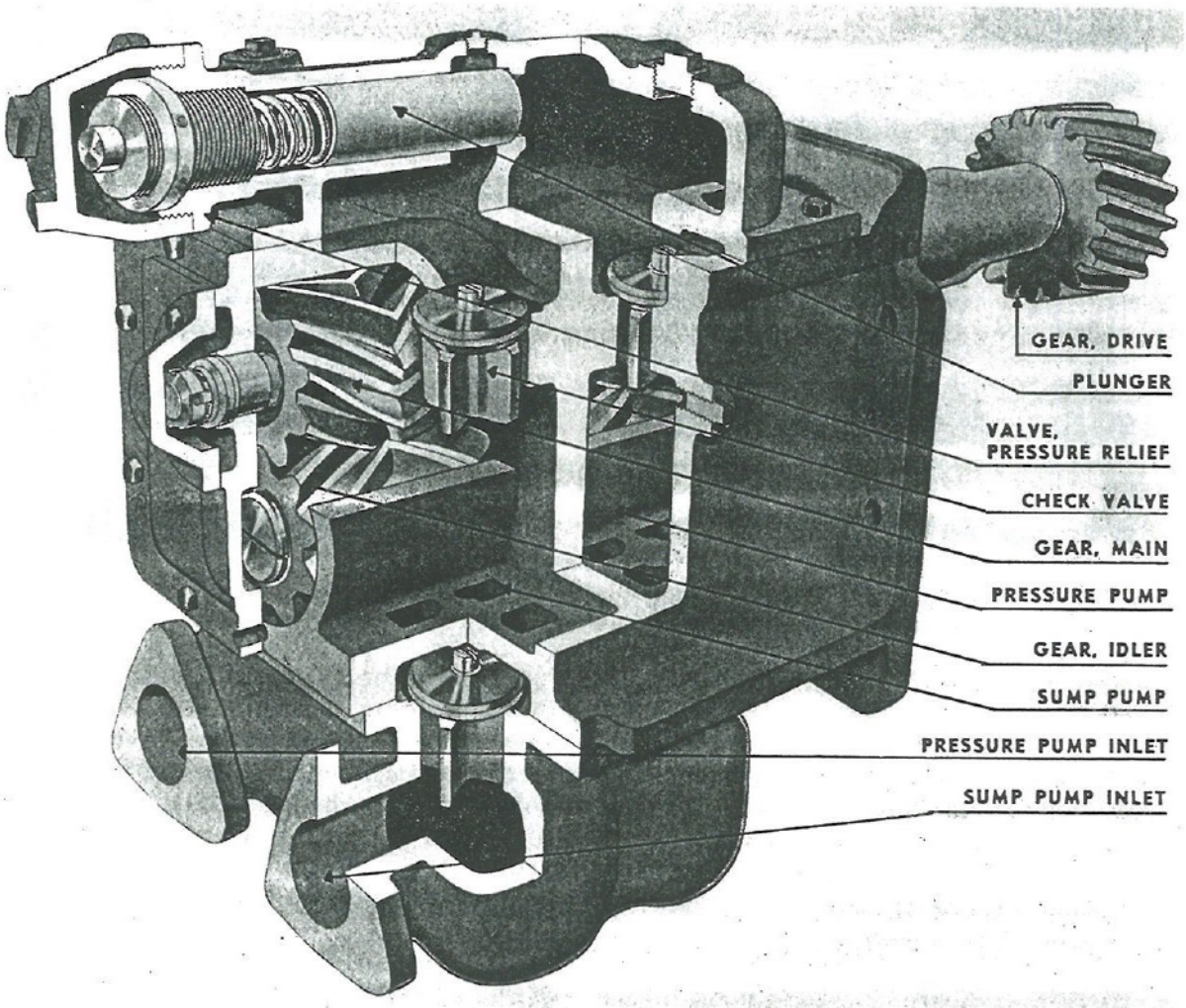

Fig. 12. Cut Away View of Lubrication Pump

oil level must be carefully recorded in the engine log. If the entries indicate that an abnormal amount of lubrication oil is being consumed, there may be a leak or some other serious trouble in the engine or lubricating system that requires attention.

(2) The lubricating oil service tank does not require any adjustments. However, when not in use, the draining and filling valves must be firmly closed. The following service is required by the oil service tank, and should be performed promptly:

(a) Keep sight glass clean for quick visibility; use a clean cloth.

(b) Daily, before operation, or every 24 hours during continuous operation, drain the tank until clean oil is seen, then closed off firmly.

(c) Keep oil level two-thirds full.

(d) When the lubricating oil in the system is changed, clean the tank thoroughly.

CAUTION: be sure that cleaning cloths or other materials are not left in tank after cleaning. The engine will suffer serious damage if supply lines are plugged.

c. Lubricating Oil Pumps. (1) Pumps that circulate the lubricating oil are vital pieces of equipment. Not only must oil be kept traveling through the engine, but it must be under

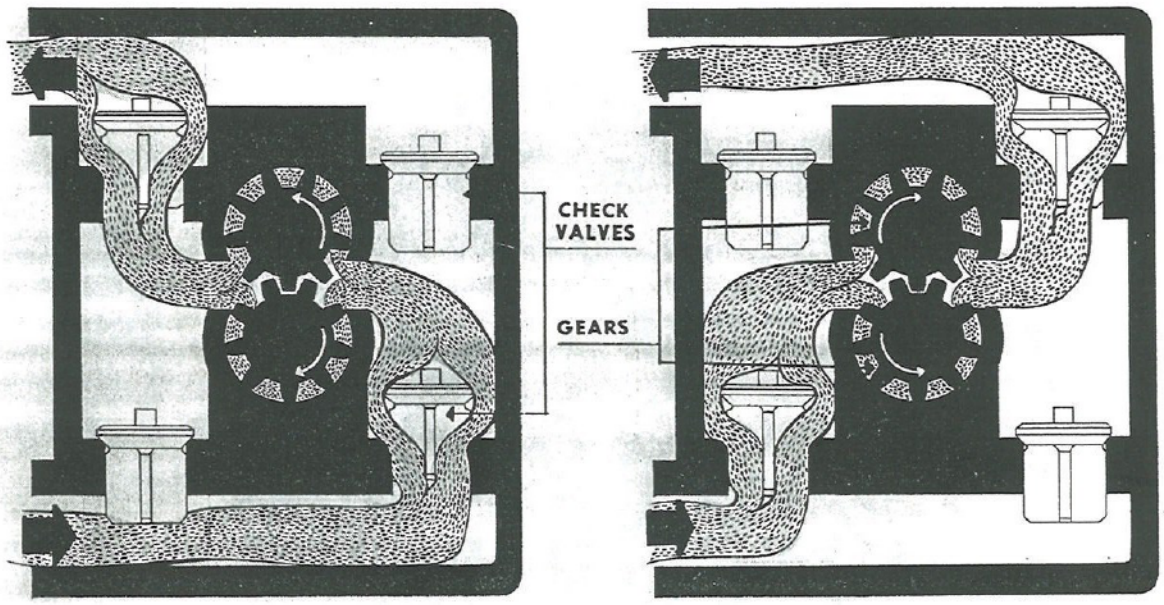

Fig. 13. Lubrication Pump Valve Operation

pressure in order to lubricate the working parts efficiently. There are two pumps in the lubricating system, the high pressure pump which forces oil through the system, and the sump, or scavenger pump, which recovers the oil for re-use from the sump. Both pumps are the same in operation, and both are contained in the same housing, as shown in Fig. 11. They are separated by a partition in the housing, but are driven by the same shaft.

(2) In Fig. 12 the lubrication pumps are shown in a cutaway view to expose the working parts. The nearest pump is the pressure unit which supplies oil to the system. The pump in the rear is the sump, or scavenger, pump. Both have their intakes, or suction connections, at the lower front, and their discharge outlets at the upper front.

Both pumps are rotary gear pumps. They are fitted in housings which permit only a minimum clearance. The turning gears create a suction that draws oil into the notches of both gears. The oil is carried in the notches of these gears around the outside diameter as they revolve to the discharge side of the pump. At this point, the gear teeth mesh and force out the oil carried in the teeth.

This describes the operation of the lubricating pumps when the engine is driving the ship ahead. However, Enterprise engines are direct reversible. To travel astern, the rotation of the engine is changed so that the propeller turns in an opposite direction. While in reverse the engine must be lubricated. Since the pumps are driven by the engine, their gears also turn in the opposite direction when the engine is operating in reverse. This would result in the discharge side of the pump becoming the intake side and the intake side becoming the discharge side. This situation does not occur, however, because a series of check valves are used. As shown in Fig. 12, these check valves are of the poppet type.

d. Check Valves. The operation of the check valves in the lubrication pumps is shown in Fig. 13.

(1) In the drawing on the left the engine is rotating in the ahead position. The oil is coming in the intake opening and passing through the pump to the second chamber. The pressure of the oil is holding the valve off its seat. The oil goes around the gears and up through the top of the first chamber where the valve is lifted by pressure to permit the oil to go out

by the discharge outlet. Notice that the valves located at the bottom of the first chamber and the top of the second chamber are seated to close off the chambers.

(2) In the drawing on the right, the check valves are shown in operation when the engine is reversed. The gears are turning in a reverse direction. The valve at the lower part of the first chamber is lifted off its seat by pressure. The oil coming in the intake passes through this opening to the gears. The gears in turn force the oil out into the second, or back chamber. The oil pressure lifts the valve at the top of this chamber, and the oil goes out through the discharge opening. Because there is no force or pressure on them, the valves that are lifted when the engine is operating in the ahead position remain closed.

e. *Pressure Regulating Valve.* (1) A relief valve mechanism is shown at the top of Fig. 12. This is the pressure regulating valve. With rotary pumps used to supply the oil system, the pressure with which the oil is delivered depends on the speed of the engine. Thus, when the engine is running at high speed the pressure and volume of the oil delivered by the pumps is increased. It is decreased when the speed of the engine is lessened. To prevent the oil pressure and volume from dropping below a safe minimum at low engine speeds, it is general practice to install pumps of a greater capacity than is required by the engine. As a further safeguard, the gear ratio is arranged so that even at lowest engine speeds, the pumps rotate fast enough to provide sufficient lubrication. The gear which drives the pumps is shown in Fig. 12 at the outside of the housing.

(2) While this arrangement assures the engine of obtaining oil at sufficiently high pressures, it is necessary to prevent the lubricating oil pressure from becoming excessive as the engine is speeded up. The pressure regulation valve does this. The valve consists of a housing or cylinder which opens into the pressure lubricating pump. Inside this housing a plunger is fitted with a spring that keeps it closed. When the pressure inside the pump is too great, the pressure works against the tension of this spring and opens the plunger. The excess oil creating the pressure then returns to the suction side of the pump.

(3) The pressure at which this valve will open, or "pop-off" is regulated by turning the adjusting screw. Turning this screw decreases or increases the tension of the spring and thus governs the pressure required to open the plunger. The proper pressure of lubricating oil in the Enterprise engine is 25 to 30 pounds per square inch when the engine is hot.

15. LUBRICATION OIL DISTRIBUTION. There are other "external" units in the lubrication oil system, but before discussing these, the "internal" workings, or the actual distribution of the lubricating oil to the various working parts, should be explained.

a. Referring again to Fig. 11, it is seen that the oil pumps are located on the front end of the engine. The lubrication oil is sent out by the pump in main supply lines, or headers, which in turn connect to smaller distribution lines. The lubricating oil is forced into the main lubrication oil header pipe, or main supply line, extending the full length of the engine down near the crankshaft. From this main supply line, branch lines lead off and connect in the top of the main bearing cap. These main bearing caps, as well as the upper halves of the main bearing shell, are drilled with a hole to permit the oil to enter the space between the bearings and the journals. Grooves are cut in the bearing surfaces of both halves and staggered so that they spread the oil evenly over the entire journal surface. Wherever shell bearings are used in Enterprise engines this policy is followed.

b. The oil is still under pressure, and it must travel on after lubricating the main bearings. Fig. 14 shows the path taken by the lubricating oil in the next step of its circulation. At the top of the main bearing there is a drilled hole and a connection through which the oil enters the main bearing. At the bottom of the main bearing journal a hole is drilled on a slant up through the connecting rod journal. This hole is drilled so that the opening is opposite the groove in top and bottom halves of the main bearing shell, and it opens into the groove

of the connecting rod bearing shells. The oil flows between the connecting rod bearing and journal to provide a cushion of lubrication. A hole is drilled up through the entire length of the connecting rod. Through this hole a portion of the oil supplying the connecting rod bearing passes up the connecting rod, lubricates the piston pin through a groove on the outside of the piston pin bushing, and enters between the piston pin and bushing through four drilled holes.

c. While the oil has been lubricating these parts, it has been traveling under pressure in confined passageways. After lubricating the piston pin the oil is released from pressure and falls. As it falls, however, the moving connecting rods throw the oil onto the lower parts of the cylinder liners. Here it is picked up by the oil scraper ring on the piston and spread evenly over the inside walls of the cylinder. The oil, leaving the cylinder walls, drains into the engine sump, and flows down to the lower point of the sump where it is recovered. The walls of the cylinders, however, are not lubricated entirely by the splashing of this oil. The further lubrication of cylinders is explained in par. 23.

d. The main lubrication oil header also supplies some small lines running to accessories and other equipment. Copper tubes running from this header carry oil that is squirted into the meshes of the gear train to lubricate this unit and the accessories driven by it. One small line branches off from the header at the front end of the engine to lubricate the governor, and another line from this same connection runs to the lubricating oil pressure gauge.

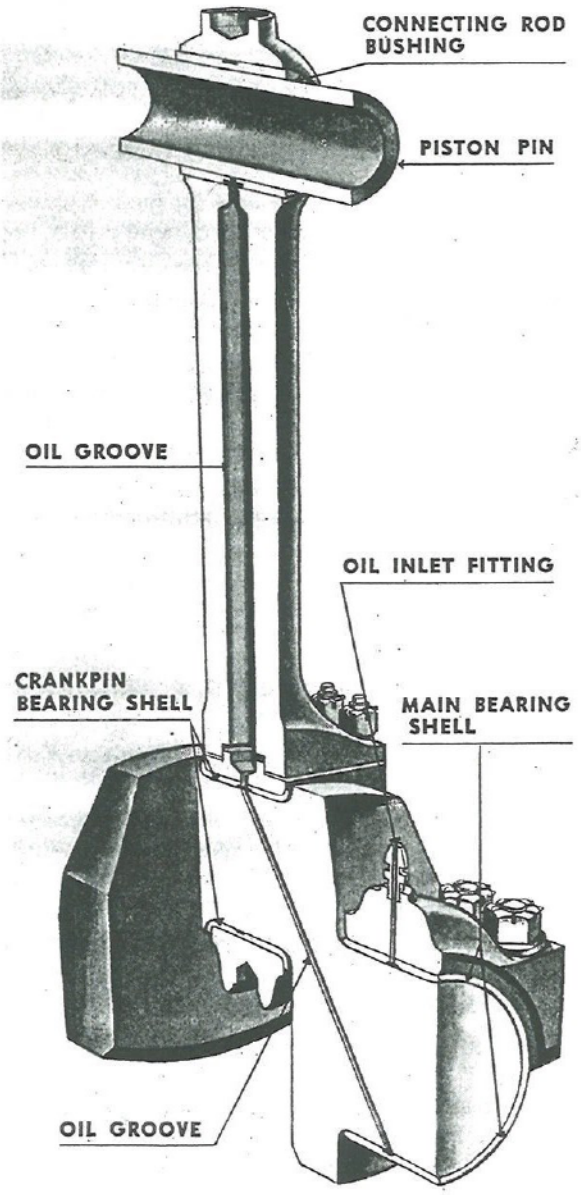

Fig. 14. Lubrication of Bearings

16. SECONDARY LUBRICATION OIL HEADERS. ***a.*** In addition to supplying lubrication to the main bearings, connecting rod bearings, piston pins, cylinder walls, gear train and other accessories, the main header, or supply line, also supplies oil to a secondary header. In Fig. 11, this secondary header, running the full length of the engine, is shown about halfway between the engine base and the top, or cylinder bonnets. A pipe with two elbows connects it to the main header below.

b. From this secondary lubricating oil header, branches lead off and connect at the upper caps of the camshaft bearings. Through holes drilled in these upper caps and upper bearing shells, oil is forced between the camshaft bearings and journals. The connections on the upper camshaft bearing caps are tee connections. The line that supplies oil to the

camshaft bearings also continues on to the tappet clusters. The tappet clusters are rifle drilled and feed into similar holes which carry lubrication into the tappet bushings. From a tee connection in the No. 6 cylinder tappet cluster, or the No. 8 cylinder on the larger engine, a small line carries oil to the fuel transfer pump shaft bearing.

c. A hole rifle drilled in the forward end of the camshaft connects to the camshaft bearing cap at No. 1 cylinder and carries oil to the thrust collar of the reversing mechanism.

d. Branch lines lubricating the rocker arm assembly in the cylinder heads are also supplied by this secondary header. The lines connect to the rocker arm shafts. These are rifle drilled through their entire length and then plugged at each end. Oil under pressure traveling through this passageway in the rocker arm shaft lubricates the rocker arm bushings. The lubrication oil then travels from these bushings into holes that are rifle drilled lengthwise in the rocker arms. This oil, still under pressure, furnishes the pressure that operates the pistons in the zero lash units, which are explained in par. 64. This oil also lubricates these units and the rocker arm rollers. When this work is completed, the oil is released from pressure, and flows back by gravity into the engine sump.

17. RETURN OF OIL. The oil, when released from pressure, returns to the sump. Fig. 11 shows the sump line through which this oil is recovered by the sump pump. The pipe is bent down to reach the oil which runs to the lowest part of the sump. This is located under the last cylinder. On the end of this pipe a coarse strainer is fitted to hold out of the system any pieces of metal or other material that might injure the sump pump. Before the recovered oil enters the sump pump it passes through a basket type strainer on the sump line which removes dirt and other substances. The lubricating oil is forced through the sump pump and back into the lubricating oil service tank. Before returning to the service tank, the oil passes through an absorbent type filter.

18. ABSORBENT TYPE FILTER. a. The absorbent type filter strains out of the oil very fine metal particles, grit, and other harmful substances. The lubricating oil leaves the sump pump en route to the oil service tank under pressure, and is forced into the chamber of the filter. Water, being heavier, settles to the bottom of the chamber and can be drained off by opening the drain plug. The oil is forced up through the filter element which is composed of layers of absorbent material. After passing through these layers, the oil reaches the hollow center of the element and enters a discharge pipe.

b. Since the oil is under pressure when passing through the filter, a relief valve is provided to prevent the filter element from collapsing when they become badly clogged with oil. The relief valve is a simple spring type valve. The spring tension is set so that if the pressure builds up to the maximum recommended pressure the valve opens. This allows the trapped oil to escape into the discharge line of the filter. Operators should not depend on relief valves, but be sure that all filter elements are changed before they become badly clogged. Before operating the engine, this filter must be drained to remove water and other substances collected at the bottom of the filter chamber. The valve should be closed firmly when finished. Before a new filter element is installed, the inside of the filter chamber should be cleaned. The cover should be replaced and tightly secured. After the oil leaves the absorbent filter, it returns to the service tank where it remains until drawn out by the lubricating oil pressure pump.

19. OIL COOLER OR HEAT EXCHANGER. *a.* Oil passing through the engine not only provides a cushion between the moving parts but also absorbs part of the heat in the engine and carries it away. When the recovered oil returns to the lubrication service tank, it is too hot for immediate re-use. And when it passes through the pressure lubrication pump it is still too warm to properly lubricate the engine. Therefore, before going into the main oil header, it must be cooled.

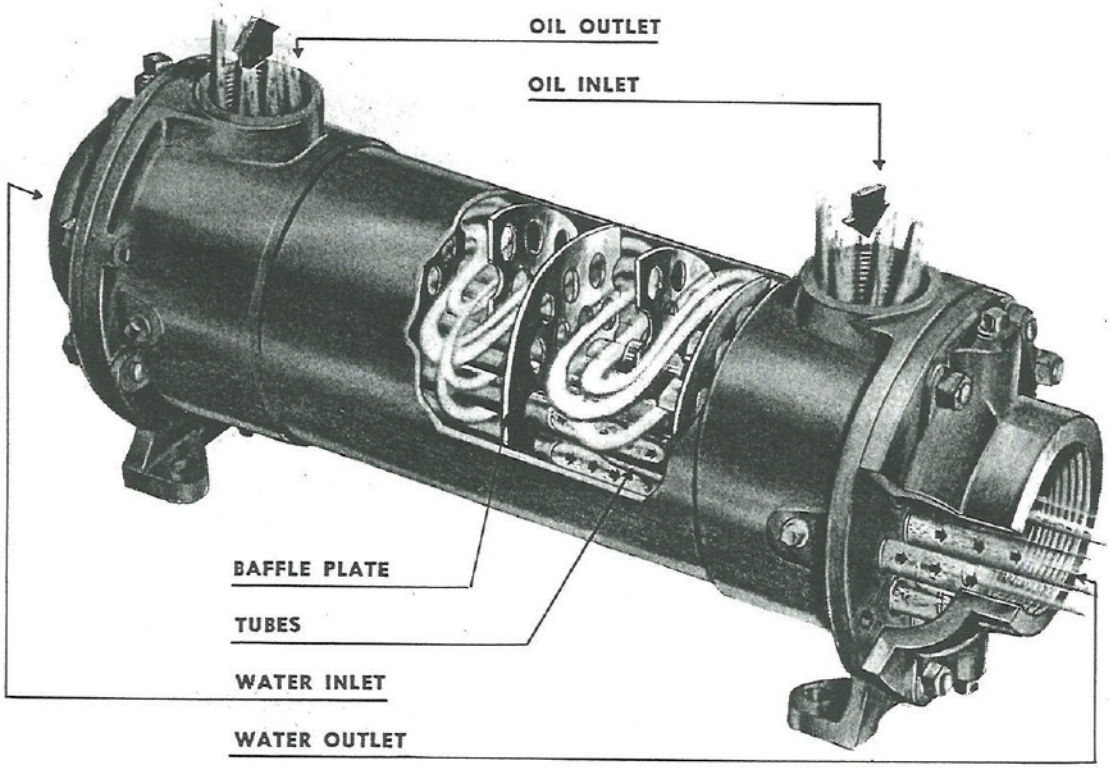

Fig. 15. Lubrication Oil Cooler

b. The lubrication oil cooler is a heat exchanger. In Fig. 11 the oil cooler is shown installed on the front end of the engine, and in Fig. 15 a cutaway view is shown of its interior. The hot oil on its way back into the engine enters the shell or chamber of the cooler under pressure and fills it completely. Cold sea water, or raw water, is pumped into the cooler and circulates through the chamber in tubes. Baffle plates, or irregularly shaped pieces of perforated metal, are placed in the pathway of the lubricating oil. These plates agitate the oil thoroughly to make certain that all of it contacts the tubes through which cold water is pumped. As the hot oil passes through the cold tubes, the heat in the oil is extracted by a process called heat exchanging. This process is explained in more detail in par. 31. When the oil leaves this cooler its temperature has been reduced to a point where it can be used again to lubricate the engine effectively.

20. THE FINAL FILTER. The lubricating oil is now on its way back to the engine. But before entering the main oil header, the oil must pass through one more unit, or another screen filter which removes any dirt that it may have acquired in the service tank or in other parts of the system while en route back to the engine. The parts of this filter are shown in Fig. 16. The filter is not equipped with a relief valve. By this time the oil should be so clean that with proper care and regular cleaning the screen should not become excessively clogged. The basket is composed of fine wire mesh screen. The spring, clamp and clamp screw provide a positive means of tightening down on the basket to keep the screen in place de-

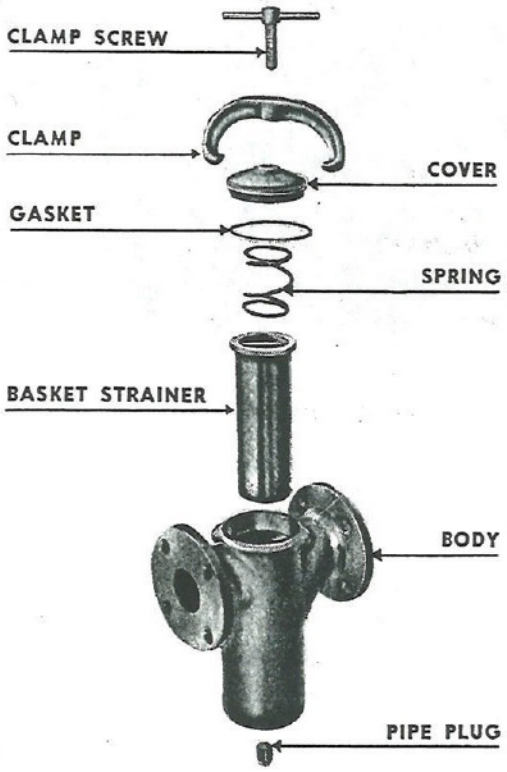

Fig. 16. Lubrication Filter

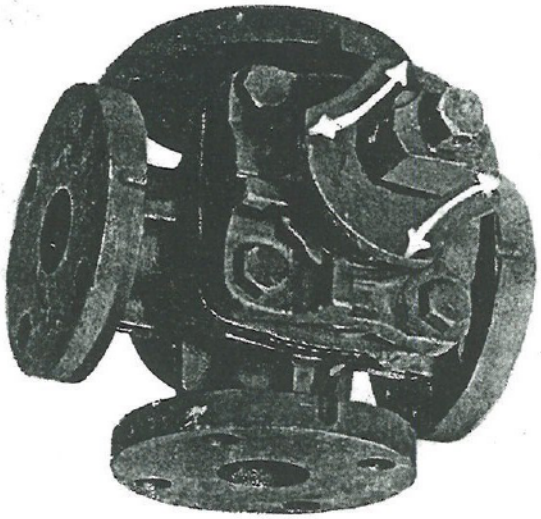

Fig. 17. Lubrication Four-Way By-Pass Valve

spite the pressure of the oil passing through it. When the oil leaves this unit, it goes directly into the main oil header and circulates through the engine.

21. BY-PASSING THE LUBRICATION OIL COOLER. ***a.*** Under ordinary operating conditions, all lubricating oil should pass through the cooler. However, occasionally when the engine has been idle for a long period, especially in cold weather, the lubricating oil will be cold and unable to flow freely. Until the engine has run long enough to raise the temperature of the oil, it is desirable to circulate the oil through the engine without cooling it.

b. The turning of a four-way valve permits the oil to by-pass the cooler. This is illustrated in Fig. 17, and is shown in position in Fig. 11 on the front end of the engine near the oil cooler. In the four-way valve, oil entering one side is ejected at a right angle to the line of entry. The arrows on the valve indicate the direction the oil will take. Thus, in the illustration, the arrows on the left show that the valve is set for the passage of oil from the top to the left side. In this position, the valve, if on the engine, would be by-passing the oil directly to the engine, but by turning the valve so that the arrows indicate a clear passage from the top to the right side, the oil would pass through the lubrication oil cooler. This valve is not a regulating valve, but must be set in the extreme position to either direct the flow into the cooler or into the engine. This valve can also be used to by-pass the cooler when that unit needs repairing.

22. BY-PASSING THE LUBRICATION FILTERS. It sometimes is desirable to change oil filter elements without stopping the engine. There is no set arrangement to accomplish this. Some installations use a four-way valve for this purpose, and others use a series of pipes and valves. The operator should become familiar with the method of by-passing the oil filters, if any, installed on his ship.

23. FORCE-FEED LUBRICATION OF CYLINDER WALLS. In par. 15c it was mentioned that the walls of the cylinders are lubricated by an-

other system besides the crankshaft splashing oil on them. This additional lubrication is accomplished by a Manzel oiler. The location of this oiler on the rear of the engine is indicated in Fig. 11.

a. The cylinder oiler is shown mounted on the engine in Fig. 18. Copper tubes carry oil to the cylinders. There are two tubes for each cylinder, and they enter the cylinder walls on opposite sides. Holes are drilled in the cylinder liners about halfway up their length, and fittings are secured in these holes to connect the tubing.

b. The oiler is composed of a group of pumps, with two required for each cylinder. They draw oil out of a common reservoir to serve their respective tubes. All the pumps are driven by a common shaft which extends the length of the oiler. On the outside end of the shaft, through a lever, rod and tappet arrangement, the shaft is turned by the camshaft of the engine. At the after end of the camshaft, a cam is provided. This cam actuates the tappet operating the oiler shaft in the same way that other engine equipment is driven by the camshaft. This is explained in pars. 60 to 63.

c. In Fig. 19 a cross section of the oiler is shown to illustrate one pump. The pump is composed of two plungers, three ball-type valves, and a regulator to control the amount of oil forced to the cylinders. The drive cam or eccentric, which is secured on the six-sided shaft, revolves. As it turns, this cam either pushes or pulls the crosshead up or down, according to the same principle of cam operation as explained in par. 61. The up and down motion of the crosshead operates two pumping plungers.

(1) On the right side of the illustration in Fig. 19 the primary, or suction plunger is shown. As the crosshead moves upward, it forces this plunger upward. The plunger in turn forces the oil ahead of it. This pressure unseats the primary delivery valve ball and permits the oil under pressure to enter into a passageway and drop out of the drip tube which is underneath the sight glass. As the crosshead moves down, it pulls down the plunger. The primary delivery valve ball seats, and as the plunger travels downward a vacuum is created which pulls the upper suction valve ball on the top of the suction pipe off its seat. This vacuum suction draws oil up this pipe. At the same time it pulls up the lower suction valve ball at the bottom of the suction pipe to prevent the oil from escaping. The oil drawn in by suction fills the chamber ahead of the plunger where it is ready for the next upward stroke of the plunger. When the chamber is filled, the vacuum is eliminated and the pressure of the oil seats the upper suction valve ball.

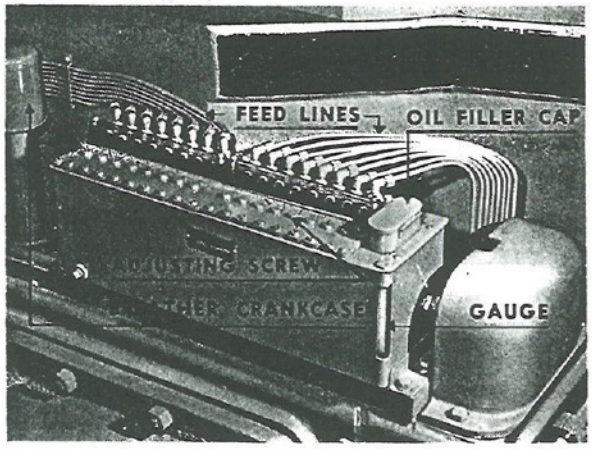

Fig. 18. Cylinder Oiler Mounted

(2) The oil delivered from the drip tube falls into the oil cup and flows into the chamber ahead of the delivery pump plunger. This plunger is also moved upward by the crosshead. As it moves upward, it forces the oil upward. The pressure unseats the double balls in the secondary delivery valve system and sends the oil through the tubing to the cylinder.

(3) The amount of oil delivered by the oiler is regulated by the length of the stroke permitted the suction plunger. This is done by adjusting the feed regulator screw. Turning this screw either raises or lowers the regulating fork. The stop flange on the bottom of this regulating fork is placed in such a manner that it contacts a flange on the bottom of the suction plunger. This controls the stroke of the plunger since it can be no greater than the distance traveled before the two flanges meet.

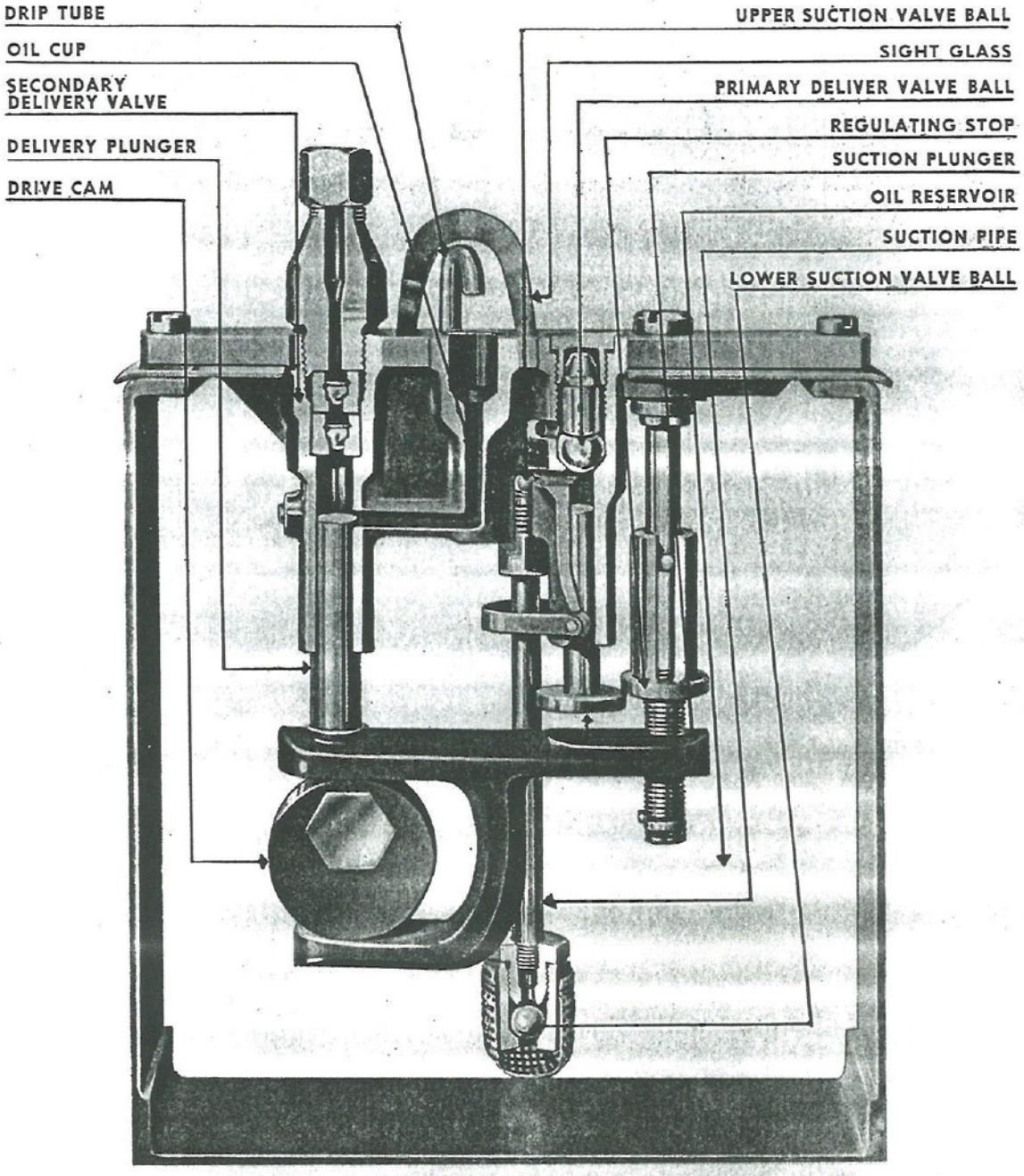

Fig. 19. Cylinder Oiler Pumping Unit

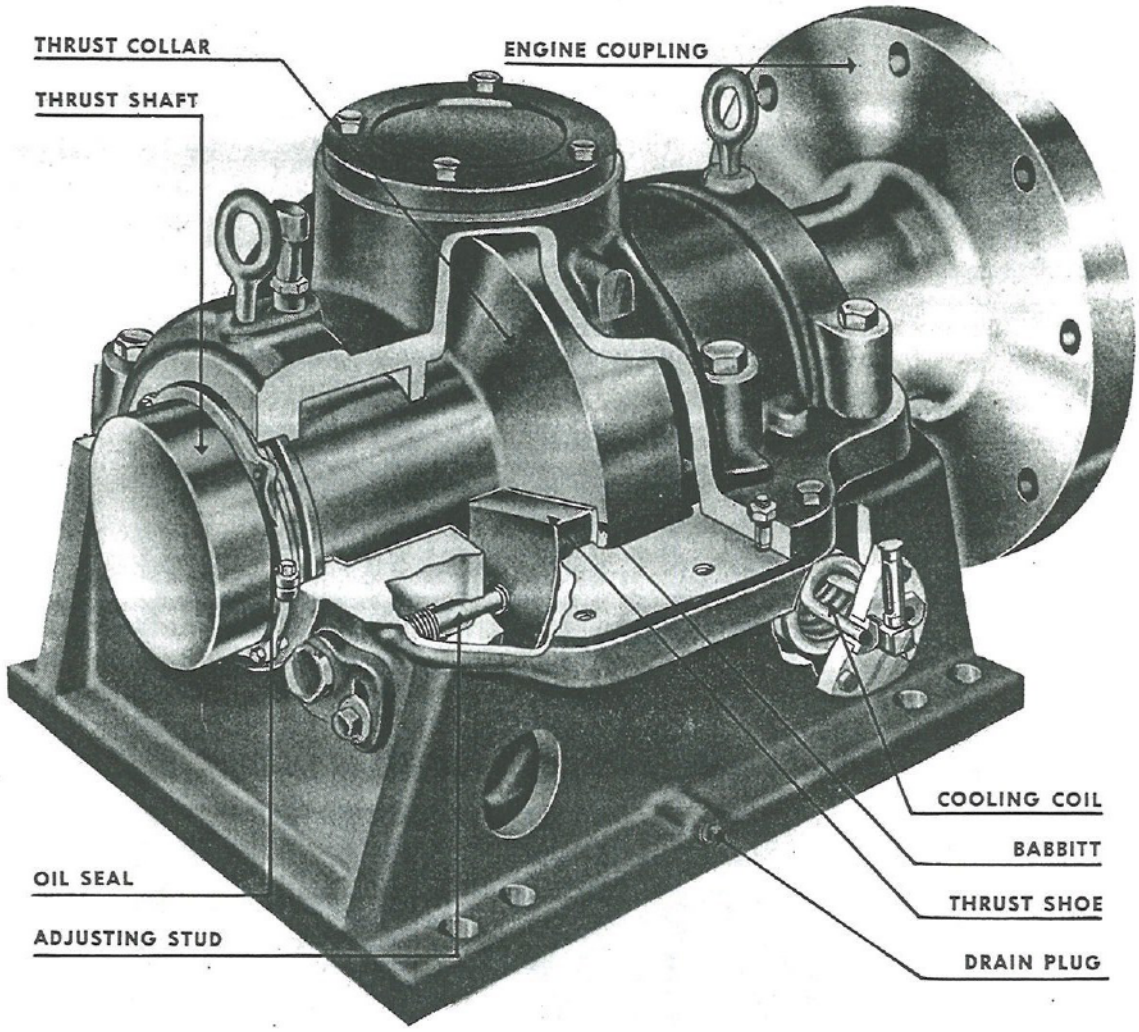

Fig. 20. Cut Away View of Kingsbury Thrust Bearing

(4) Oil delivered by the cylinder oiler drops into the sump and is returned to the internal lubricating system of the engine. The reservoir in the oiler is filled independently and should be checked every eight hours. The sight glass on the corner of the oiler housing shown in Fig. 18 indicates the oil level at all times. The reservoir has a capacity of six quarts of oil which should be replenished through the filler cap on the top. Exercise care to only use clean oil of the same grade and weight as used in the engine. The amount of oil delivered by the oiler can be regulated from one drop every four or five strokes to a maximum of thirteen drops on each stroke. Turning the regulating screw to the left increases the amount of oil delivered, while turning to the right reduces the amount. Approximately twelve complete turns are required to adjust from minimum to maximum amounts. The amount of oil each pump in the oiler is delivering can be checked by watching the drops from each drip tube through the sight glass. Check this drip every watch or eight hours to see that each pump is delivering two drops of oil per stroke.

24. HAND OILING AND GREASING. ***a.*** Not all parts and accessories of the engine can be lu-

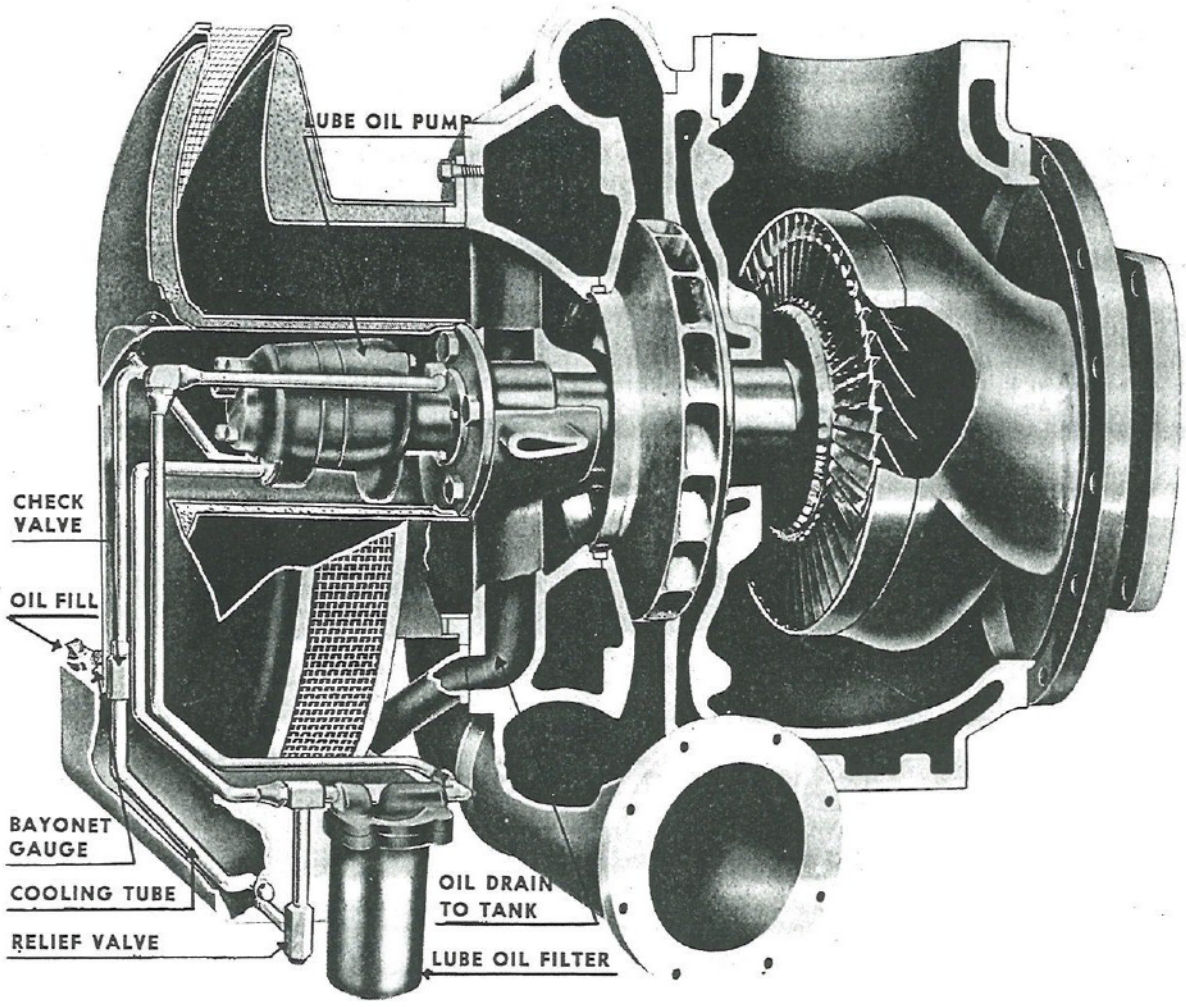

Fig. 21. Lubrication of Turbocharger

bricated by the system described, and these require hand oiling or greasing. This work, as outlined below, must be done regularly and promptly or serious trouble will be encountered.

b. Oil the governor linkage on the fuel control every 120 hours while the engine is in operation.

c. Oil the engine control box every 120 hours.

d. Grease the idler pulleys on the compressor drive every 120 hours.

e. Check the lubrication oil level in the thrust bearing and compressor every 120 hours and add oil when necessary to bring up to the proper level.

f. Check the pump supplying the sea water system every 120 hours, and add grease to the grease cups when needed. Turn down the grease cups one-third of a turn every 24 hours.

25. THRUST BEARING. The thrust bearing is located at the rear end of the engine, connected to the flywheel. The importance of this unit is explained in subsequent pages. Enterprise engines are equipped with the Kingsbury thrust bearing, shown in Fig. 20. This bearing must have lubricating oil. The thrust collar in the Kingsbury bearing lubricates the other parts

by the oil it picks up from the oil reservoir in the base. A sight glass at the base of the thrust bearing indicates how much oil is available. The oil level must be kept up. After 500 hours of operation, the oil should be drained and replaced.

26. TURBOCHARGER LUBRICATION. The turbocharger unit has its own lubrication system. On the left side of Fig. 21, underneath the air intake screen, an oil reservoir is shown. On the left end of the rotor shaft the lubricating oil pump is installed, and it operates from this shaft. The oil is picked up from the reservoir by the pump and passes through a relief valve which by-passes any surplus oil back to the oil reservoir. The oil is then forced under pressure through a filter and into the journals and bearings of the unit through rifle drilled passages. The used oil is then collected in drainage ribs and is carried back to the pipe which drains into the tank. The lubricating oil is circulated continuously. A bayonet-type gauge is located on the lubrication oil tank to permit checking the oil level. Clean the lubricating oil tank and screen at the suction pumps after the first 200 operating hours, every 2000 hours after that. Renew lubricating oil filter cartridge every 2000 hours, oftener if needed. Check oil level daily, and add lubricating oil when necessary. If oil consumption exceeds more than one quart every 24 hours, investigate. Grade of oil should be 2-104B.

SECTION IV
ENGINE COOLING SYSTEM

27. COOLING SYSTEM. The burning of Diesel fuel oil produces heat. The friction of moving parts also produces heat. The heat from both of these sources must be controlled. The cooling system is as important as the lubrication system in controlling this harmful heat. Generally speaking, the two systems function together to do this work.

28. "RAW" WATER COOLING FOR SHIPS. Water is used for cooling engines on ships. At one time it was the common practice to circulate sea water, or raw water, through the engine system. However, on ships operating in salt water many difficulties were encountered which resulted in damage to the engines. In addition to salt, sea water contains other chemicals harmful to engine parts. Under certain conditions the engines would have to be dismantled to remove the crustations of salt and other chemicals. The building up of these deposits gradually decreased the size of the water passages, with a resultant loss of efficiency until the engine no longer obtained suf-

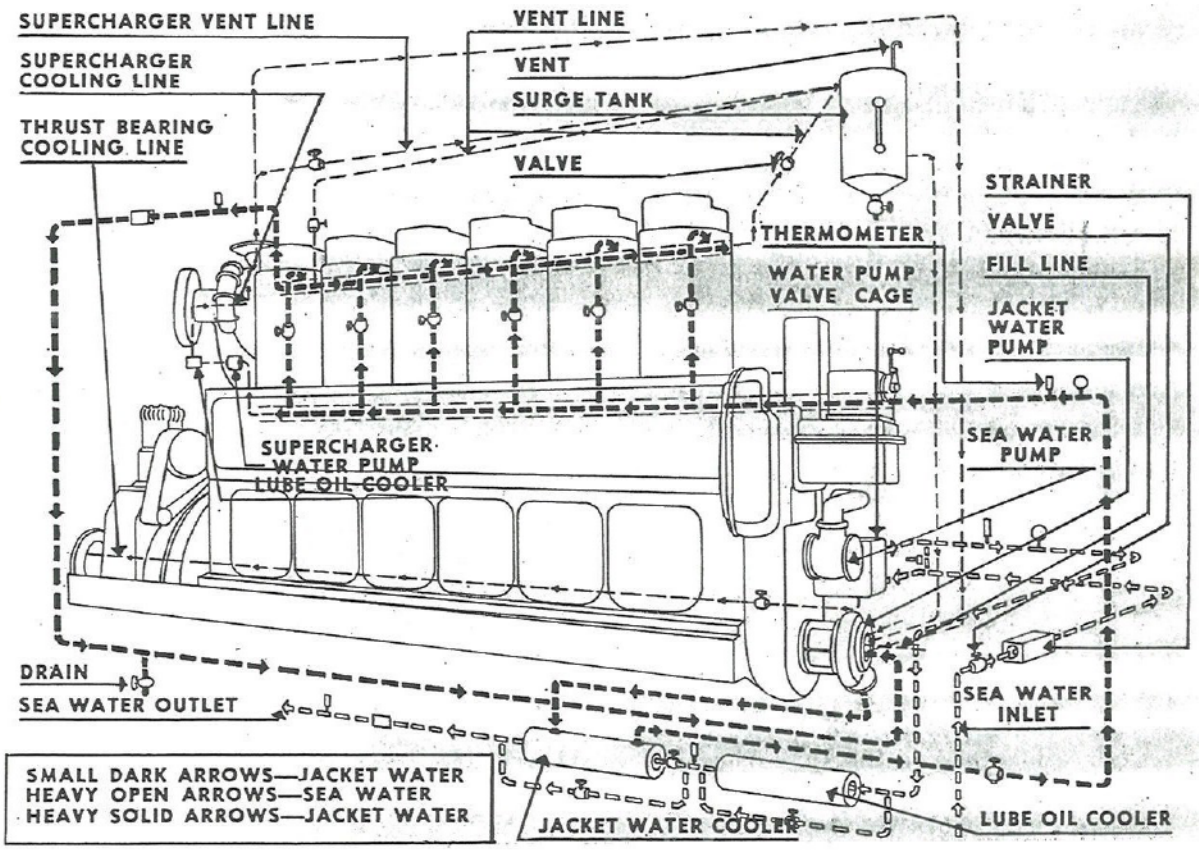

Fig. 22. Cooling of Six-Cylinder Engine

ficient cooling. Ships operating in fresh water lakes, rivers, etc., sometimes still use raw water for engine cooling, but even fresh water contains chemicals that form deposits on metal when heated. In time these deposits close up the passages in the cooling system. Even a thin coating of these deposits serves as an insulation that prevents the lower water temperature from reaching the hot metals. With the development of marine Diesel engines, a better system of cooling was necessary. This led to the development of the heat exchanger principle, in which sea water is used to cool the fresh water which circulates in the engine jackets. This fresh water is commonly called jacket water.

29. ENTERPRISE SYSTEM. The cooling system of the six-cylinder engine is shown in Fig. 22. This is a schematic drawing, and the various units are not necessarily located where shown. It will be noticed that the engine uses two water systems, one for raw or sea water and one for fresh or jacket water. The essential units in the cooling system, besides the necessary valves and piping are:

For the Jacket Water

1. A tank to hold a supply of fresh water to replenish the quantity circulating in the system.
2. A heat exchanger, or cooler.
3. A centrifugal pump.
4. Cooling passages through which water circulates.
5. A surge tank for the expanding water.
6. Temperature control mechanism.
7. A pump and necessary piping to circulate water through the turbocharger.

For the Raw Water

1. An intake and outlet.
2. A pump.

30. FRESH WATER STORAGE TANK. A tank or tanks are installed on the ship. These are kept filled with fresh water to supply the engine jacket. Pipes and valves connect the tanks to the system so that water can be drawn out of the tanks to replace losses due to evaporation, leaks, and other causes. No special design is followed in building these tanks.

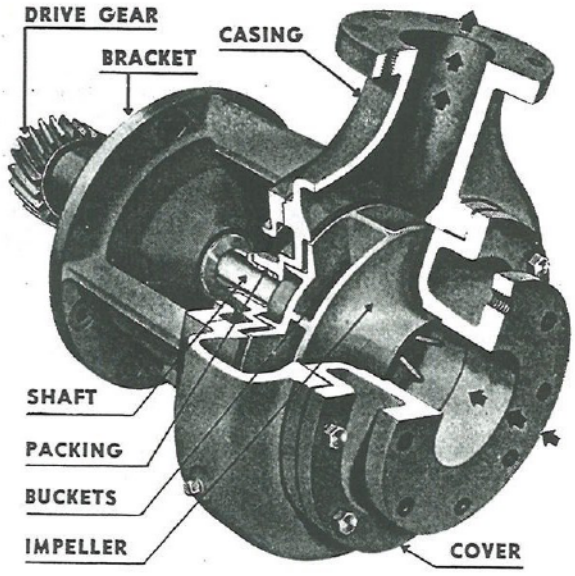

Fig. 23. Circulating Water Pump

31. JACKET WATER PUMP. An explanation of the cooling system starts with the jacket water pump. The pump, shown in Fig. 23, is a centrifugal type with a straight vane impeller. The impeller is geared to the engine, and it whirls around at great speed. It draws water into the "buckets" or chambers formed in the impeller by the vanes. The whirling of the impeller creates a centrifugal force which tries to throw the water out of these "buckets." The housing prevents this from happening, but when the "buckets" revolve around in front of the outlet, the water is hurled through this opening. Since there are numerous "buckets" on the impeller, which keep spinning, a heavy volume of water at high pressure is continually thrown out of the pump. The jacket water pump continues to operate in both ahead and astern operations.

32. JACKET WATER CIRCULATION. *a.* The water leaves the jacket water pump and goes into the heat exchanger. Leaving the heat ex-

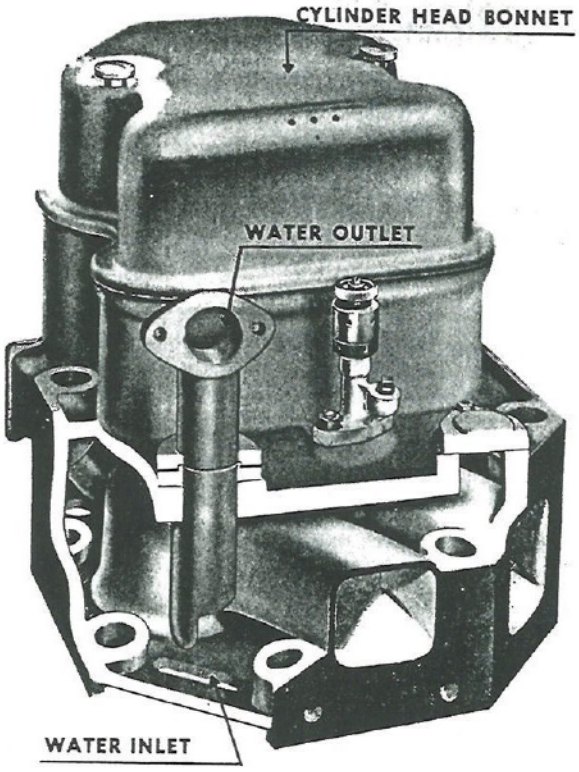

Fig. 24. Cylinder Head Water Passages

changer, it goes into the manifold which runs the length of the engine and opens up into the cooling spaces around the cylinders. Passages are cast in the engine block and sealed off by the cylinder liners. The water rises in these passages to cool the cylinder walls and pistons. When the water reaches the top of the block, it leaves through holes and enters into the cylinder head through corresponding holes to fill the cooling passages surrounding the combustion chamber, intake and exhaust valves, and the nozzle. The cooling of these parts is shown in Fig. 24.

b. When the water leaves the cylinder head it enters a pipe, called a water jumper, located at the top of the cylinder head. This carries it into the cooling passages in the exhaust manifold. The water has now completed its work and starts back to the jacket water pump for circulation.

c. The path of the cooling water, or jacket water in the eight-cylinder engine, is shown in Fig. 25.

33. TURBOCHARGER COOLER. a. The turbocharger unit draws fresh water from the engine jacket cooling system for cooling. The electric motor driven centrifugal pump is shown in Fig. 26. This supplies water to the unit. The water is drawn out of the main jacket water header in the engine. After completing its work in the turbocharger it is returned to the surge tank.

b. There are two parallel water cooling systems in the turbocharger, but both use the same intake and discharge connections. In one system fresh water is conducted through tubes in the lubricating oil reservoir to keep the oil cool. This is just another use of the heat exchanger principle. Water leaving the oil cooling tubes is discharged into the passages that cool the turbine.

c. The other turbocharger water system conducts water through the cooling passages around the turbine. This counteracts the great heat of the exhaust gases entering the unit and prevents the parts from warping. The two systems are illustrated in Fig. 27.

34. SURGE TANK. In Fig. 22 and Fig. 25, small lines are shown leading up to the surge tank. These small lines are connected into every high point on the engine. They are fitted with valves that are only opened to a very slight degree since a full flow of water into the surge tank is not desired. Up to this point the water circulation through the engine has been under pressure and confined to small spaces. At the same time, it has been heated to a comparatively high temperature. Water, like gas, expands when heated. If this pressure were not relieved, the pipeline or gaskets would be blown out. To overcome this, a small amount of the hot water flows through a ½-inch pipeline into the surge tank. This tank is a simple tank with an inlet and outlet, an air vent, and a sight glass. The overflow of water resulting from the heating of the fresh water in the engine circulation system can be accommodated in this tank. At the bottom of the tank, a pipe-

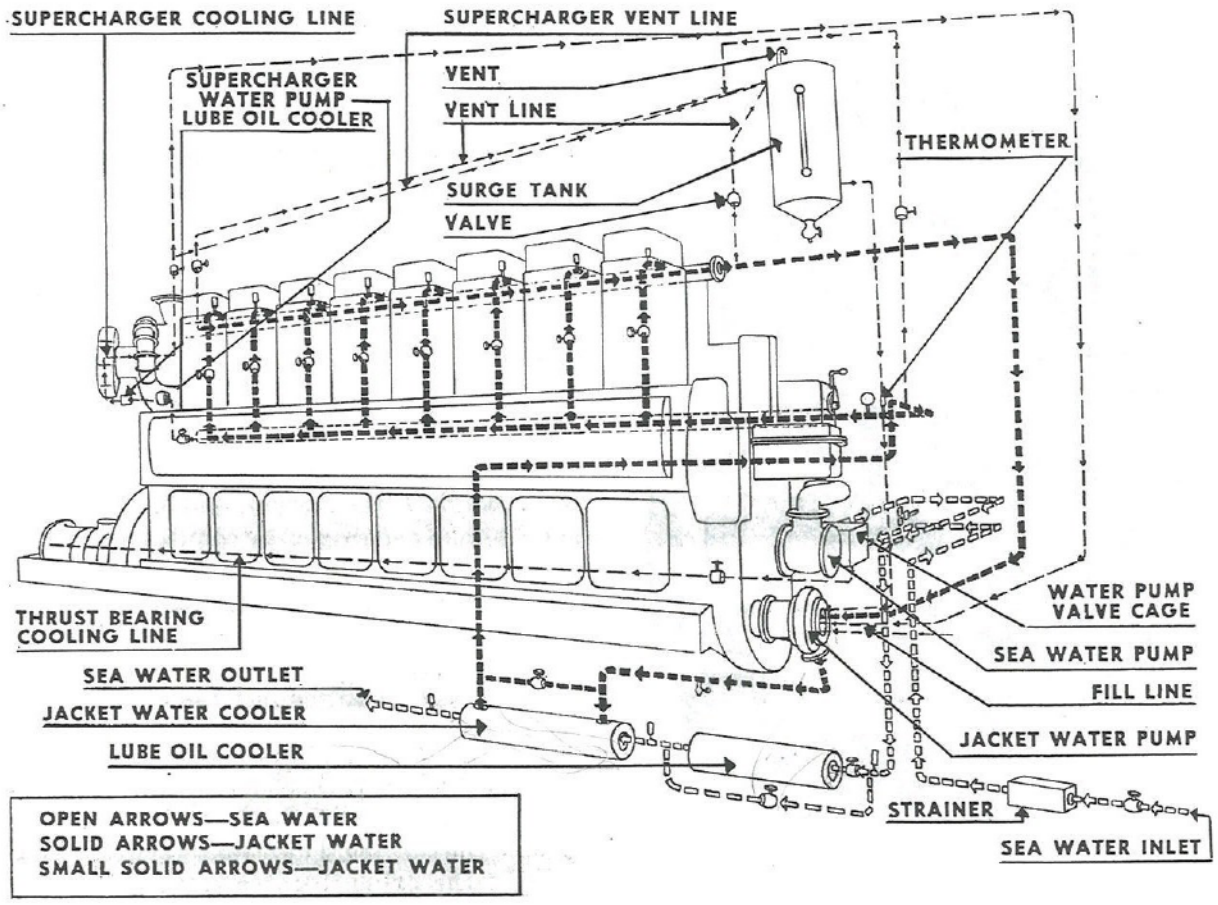

Fig. 25. Cooling of Eight-Cylinder Engine

line is connected with the intake of this jacket water pump. Since the flow of water into the tank has the same volume and pressure as the flow out of the tank, it will not overflow. In addition to taking care of the water expansion, the surge tank also serves two other important purposes. Any air or steam developed in the water system naturally rises to the high points in the engine. From these parts it is led into the surge tank where it escapes, and thus is prevented from blocking the system. The surge tank also builds up a working head for the jacket water circulating pump. This is a centrifugal pump, and it works most efficiently when water reaches it under pressure. The small amount of water that goes into the surge tank drops down to the pump, creating the pressure needed to attain this efficiency.

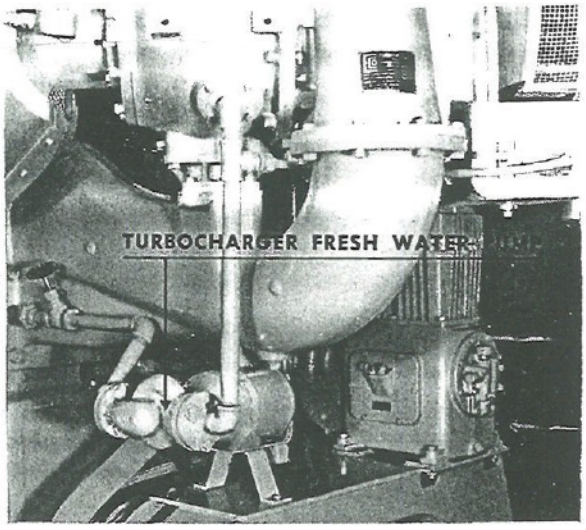

Fig. 26. Water Pump Serving Turbocharger

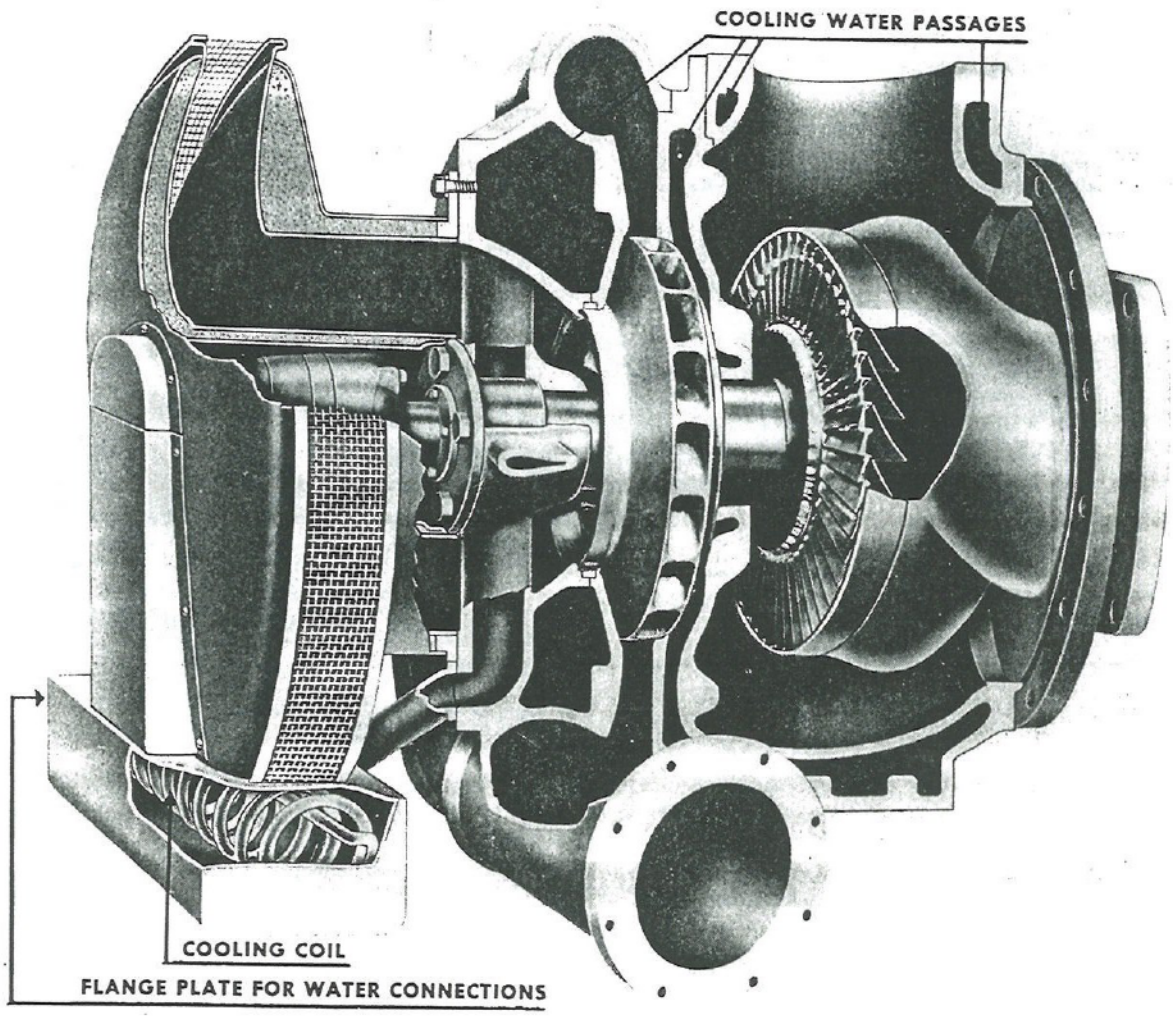

Fig. 27. Cooling System on Turbocharger

35. HEAT EXCHANGER. The heat exchanger is shown in both Fig. 22 and Fig. 25. During its circuit, before entering the engine, the jacket water enters the heat exchanger, or jacket water cooler. A cutaway view of this jacket water cooler is shown in Fig. 28. It is similar to the one used to cool the lubrication oil.

As shown in Fig. 22, there is a valve on the jacket water line just above the jacket water cooler. This valve is closed, making it necessary for the water to go through the heat exchanger or cooler. The water from the circulating system enters the intake on the top of the cooler and passes under pressure through this unit into the outlet on top. Then it goes back into the pipeline again. However, on the right end of the cooler, cold raw, or sea water, is forced through the tubing. The jacket water is agitated by the baffle plates so that all the water contacts the cold tubes. In doing so it loses a great part of its heat to them. There is only a limited quantity of jacket water, and after leaving the engine it has no way of heating itself. On the other hand, the supply of cold sea water is inexhaustible. The water which has taken heat away from the engine goes back into the sea, lake, or river where it is quickly dissipated. The jacket water goes back to the inlet side of the centrifugal pump for recirculation through the engine.

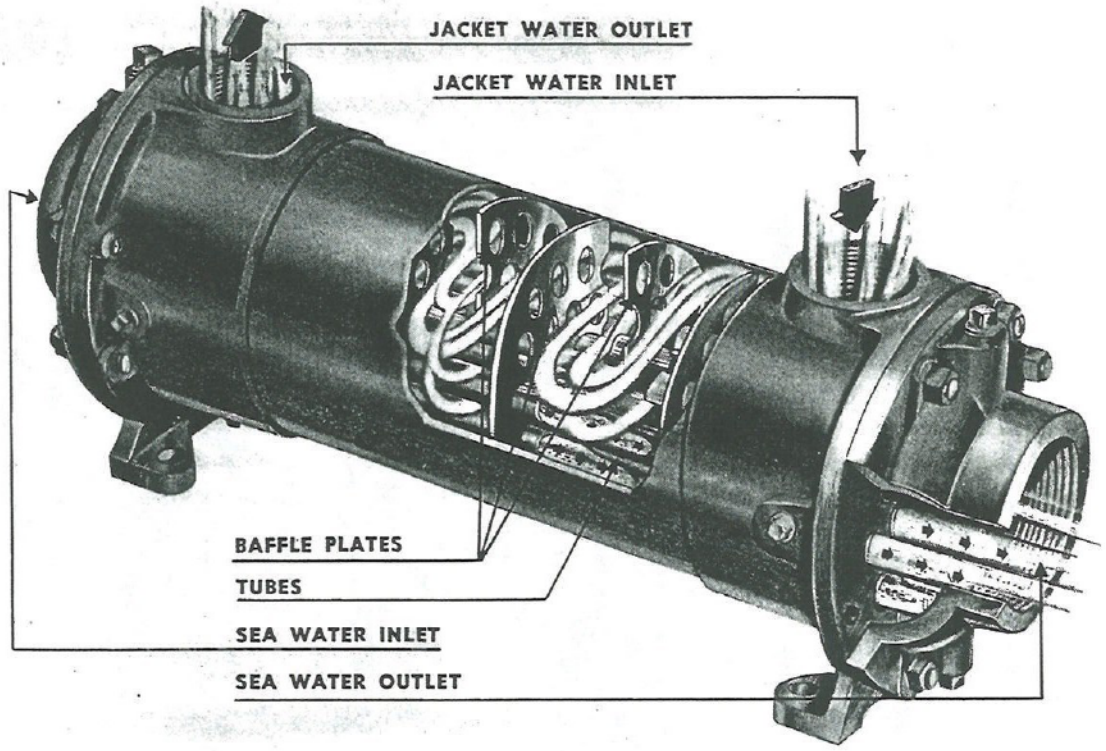

Fig. 28. Operation of Heat Exchanger

36. "RAW" WATER PUMP. ***a.*** Enterprise engines use the Viking pump, illustrated in Fig. 29, to pump the raw, or sea water. It is mounted on the front of the engine. This pump has an intake and an outlet. The intake is connected by piping to a sea water chest, or other opening, cut in the hull of the ship far enough below the water line so that it will be in operation regardless of how much the ship rolls. In Fig. 30 the two common types of raw water intakes are illustrated. The drawing on the left shows the intake often seen on wooden hulls; it has a strainer placed over the outside. The preferred installation is shown at right, with a sea chest admitting the water into a box built inside the hull, fitted with a strainer which may be removed and cleaned.

b. The raw water pump is of the positive displacement type, composed of a rotor revolving inside a housing. A system of valves is included with this pump to permit operation of the raw water system when the engine is in reverse. These valves are contained in a valve cage connected to the pump, as shown in Figs. 22 and 25. The valve is composed of four discs held in place by the tension of springs, as illustrated in Fig. 31. The arrows indicate the way the water flows. It comes in on the lower right-hand side, goes through the pump which is connected to the rear face of the valve, and then is ejected through the opening at the upper right. Fig. 31 shows the position of the valves when the engine is running in the ahead position. The rotation of the rotor, when turning in this direction, creates a suction which lifts the bottom valve on the lower left side to admit the water to the pump. The water then goes through the pump, and is forced out

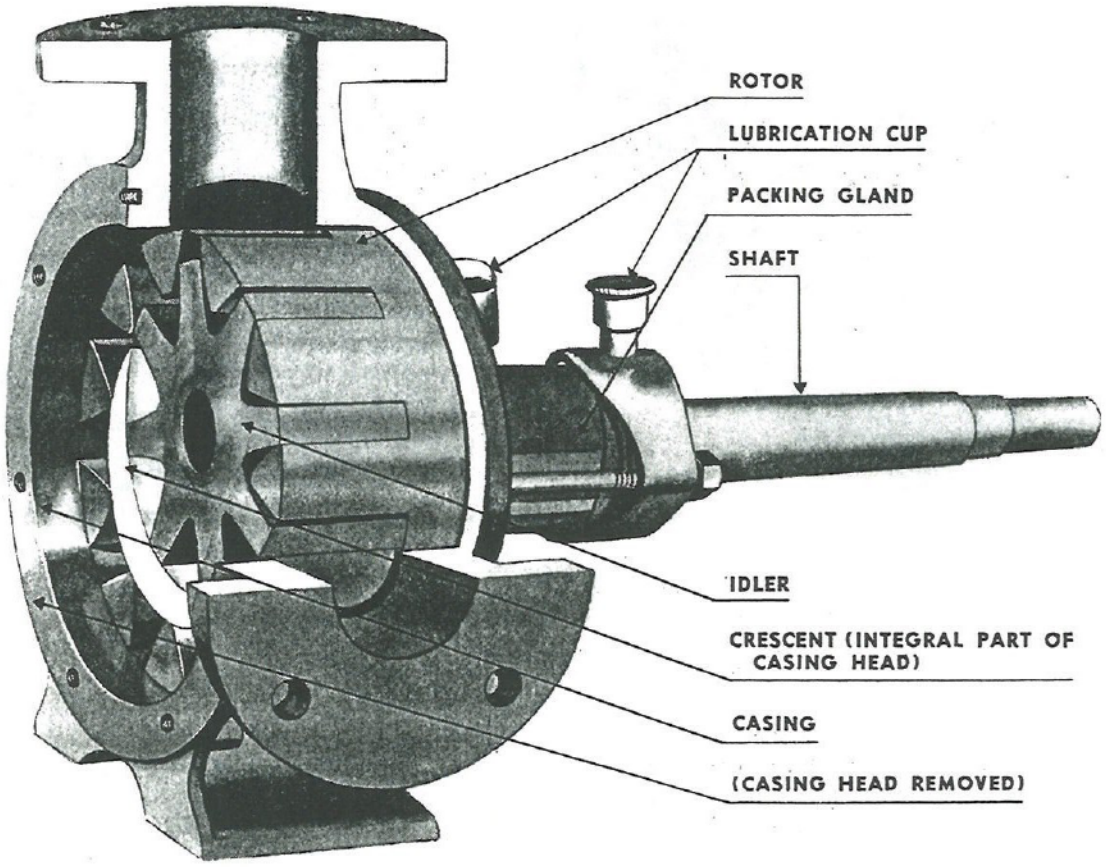

Fig. 29. Sea Water Pump Cut Away

through the opening in the back on the right side. The pressure lifts the upper right disc valve to permit the water to flow out through the discharge.

c. Fig. 32 shows how the valve works when the engine is in reverse. The direction of the rotor in the pump, like the engine, also is reversed to create a suction that draws on the disc valve in the lower right of the valve cage. The water goes into the pump through the rear opening on the right, and enters the cage again through the lower left opening to the pump. The pressure of the water lifts the upper left valve, and the water flows through the exit on the upper right.

37. RAW WATER COURSE. The fresh water in the jacket keeps running through the system over and over again. The raw or sea water is not held inside the ship. In Figs. 22 and 25 the course of the raw water is shown. It enters the pump through the lower connection of the valve cage and is discharged through the upper connection to go through the two heat exchangers. It first passes through the lubrication oil cooler, then through the jacket water cooler, and finally is discharged overboard. After the raw water passes through the heat exchangers its usefulness for these purposes is ended.

38. TEMPERATURE CONTROL. *a.* Water can be either too hot or too cold for efficient engine operation. Enterprise engines perform best under normal load when the temperature of the water entering the engine is 130° F and

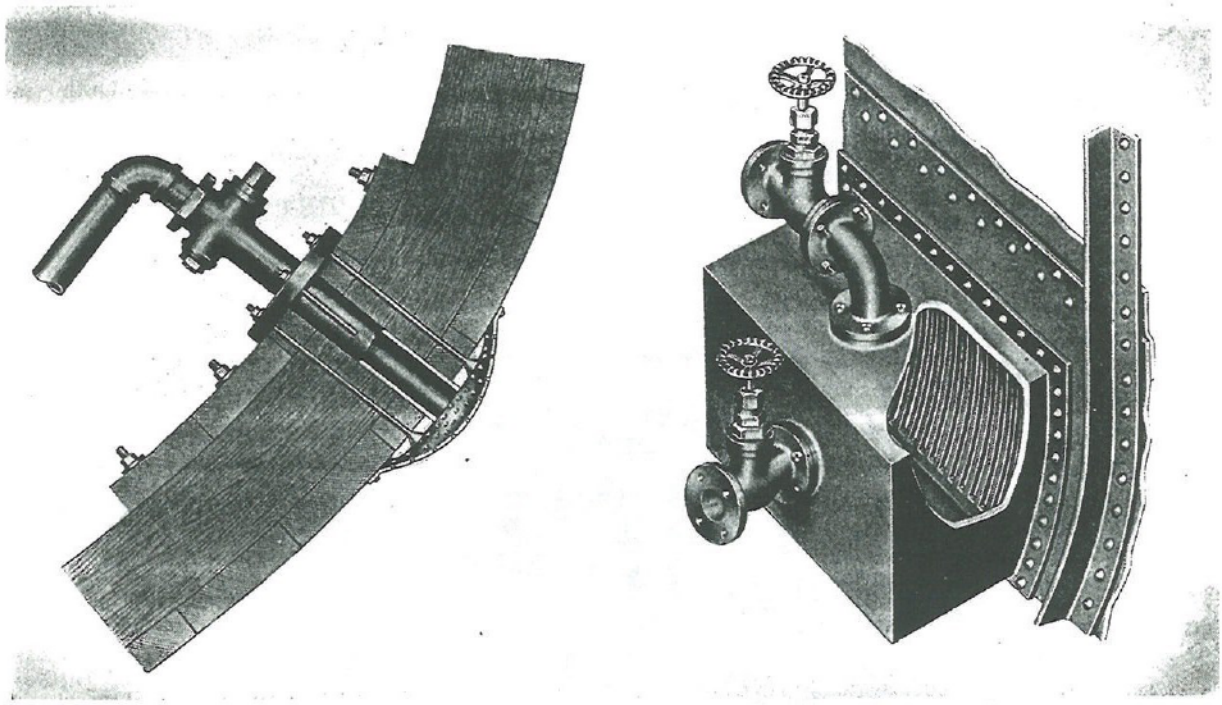

Fig. 30. Sea Chests for Raw Water Intake

150° F on leaving. The maintenance of the jacket water temperature within this range is accomplished by setting the control valves which governs the amount of the water passing through the jacket water cooler. With these valves closed all the hot jacket water must go through the heat exchanger before recirculating through the engine. Partial closing of the valves results in only part of the water going through the heat exchanger.

b. Thermometers are installed on various parts of the Enterprise engine. The temperature of water coming into the cooling jacket is indicated by a thermometer located at the manifold entrance. This will indicate whether the water coming into the engine requires heating or cooling. If a change in temperature is needed, the operator will adjust the temperature control valves to attain the right temperature. A thermometer is also installed on every cylinder head. If one or more cylinder thermometers shows a temperature 15 to 20 degrees higher than the others, it is an indication that the piston is carrying a heavier load than its share, that it does not have enough clearance, or that there is some trouble with either the oil or jacket water distribution systems. If the temperature continues to rise, the trouble should be discovered and corrected.

39. THRUST BEARING COOLING. a. The lubrication of the thrust bearing is explained in Section III. In Figs. 23 and 26 a water line to the thrust bearing is shown connected to the valve cage of the raw water pump. Before explaining the cooling of the thrust bearing, the importance of this unit should be stressed. A typical thrust bearing is illustrated in Fig. 20.

b. When a ship engine is running, it turns a shaft which causes the propeller, or screw, to revolve. The propeller has several blades which have a definite pitch to them. The outside edges of the blade cut into the water and force it backward. The propeller is constantly trying to push ahead in the same manner that a wood screw when turned into a wooden block will pull itself forward. This forward motion is called "axial thrust."

c. If this axial thrust were permitted to go to the engine, a bent crankshaft, misalignment

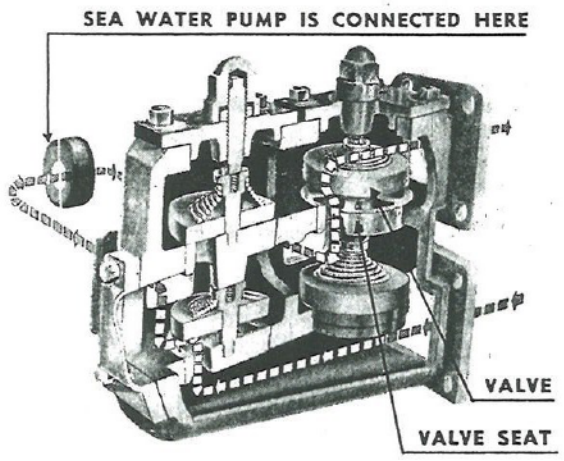

Fig. 31. Sea Water Pump Valve Operation During Ahead Running

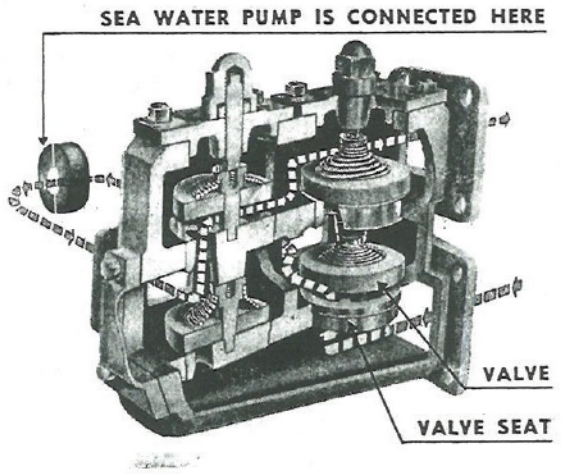

Fig. 32. Sea Water Pump Valve Operation During Astern Running

of the engine, and other damage would result. To overcome this axial thrust, the thrust bearing is used to connect the engine flywheel with the propeller shaft. The thrust shaft on the Kingsbury bearing is a short shaft with a raised flange in the middle. This flange is known as the thrust collar, and it is part of the shaft forging. On each side of this thrust collar, enclosed in a housing, are thrust shoes which prevent the thrust collar from moving either forward or backward. The axial thrust is stopped by the front thrust shoe which rubs against the thrust collar.

d. There is constant friction at this point. In revolving, the thrust collar brings up oil from the lubrication reservoir in the base of the housing to lubricate itself and the thrust shoe it rubs against. In the Kingsbury thrust bearing, the oil is cooled with sea or raw water. Again the heat exchanger principle is employed. In the lubricating oil reservoir at the base of the thrust bearing housing, tubing is arranged through which the cold raw water is pumped. There is enough tubing so that the oil has the opportunity to contact some part of it. The raw water coming directly from the valve cage of the raw water pump goes through this tubing and is then discharged overboard. If a water cooling system is used, it is important the operator be positive at all times that a water supply is reaching the bearing.

e. The bearing is fitted with a thermometer. The maximum operating temperature of this thrust bearing is 160° F. In rough water, when the propeller may raise out of the water, the temperature of the thrust bearing may increase. When this occurs, the engine should be slowed down. If this is not possible, the bearing should be packed with ice or cold water should be sprayed over it.

SECTION V
ENGINE FUEL SYSTEM

40. GENERAL. An engine in operation requires a constant supply of fuel. Facilities must be provided on ships to store the supply needed, to clean the fuel, to subject it to pressure, to deliver it to the cylinders, to force it into a spray, and to control the quantity and the intervals of its delivery to each cylinder.

41. OUTLINE OF SYSTEM. The fuel system on the Enterprise engines starts at the aft, or back, end of the engine, as shown in Fig. 33. The fuel leaves the storage tanks, not shown in this illustration, and passes through a filter. Then it goes into the fuel oil transfer pump and into the accumulator tank. From the accumulator tank it is forced through absorbent filters. From there it moves into the fuel oil header which supplies the fuel injection pumps that force the fuel into the nozzles through which it is sprayed into the cylinders at the proper time. Any fuel leaking from the nozzles or fuel pumps drops back into the drain line located underneath the fuel header and it returns to a waste tank or to the fuel tanks. The action of the entire system is fast and precise. Each unit in the system will be discussed separately, in the subsequent paragraphs, starting from the time the fuel leaves the storage tank.

42. SCRAPER TYPE FILTER. After leaving the storage tank, the fuel oil passes through a scraper type filter. This is a basic type of filter composed of a chamber or housing and fitted with a fine wire mesh screen through which the oil passes. As the fuel passes through the filter, dirt particles are screened out. There is a handle on top of the filter that turns a knife blade fitted around the outside of this filter. The blade scrapes off accumulated dirt. A drain is provided at the bottom of the filter to draw out dirt and also any water that may be in the fuel. In some installations, two scraper type filters are provided with a three-position control handle between them which permits one filter to be used while the other is being cleaned. Normally, only one filter should be used at a time, leaving a spare available. When the engine is operating, the scraper handle should be turned at least once every hour. When the mesh in the filter becomes clogged, it can be easily taken out and cleaned, care being taken not to damage the gaskets sealing the filter.

43. FUEL TRANSFER PUMP. ***a.*** After passing through the scraper filter, the fuel is taken into the fuel transfer pump. The pump places the fuel under pressure and forces it through the system. This pump is shown in Fig. 33 located at the end of the pipe lines. The fuel transfer pump, driven by the camshaft of the engine, is of a simple design, consisting of a cylinder, or housing and a plunger, or piston, with a suction valve and a discharge valve.

b. The suction stroke of the piston draws oil into the cylinder, as shown in Fig. 34. The suction also opens the suction valve and, at the same time, holds the discharge valve closed. At the completion of the suction stroke, the fuel is in front of the piston, as shown in Fig. 35. Then it starts on its discharge or delivery stroke, developing a pressure which keeps the suction valve closed and opens the discharge valve when the proper amount of pressure has been reached.

c. Since the fuel transfer pump operates from the engine, its speed increases or decreases with the speed of the engine. To guard against excessive pressures, a pressure regulating valve similar to the one used on the lubrication oil pump is fitted on the discharge end of the pump. The valve is spring loaded and, by adjusting the tension of the spring with the fitting provided for this purpose, the fuel delivery pressure is maintained. This pressure should not be over 20 pounds per

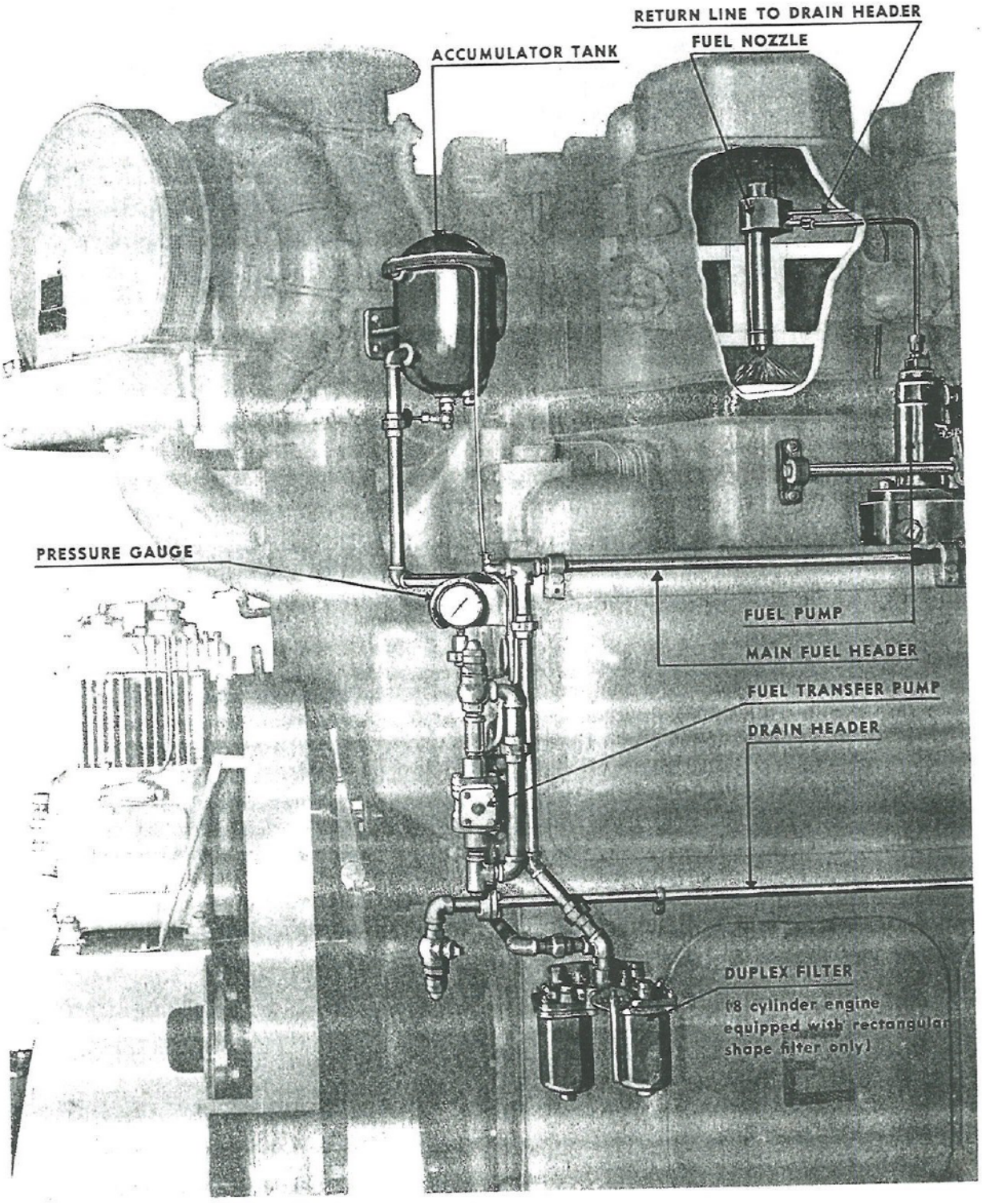

Fig. 33. System of Fuel Delivery

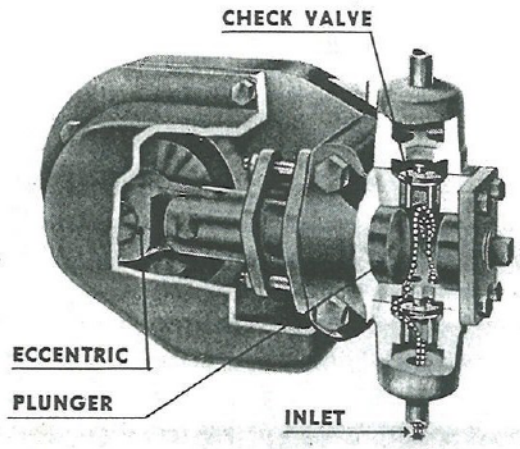

Fig. 34. Fuel Pump on Intake Stroke

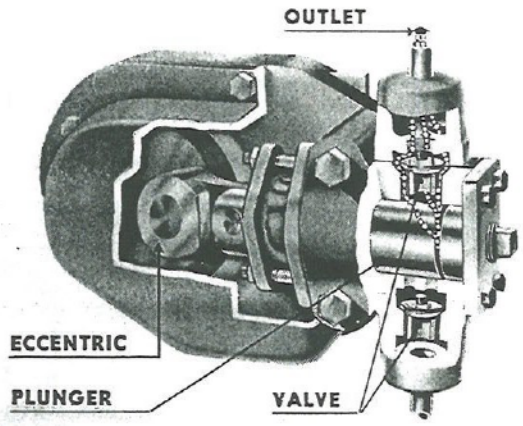

Fig. 35. Fuel Pump on Discharge Stroke

square inch. When the pressure developed by the fuel transfer pump is excessive, the pressure regulator valve spring is compressed and the valve unseated. The fuel then escapes by a by-pass back to the suction end until the pressure of the fuel delivery is decreased.

44. ACCUMULATOR TANK. Fuel oil under pressure from the fuel transfer pump enters the fuel accumulator tank. This small tank stores fuel under pressure for the immediate needs of the engine. It also allows any air in the fuel to escape. The tank is fitted with a float valve. The incoming fuel pushes trapped air to the dome of the tank, and the float valve, riding on the oil level, permits air to escape. When the tank is filled with fuel, the air escape outlet is closed. A drain plug in the bottom of the tank permits the drawing off of water and dirt.

45. ABSORBENT FILTER. The fuel oil leaves the accumulator tank and passes through an absorbent filter for a final cleaning before entering the engine. The absorbent type filter is shown in Fig. 33. There are two of them on the engine. A control handle is provided so that only one filter is used at a time, leaving the other ready for use when it is necessary to clean one. When the fuel is especially dirty, it is advisable to use both filters. One may be shut off for cleaning if the engine must be kept running. The elements in these filters are about the same as used in the absorbent filters in the lubrication oil system. The filters should be drained of sludge daily and inspected weekly.

46. FUEL PRESSURE GAUGE. When the fuel leaves the absorbent filter it goes into two pipe lines, as shown in Fig. 33. One is a short piece of tubing which leads to the fuel pressure gauge. This gauge records the fuel pressure as it enters the engine. At full running speed, the pressure should not be over 20 pounds.

47. FUEL HEADER. The other line leading from the absorbent filter carries the fuel into the fuel header, or main supply line. This line extends the length of the engine. The header supplies the fuel to the fuel injection pumps. There is a fuel injection pump for every cylinder, each drawing oil from the header.

48. FUEL INJECTION PUMPS. Each fuel injection pump has two jobs. One is to deliver fuel to the cylinder, and the other is to measure the quantity of fuel sprayed into the combustion chamber for firing. The pumps are shown installed on the engine in Fig. 33, along

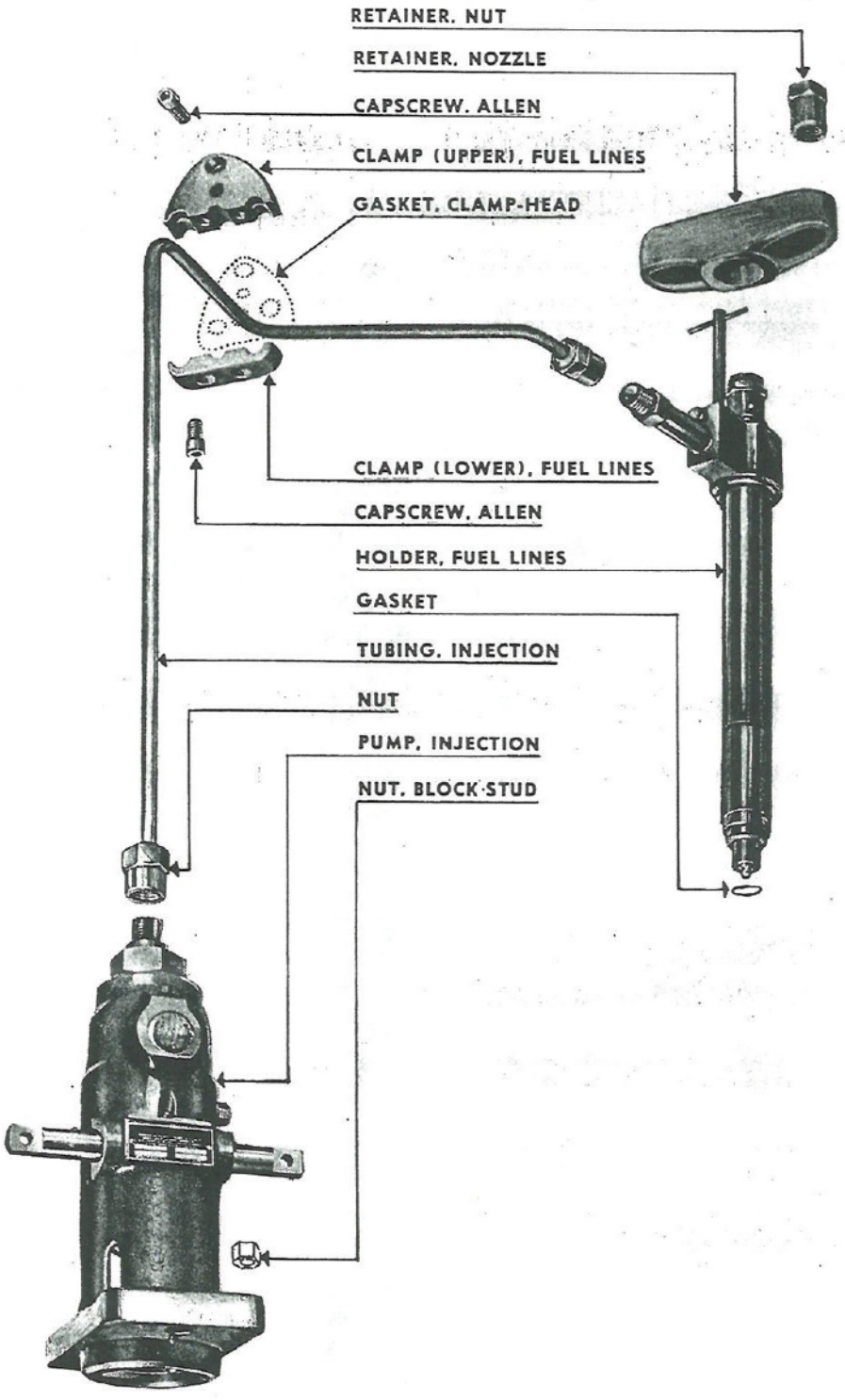

Fig. 36. Fuel Injection Pump and Nozzle with Connecting Tubing

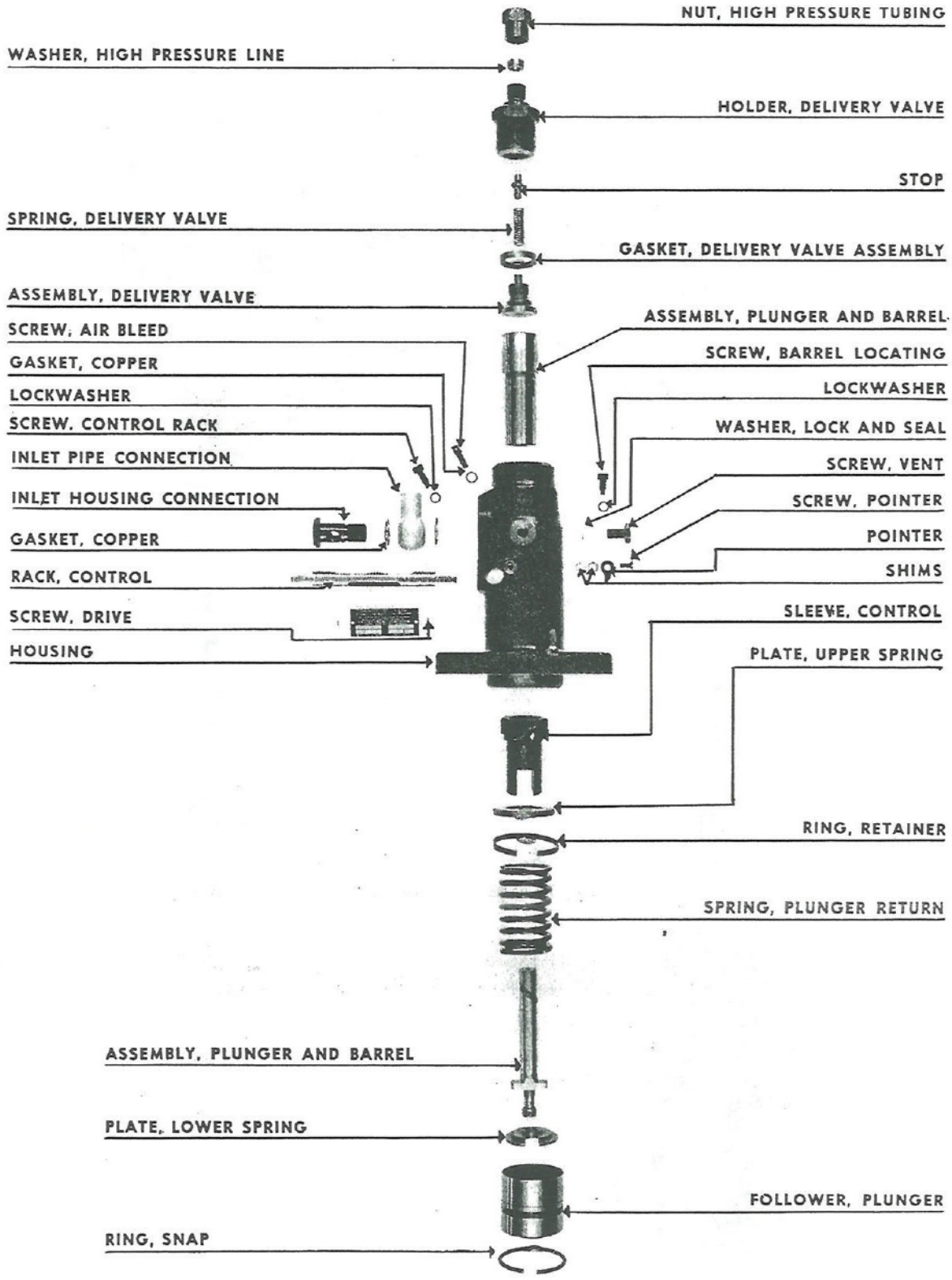

Fig. 37. Fuel Injection Pump Parts

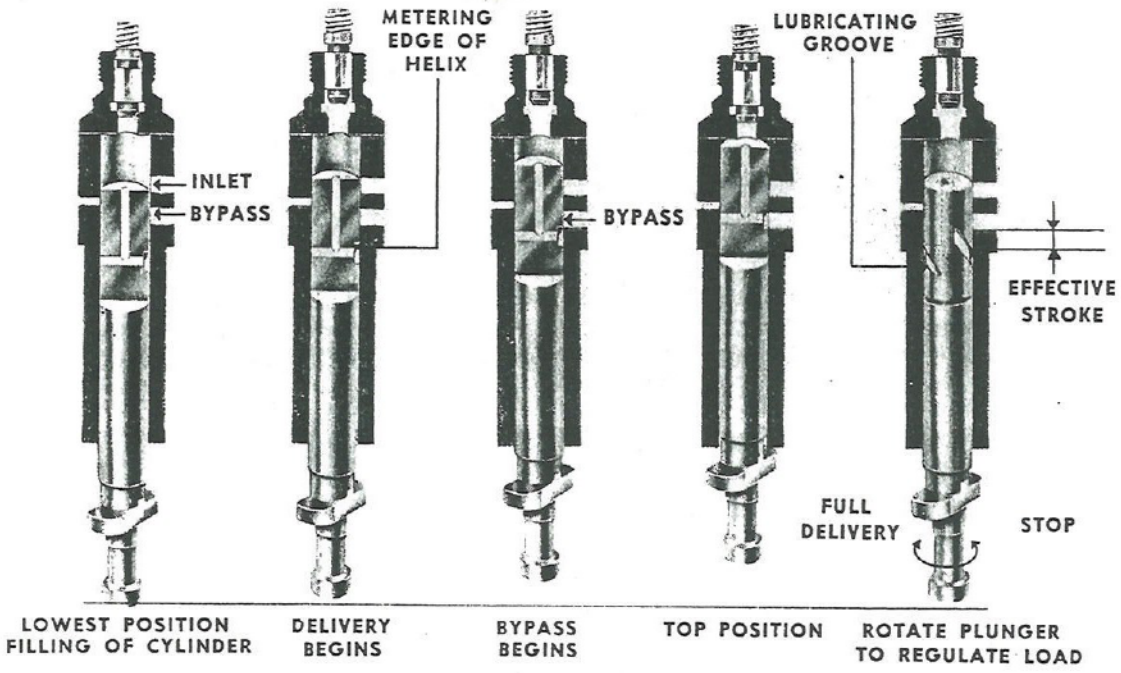

Fig. 38. Fuel Injection Pump in Operation

with the tubing which leads to the fuel injection nozzles in the cylinder heads. In Fig. 36 the fuel injection pump and fuel injection nozzle are shown together, partially disassembled. The fuel injection pump is driven by a fuel tappet roller that contacts a cam lobe on the camshaft at the proper intervals to insure fuel delivery to each cylinder at the correct time. The operation of the camshaft is fully explained in Sect. VI. Basically, the fuel injection pump is of the simple plunger type. It is composed of a cylinder, or housing, in which a plunger or piston moves up and down. On the downward stroke the piston draws in fuel, and on the upward stroke it forces the fuel out into the delivery line. However, since the amount of fuel delivered to each cylinder determines the speed and power developed, it is necessary that something be done to permit only part of a full pump load of fuel to reach the cylinder when the engine is being run at less than full speed. This is done by a by-pass system.

49. FUEL BY-PASS. ***a.*** In Fig. 37 the fuel injection pump is shown taken completely apart. In Fig. 38 a series of cutaway drawings of a fuel injection pump shows the steps of operation. On the top of the plunger, in the center, a hole is drilled down the plunger to a point approximately two-thirds of its length. On the right side of the plunger a curved groove is cut on the outside of the plunger on an angle. Into this curved groove, or helix, a hole is drilled crosswise through the plunger meeting the hole drilled through the center. Thus, the lengthwise hole, the crosswise hole, and the helix form one continuous passage through the fuel pump plunger. Figs. 37 and 38 also show that the pump barrel has two holes drilled on the right side. The top hole is the inlet port. The hole just below it is the by-pass port. There is a smaller curved groove on the plunger on the opposite side from the helix but it functions only as a means of lubricating the pump barrel.

b. Fig. 38 shows the operation of the by-pass system. In drawing on the extreme left, fuel oil has filled the pump chamber through the inlet port, and the plunger has started on the upward stroke. At the same time that the pump chamber filled with fuel, the holes

drilled in the plunger and the helix groove also filled up but the oil contained in them is prevented from escaping by the close fit of the plunger in the pump barrel. In the next drawing, the fuel oil in the pump chamber is subjected to high pressure by the upward stroke of the plunger and is forced out through the delivery valve at the top of the pump into the injection tubing which delivers the fuel into the cylinder combustion chamber through the spray nozzle. The next drawing illustrates the next stage in the upward travel of the plunger. At the same time that the upward movement of the plunger has been subjecting the fuel to pressure the helix groove in the plunger has been moving closer to the by-pass port in the pump barrel. The instant this happens, as shown in the drawing, the fuel under pressure is by-passed back through the hole in the center of the plunger, out through the helix groove and through the by-pass port. As soon as the by-passing of fuel starts, the pump stops delivering fuel into the injection tubing, and the effective stroke of the plunger ends. In the next drawing the plunger is shown at the top position but all fuel contained in the pump is escaping through the by-pass. Thus, regardless of the amount of fuel required to maintain a desired engine speed, the plunger in the fuel injection pump always makes a complete stroke. The effective stroke of the plunger is controlled, however, by the distance the plunger can travel before the helix reaches the by-pass port. In drawing on the extreme right the helix on the plunger is shown in a different position so that the effective stroke is much shorter than in other drawings.

c. The changing of the effective stroke of the plunger is accomplished by rotating the plunger. This, in turn, alters the point at which the curved, or slanted, helix groove, meets the by-pass port. The plunger is rotated by moving the fuel control rack, or rod, as shown in Fig. 37, on the fuel injection pump. The fuel control rack moves either in or out of the fuel injection pump housing and turns the regulating sleeve, which, in turn, changes the position of the plunger. Each fuel rack is secured to the fuel control shaft as shown in Fig. 33. When the throttle setting is changed, the governor adjusts the control shaft to deliver the speed desired.

d. The system operates as follows: The operator sets the throttle for half speed. The control shaft pulls the fuel racks on all the pumps to half open. The fuel racks turn the plungers in all the injection pumps to such a position that when the plunger is halfway through the delivery stroke, the helix will meet the by-pass port and the balance of the fuel in the pump chamber is by-passed back to the suction side of the fuel injection pump. If the operator changes the throttle to closed, the control shaft pulls all the fuel racks to the closed position. This means that the fuel pump plungers are rotated so that the helix groove meets the by-pass port before the inlet port is closed, thereby by-passing all the fuel.

50. FUEL DELIVERY VALVE. At the top of Fig. 37 the fuel delivery valve is shown as a part of the fuel injection pump. This valve acts as a check valve to prevent fuel oil from bleeding back into the fuel injection pump and to keep the injection tubing filled at all times. The air compression inside the combustion chamber of the cylinder when the fuel is injected is 400 pounds. The fuel must enter the combustion chamber at a pressure that not only will force entry into the solid mass of air, but also will atomize the oil. This pressure ranges from 2000 to 8000 pounds, depending on the engine speed.

51. FUEL SPRAY NOZZLE. a. At this stage the fuel is in the injection tubing and is ready to enter the cylinder through the fuel spray nozzle. In Fig. 36 this nozzle is illustrated with the fuel injection pump and the fuel tubing. In Fig. 39 it is shown disassembled. The tip of the nozzle has fine holes through which the fuel enters the cylinder in a highly atomized state. Because these holes are so small, every precaution must be taken to deliver only clean fuel. As the fuel enters the fuel inlet of the nozzle, it must pass through another filter. This is called an edge filter. It is a simple mechanism with a filter placed in the path of the fuel, and its purpose is to screen out any particles of dirt that may still be in the fuel.

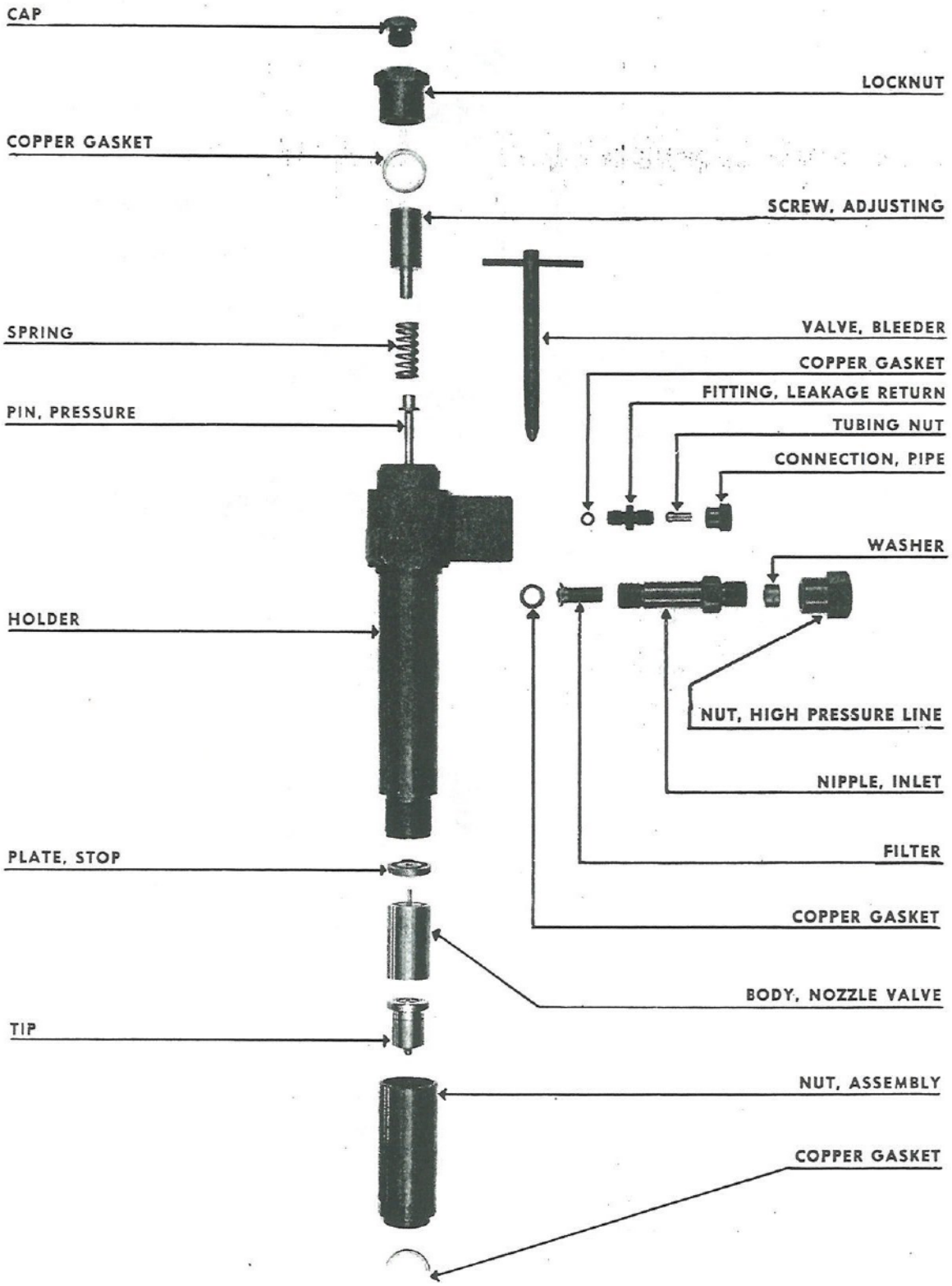

Fig. 39. Fuel Nozzle Parts

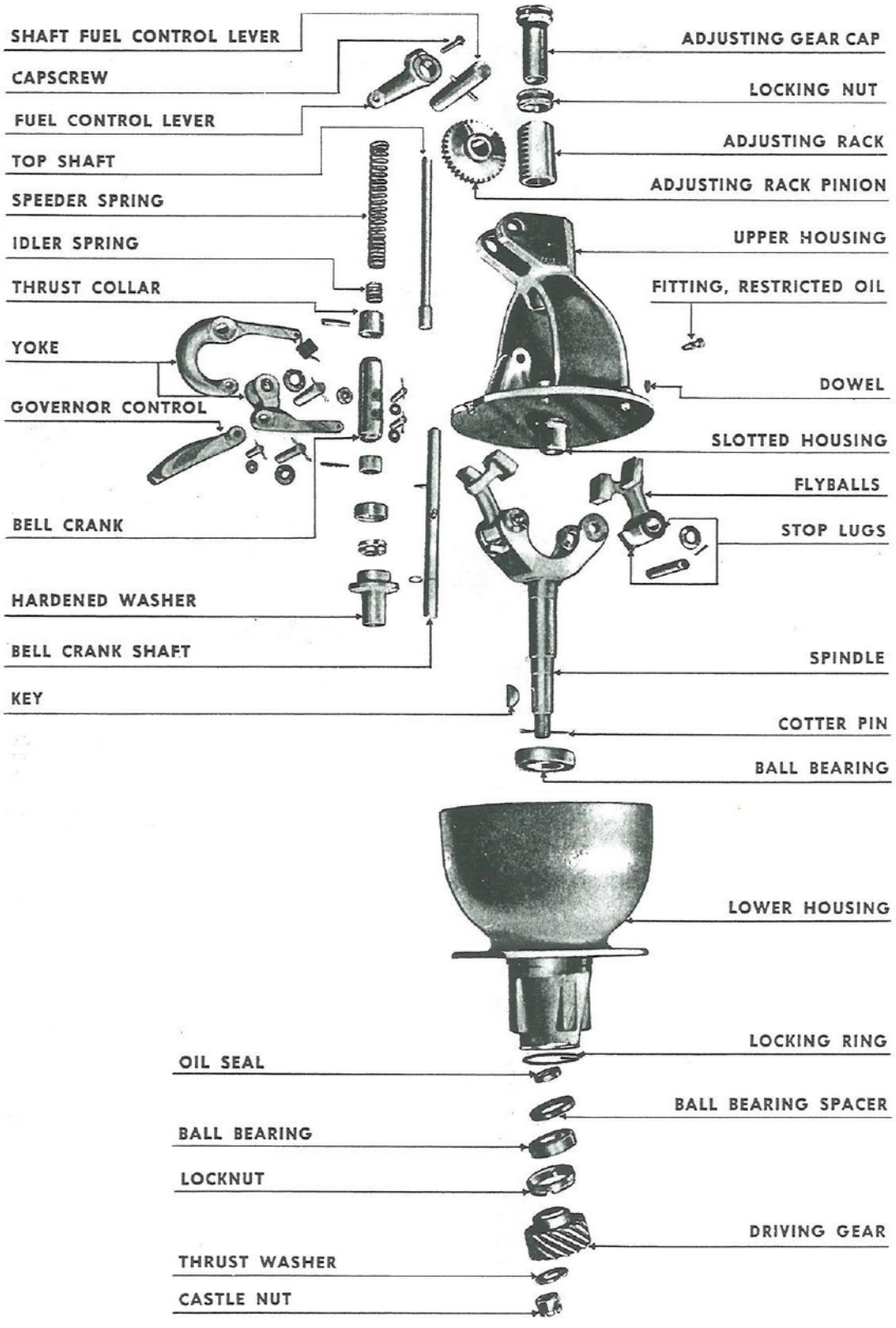

Fig. 40. Fuel Governor Parts (Mechanical)

b. The fuel spray nozzle, in principle, is a highly machined and perfected spring loaded pressure relief valve. An adjusting screw sets the tension of the spring to hold the valve closed until the fuel in the injection tubing attains sufficient pressure to overcome the spring tension. The valve is then unseated and the fuel rushes out through the nozzle tip and into the cylinder. A bleeder valve and fittings also are shown in Fig. 39. The functions of these parts are explained later.

52. "BLEEDING" THE FUEL SYSTEM. Air must be kept out of the fuel system. Usually when an engine has been idle for some time, or when parts of the fuel oil system have been dismantled, some air gets into the fuel system. The removal or "bleeding" of air from the system starts with the storage tanks. The valve admitting fuel oil must be opened. Then the vent plugs in filters must be opened and the fuels allowed to escape until all air has been removed. Then the vent plugs on fuel pumps must be removed, and the fuel allowed to run until it comes out in a smooth flow without air bubbles. The injection lines must be cleared of air, as follows:

All injection pumps should be set at full fuel. The operating control interlock will keep the injection pumps in the stop, or no fuel position when the engine is shut down. The control should be moved to the ahead, or astern, operating position. When this position is reached the interlock will have cleared, and the tension of the governor spring will open the fuel pumps to the full fuel position.

The nozzle bleeder valve should be opened slightly and the pumps primed by means of the priming shaft until a definite resistance is felt. This indicates that all the air has been expelled. Do not use too long a wrench nor too great a force on the priming shaft. If, upon attempting to prime a pump, no resistance is felt, it is an indication that the fuel tappet is on the peak of the fuel cam. In such a case, the pumps that are not in this position should be primed, and the engine barred over until the tappets contact a low point on the cam. Then it will be possible to prime the remaining pumps.

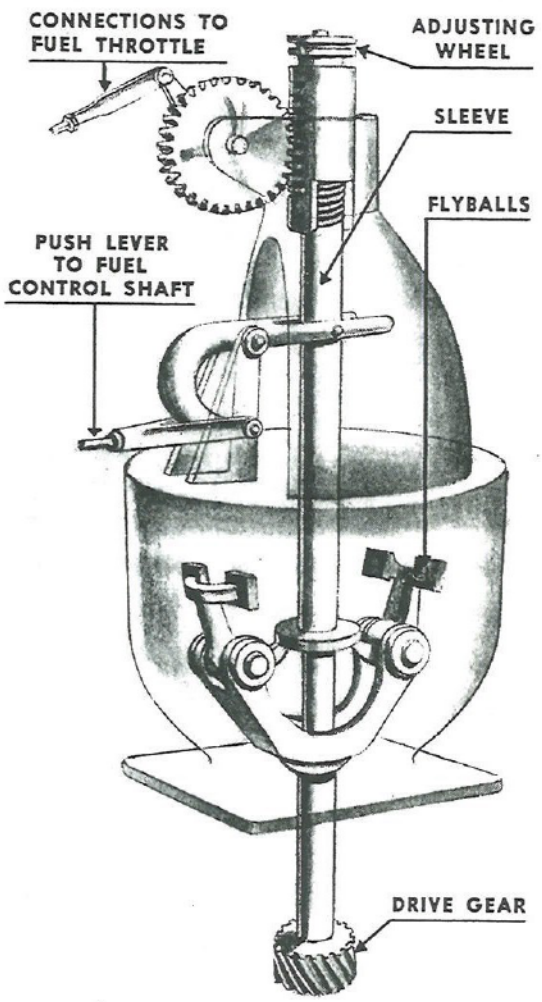

Fig. 41. Governor, Mechanical, in Idling Position

This condition can be seen by observing the timing mark in the window in the fuel pump body.

53. THE GOVERNOR. The engine speed must be controlled constantly by increasing or decreasing the amount of fuel delivered to the cylinders to maintain a steady speed. The operator cannot visually gauge the demands that are put upon the engine to hold the speed constant. Cross currents, changing tides, climbing waves, and so on, all place varying loads upon the engine, and these loads change constantly. Therefore, when the throttle is set at a desired speed, a unit called the governor

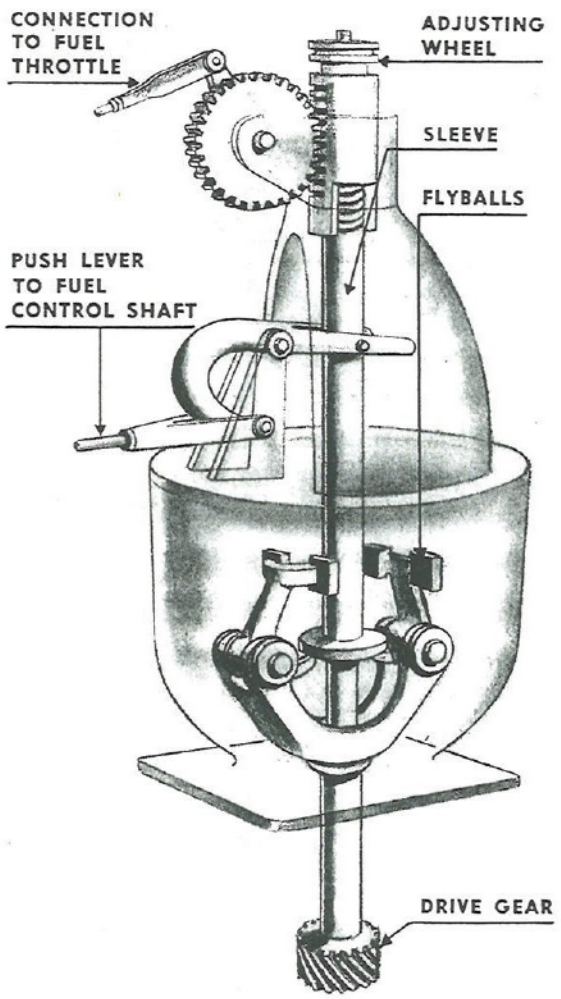

Fig. 42. Governor, Mechanical, in Half Speed Position

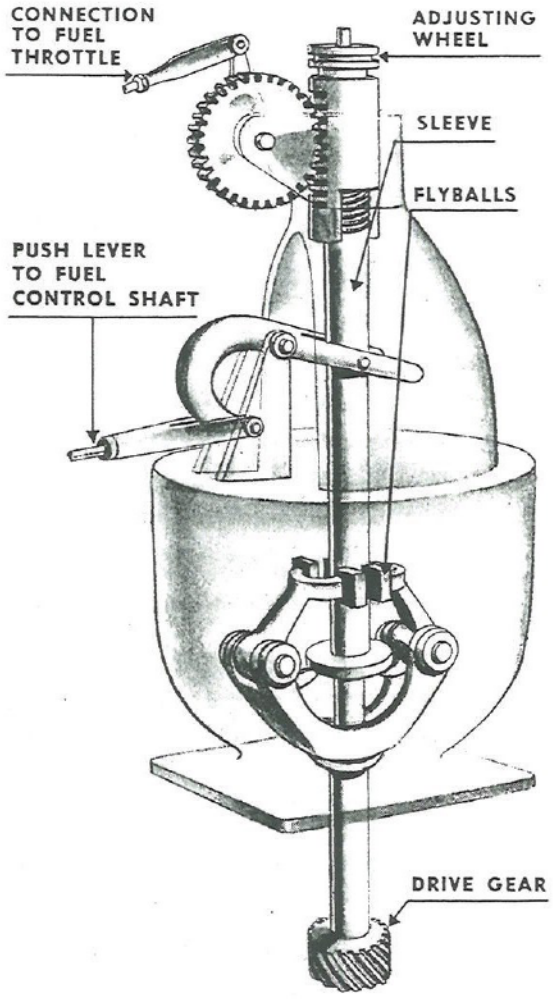

Fig. 43. Governor, Mechanical, in Full Speed Position

is responsible for maintaining the speed. The governor actually rotates the fuel control shaft which regulates the adjustment of the fuel racks in the individual fuel injection pumps. A heavier load requires more fuel, and a lighter load requires less. The governor also protects the engine. If the propeller should fall off, the engine would run up to a speed which would wreck it unless it were controlled. Even where a constant load is experienced, an engine having no governor would pick up greater speed due to momentum. Enterprise engines are equipped with either a mechanical flyball-type governor or a Woodward hydraulic governor.

54. MECHANICAL GOVERNOR. *a.* The parts of the Enterprise engine governor are shown in Fig. 40. Figs. 41, 42 and 43 show how the governor works.

b. Fig. 41 shows the position of the governor when it is holding the fuel injection pumps almost closed or corresponding to idling speed. By setting the throttle to idling speed, the throttle linkage changes the position of the adjusting pinion on the top of the governor so

that the spring exerts only a little pressure on the shaft and sleeve. The sleeve, in turn, exerts only a little pressure on the sleeve washer which controls the position of the flyball arms which can remain away from the center shaft. The linkage from the yoke to the fuel control shaft holds the fuel racks on the fuel injection pumps to the idling setting.

c. Fig. 42 shows the governor when the engine is running at approximately half-speed. By changing the throttle setting, the adjusting pinion at the top of the governor is changed so that it pushes down on the spring. This increased spring tension exerts greater pressure against the sleeve which forces down the sleeve washer permitting the flyballs to move closer to the shaft. This changes the position of the yoke which is connected to the fuel control shaft.

d. Fig. 43 shows the position of the governor when the throttle is set at full speed. The adjustment of the pinion results in increased spring tension which forces down the sleeve. The sleeve then pushes down on the sleeve washer, permitting the flyballs to close in against the shaft. This change alters the position of the yoke which, in turn, is reflected by the settings of the fuel racks on the fuel injection pumps.

e. Should the engine increase in speed, due to the propeller leaving the water or falling off the shafting, the rotative speed of the governor shaft will increase. This will cause an increase in the centrifugal force and cause the flyball weights to fly outward from the shaft and change the position of the yoke. This will result in the linkage to the fuel control shaft changing position to close down the amount of fuel delivered by the fuel injection pumps and maintain the speed within the desired limits. The governor should not cause any trouble, but under service conditions there is a possibility that a sudden stress might make it necessary to run the engine temporarily without the governor functioning. In this emergency, the governor should be disconnected from the throttle and fuel control linkage. The fuel control shaft should be operated with a wrench.

55. HYDRAULIC GOVERNING SYSTEM. Enterprise engines with this type of equipment use the Woodward hydraulic governor. Its function is the same as the mechanical type governor explained in par. 54. In many other ways it is also similar to the mechanical governor. The hydraulic governing system built on the engine is shown in Fig. 44.

a. In Fig. 44 the throttle lever is shown. The operator sets the throttle for the desired speed. This either pushes or pulls the throttle lever rod. This rod is not directly connected to the hydraulic governor but as shown it connects to a gear box. A shaft from the gear box is connected to the governor. The function of the gears in the gear box is to transform lateral motion into the rotative motion required to adjust the hydraulic governor. The changing of the throttle lever causes the throttle rod to move in a lateral direction. The gears in the gear box absorb this lateral motion and cause it to turn the shaft to the governor in either a clockwise, or counter-clockwise direction.

b. The rest of the units shown in Fig. 44 are explained in par. 57.

56. THE HYDRAULIC GOVERNOR. The hydraulic governor is shown cut away in Fig. 45. As shown, the governor is equipped with a set of flyballs and springs, similar in principle to the mechanical governor explained in par. 54. In addition, it also contains four plungers which are operated by oil pressure. The governor contains its own gear type oil pump,

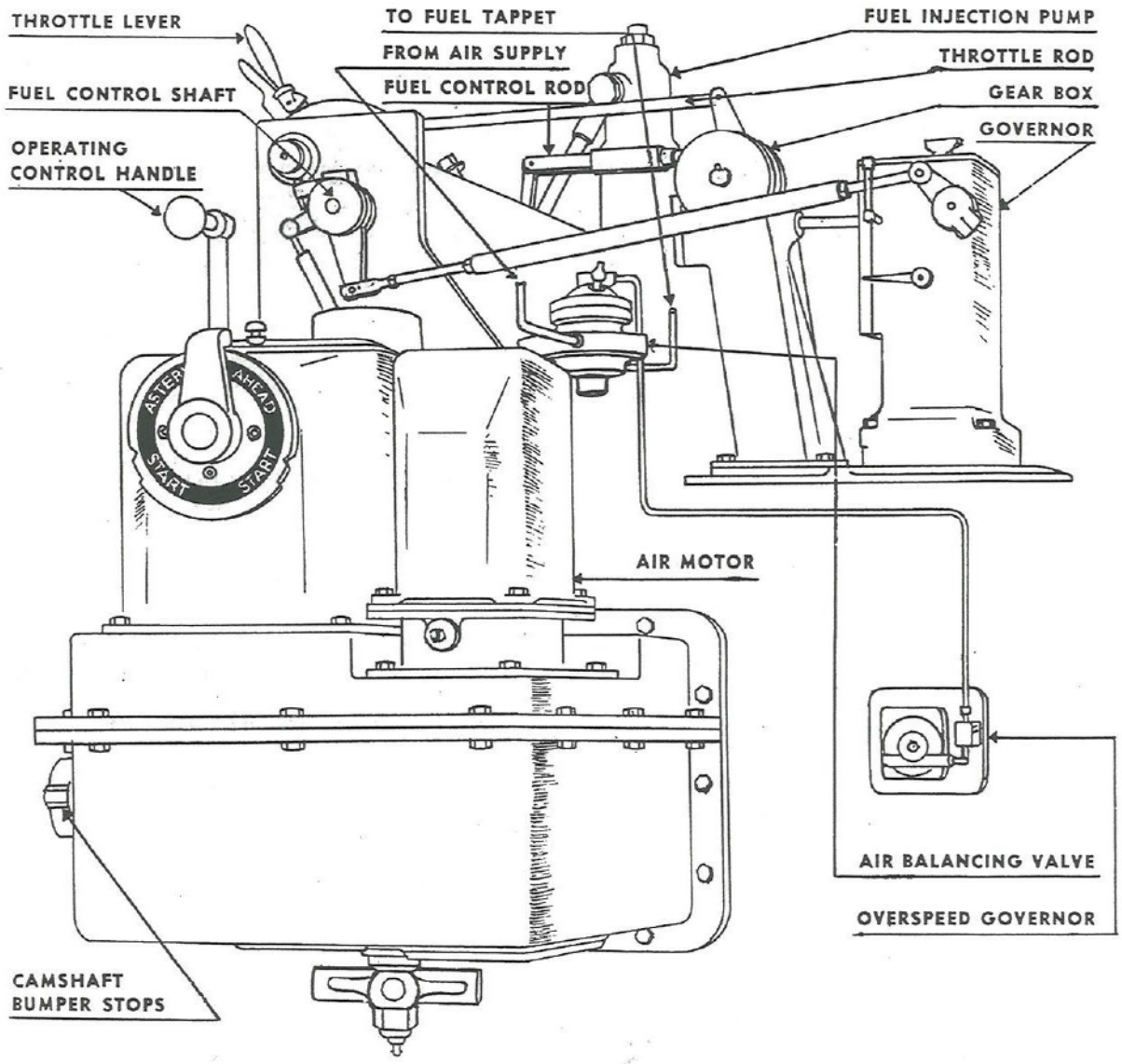

Fig. 44. Overspeed Governor System

similar in principle to the engine lubrication pumps. There is a supply of oil inside the housing of the governor. The governor is attached to the rest of the engine at three points, as follows:

(1) The shaft of the adjusting rack pinion is connected to the shaft from the gear box as shown in Fig. 45. The ends of both shafts are ridged and connected by a ridged sleeve. The operator sets the throttle lever at the desired speed and the gears in this gear box rotate the adjusting rack pinion in the proper direction. The pinion, geared into the adjusting rack, then moves this unit either up or down, decreasing or increasing the tension of the speeder spring.

(2) The ridged terminal shaft extending from the side of the governor is connected to the control linkage moving the fuel control shaft which determines the injection settings of the fuel injection pumps.

(3) The ridged drive shaft at the bottom of

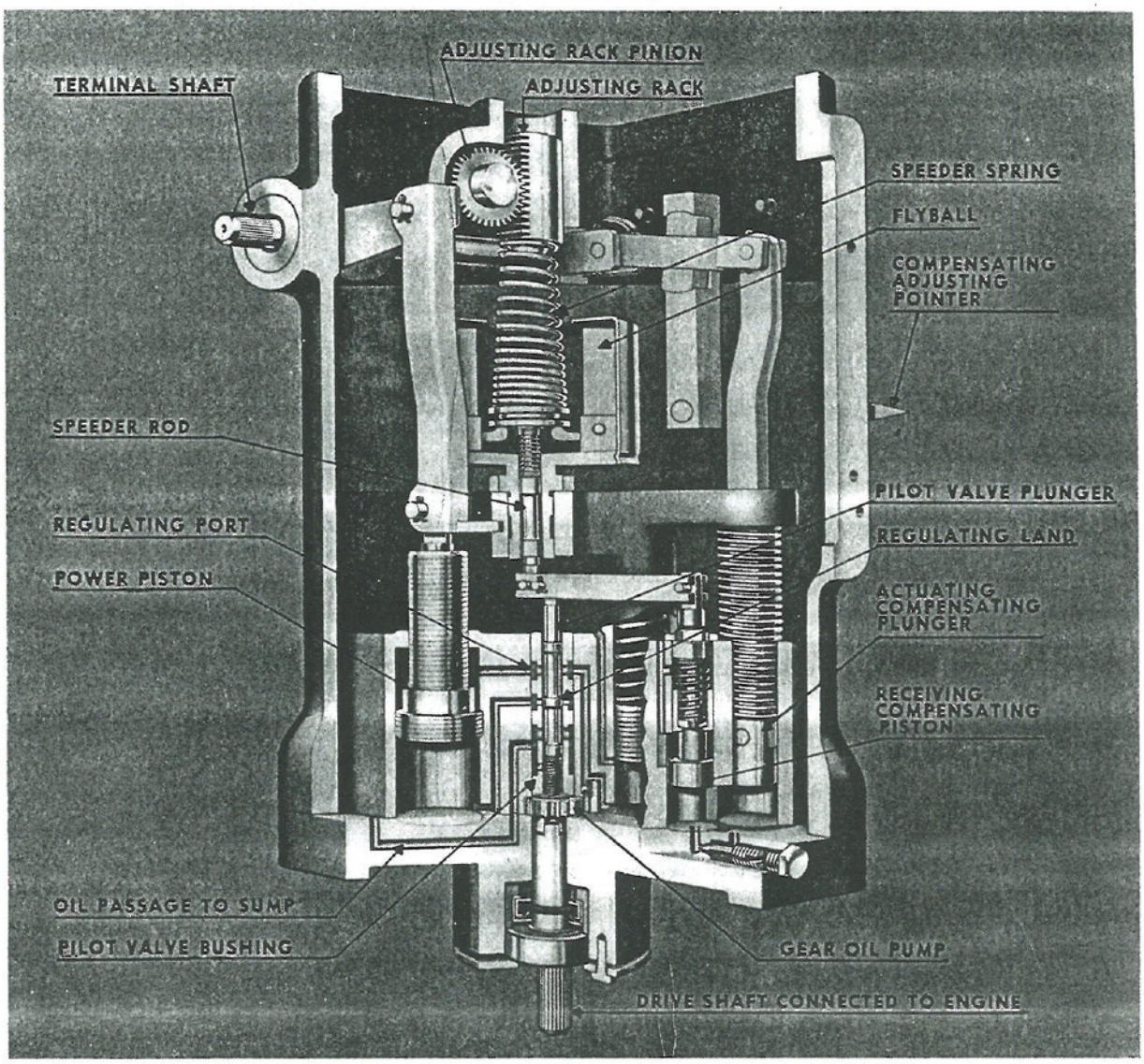

Fig. 45. Governor, Hydraulic, Operation at Normal Speed

the governor is connected to the engine. A gear driven by the engine and fitted with a ridged shaft of the same dimension is connected to the governor drive shaft with a ridged coupling sleeve. The drive shaft operates the oil pump in the governor and through a gear arrangement, drives the flyball shaft.

57. OPERATION OF THE GOVERNOR. a. In Fig. 45 the governor is shown when the engine is running at normal speed under steady load. The flyballs, speeder rod, pilot valve plunger, and receiving compensating piston are in normal positions. Notice that the regulating port in the pilot valve bushing is covered by the land, or flange, on the pilot valve plunger. The oil pump is always in operation, but the oil is either escaping into the sump through a passage or going into the power cylinder above the power piston to maintain a steady pressure on the top of the power piston. The power piston is held stationary, however, due to the

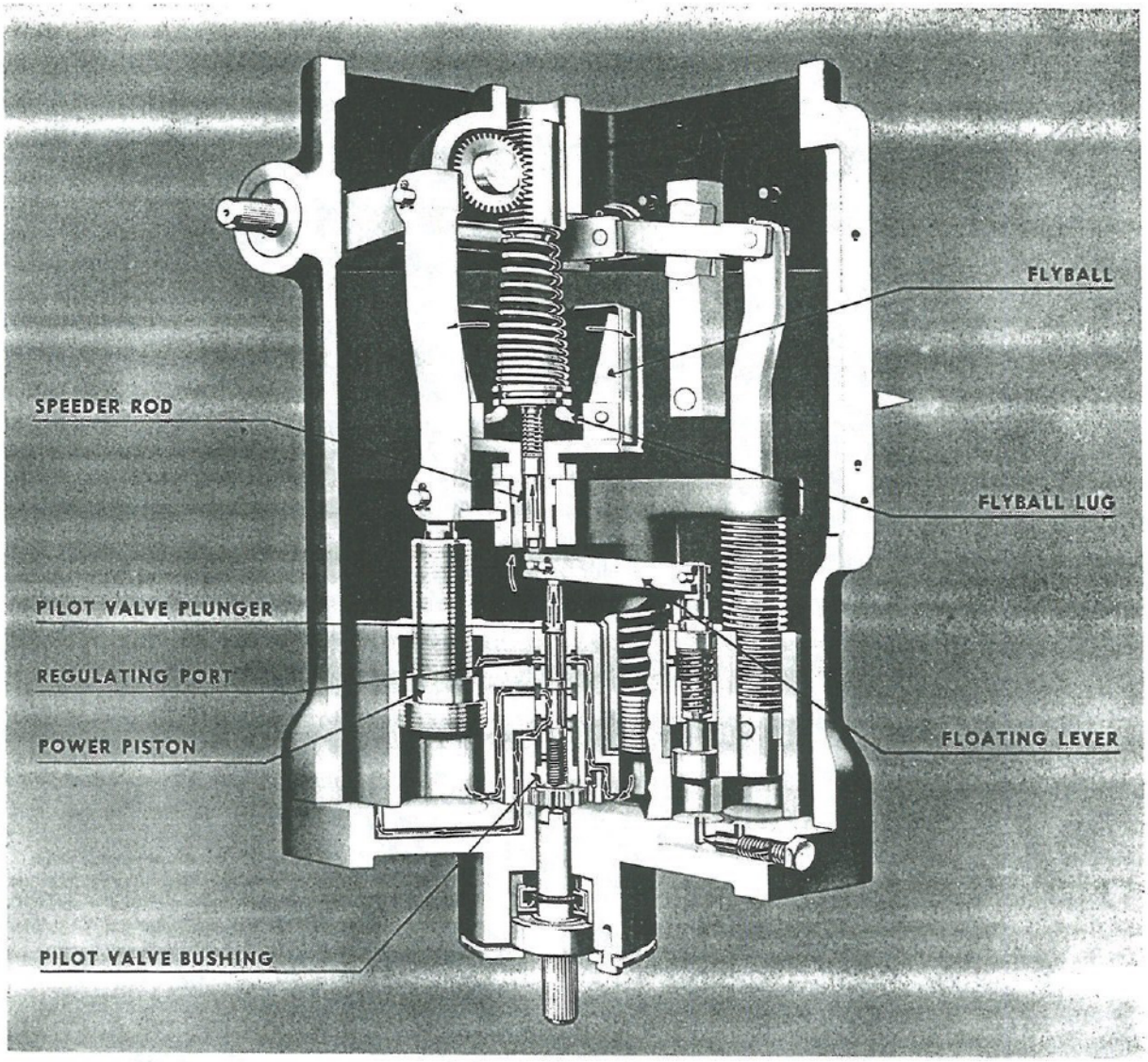

Fig. 46. Governor, Hydraulic, Operation at Increased Speed

pressure of oil trapped underneath the power piston. The terminal shaft, therefore, is also held stationary.

b. In Fig. 46 the load on the engine has decreased and the engine speeds up. As the engine speed increases, the flyballs are moved outward by centrifugal force. The flyball lugs exert upward pressure on the speeder spring which pulls up the speeder rod. As the speeder rod moves upward it raises the inner end of the floating lever to which it is attached. The movement of the floating lever raises the pilot valve plunger which is also attached to it uncovering the regulating port in the pilot valve bushing. The opening of the regulating port permits the oil trapped under the power piston to escape into the sump, as shown by the directional arrows in the illustration. The oil pressure on top of the power piston is now unopposed and moves the piston downward.

c. In Fig. 47 the oil pressure on top of the power piston has pushed it down to the bottom

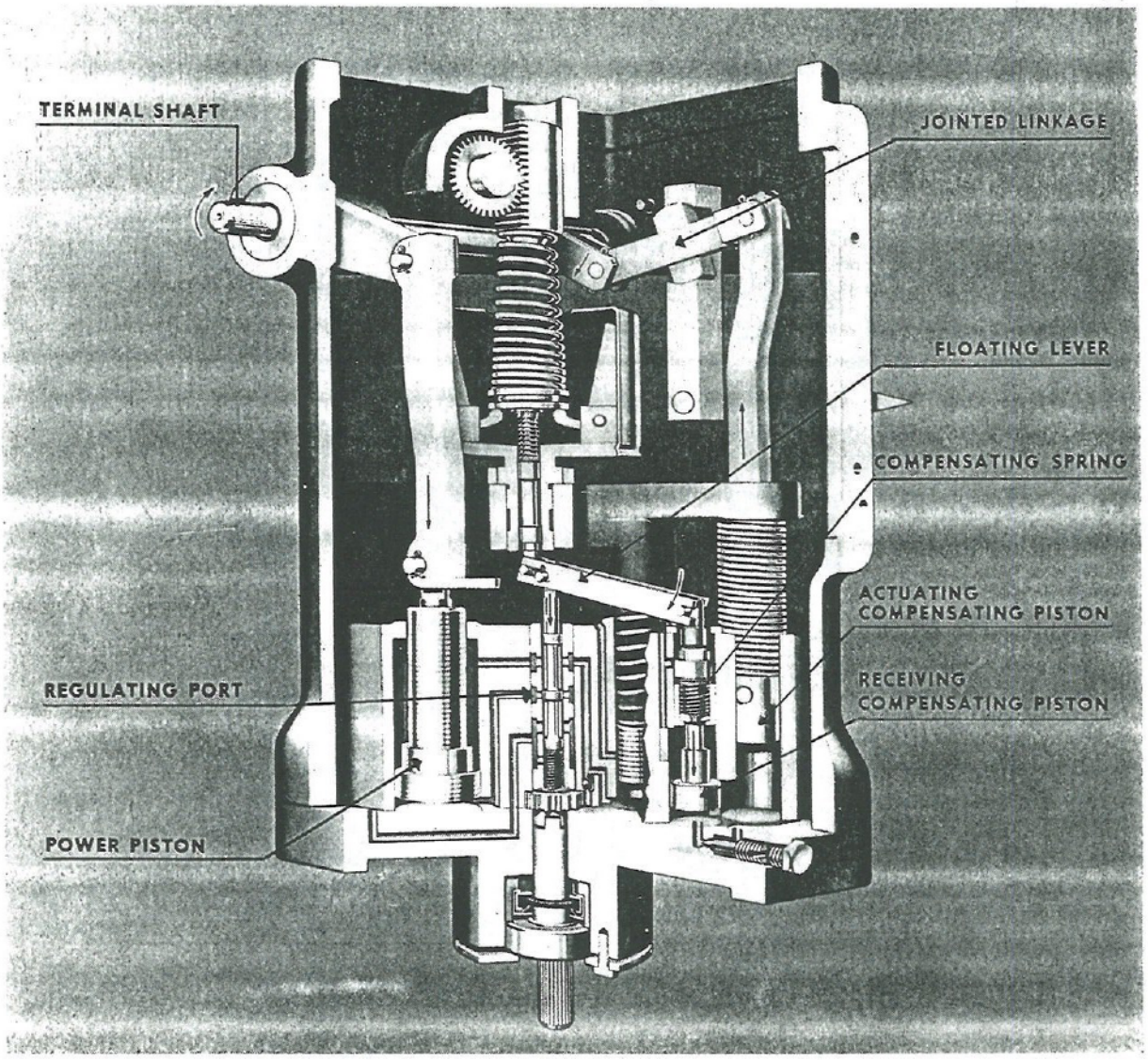

Fig. 47. Governor, Hydraulic, Operating to Decrease Fuel Delivery

of the cylinder. As it moved down, it pulled down the piston rod, rotating the terminal shaft in a clockwise direction to decrease the amount of fuel delivered to the engine. As the terminal shaft rotates it forces downward the short piece of the jointed linkage attached to it. This forces the inner end of the longer piece of the jointed linkage downward and pulls the actuating compensating piston upward. As the actuating compensating piston moves upward it creates a suction which draws down the receiving compensating piston, compressing the compensating spring, and lowering the outer end of the float lever as well as the pilot valve plunger. This movement of the power piston, actuating compensating piston, receiving compensation piston, and pilot valve plunger continues until the regulating on the pilot valve covers the regulating port. As soon as the regulating port is closed, the trapped oil underneath the piston prevents the oil pressure on top of the piston from moving. The

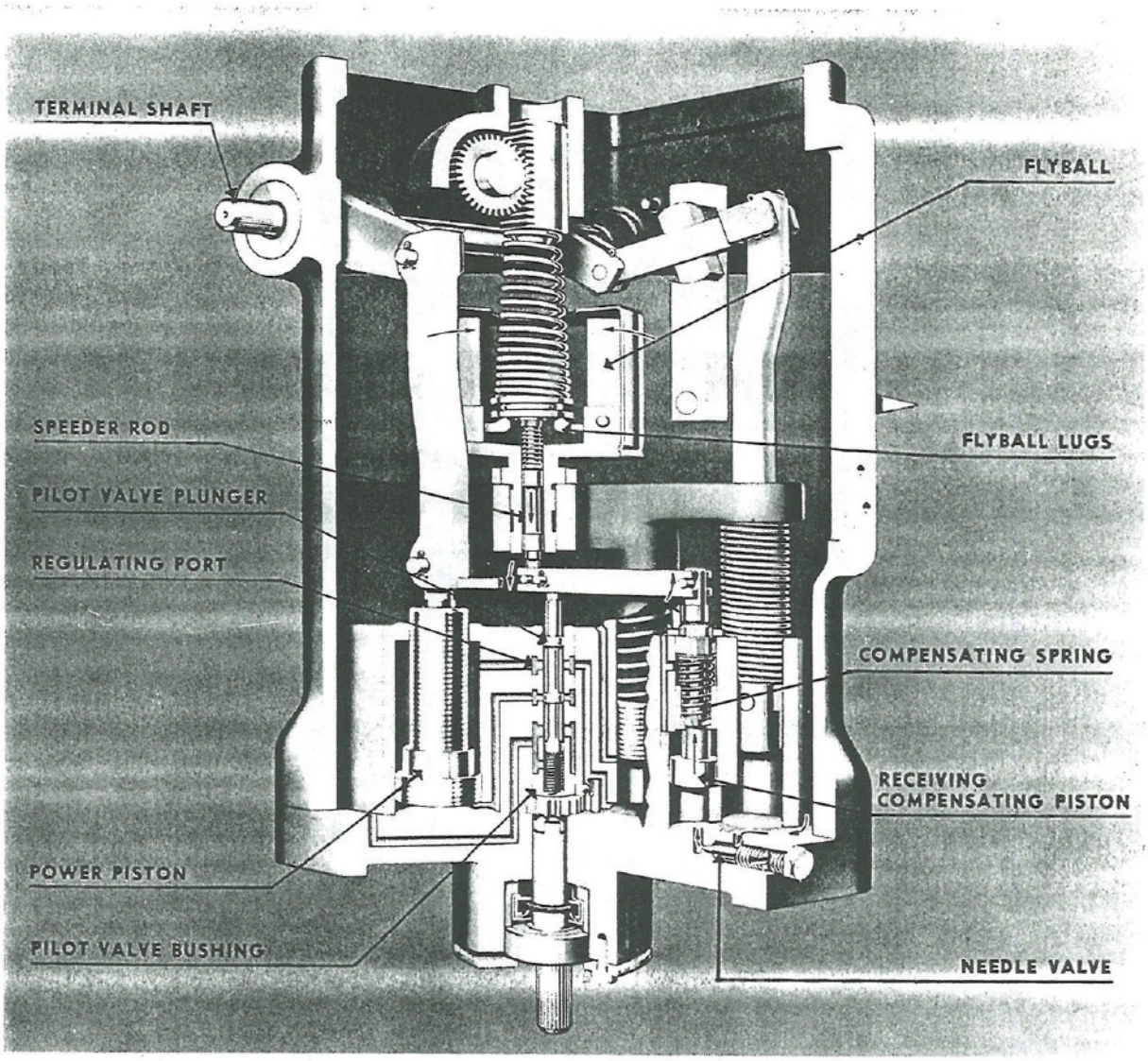

Fig. 48. Governor, Hydraulic, Operation at Normal After Compensating for Speed Increase

power piston is then held stationary, and the rotation of the terminal shaft is stopped at a position that will permit the delivery of only enough fuel to the engine to maintain the desired speed under the decreased load.

d. Fig. 48 illustrates the next step. Engine speed has decreased to the normal, or desired rate, and the flyballs close in to the normal position. As the flyballs move inward, the flyball lugs move downward, releasing tension on the speeder spring which pushes the speeder rod to normal position. The receiving compensating piston is returned to normal position by the compensating spring at the same rate as the speeder rod, thus keeping the regulating port in the pilot valve bushing covered by the land on the pilot valve plunger. The rate at which the receiving compensating piston is returned to the normal position is determined by the flow of oil through the needle valve. At the completion of this cycle, flyballs, speeder rod, pilot valve plunger and receiving compensating piston are all in normal positions. The

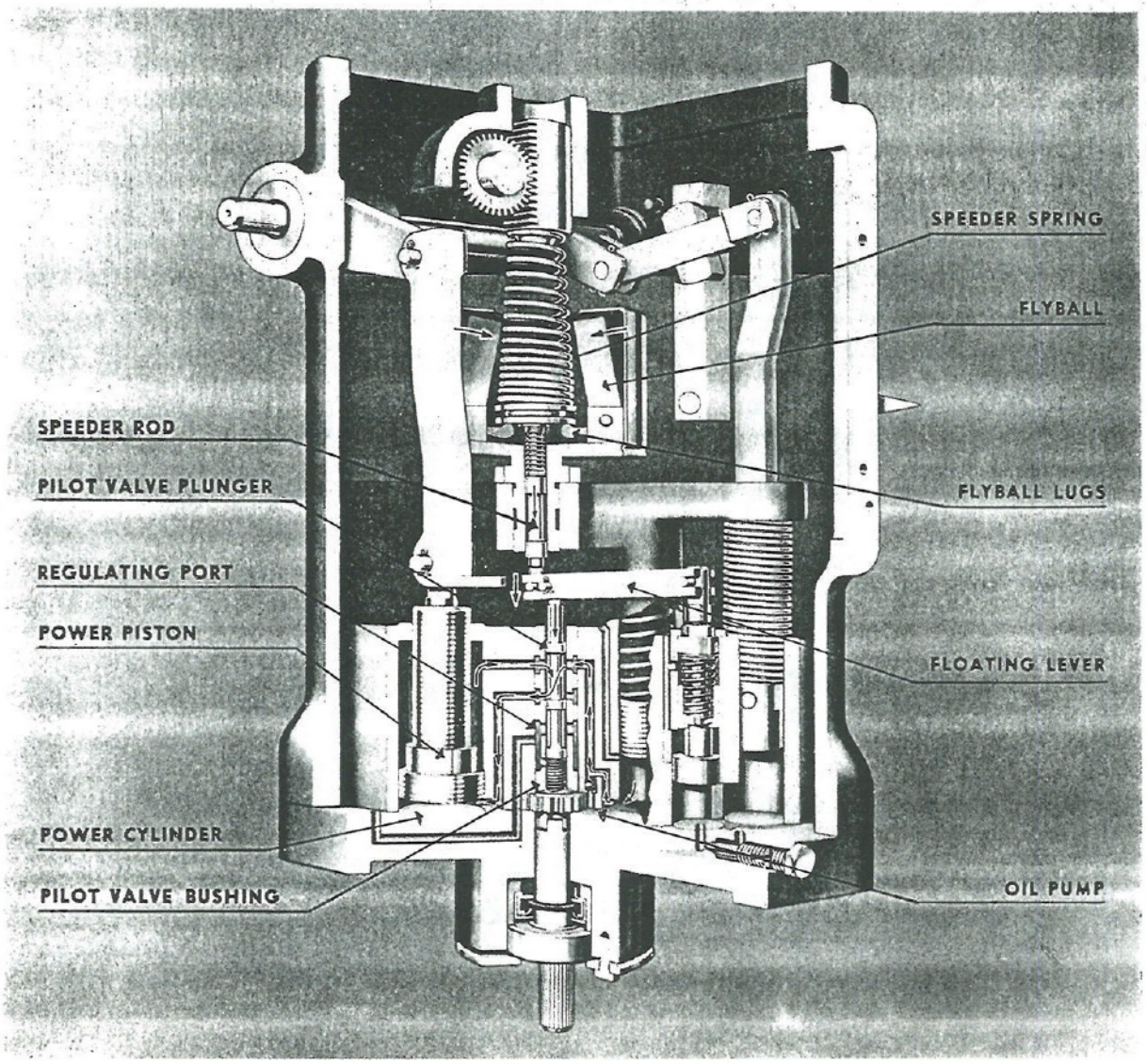

Fig. 49. Governor, Hydraulic, Operation at Reduced Speed

power piston and terminal shaft are stationary in positions required to deliver sufficient fuel to the engine to maintain desired speed under the decreased load.

e. In Fig. 49 the governor is shown as the load on the engine is increased, causing the speed to fall below the desired rate. The decreased speed lessens the centrifugal force on the flyballs and they move inward. The flyball lugs drop further downward permitting the speeder spring to expand further. This spring expansion forces the speeder rod downward. The speeder rod pushes the inner end of the floating lever downward which, in turn, forces the pilot valve plunger downward. The land is then pushed below the regulating port. As shown by the directional arrows in the oil passages on the illustration, the oil pump then forces oil under the power piston. Notice that the area of bottom end of the power piston is larger than the area of the top end. This results in greater pressure on the bottom of the power piston, and oil above the piston is forced

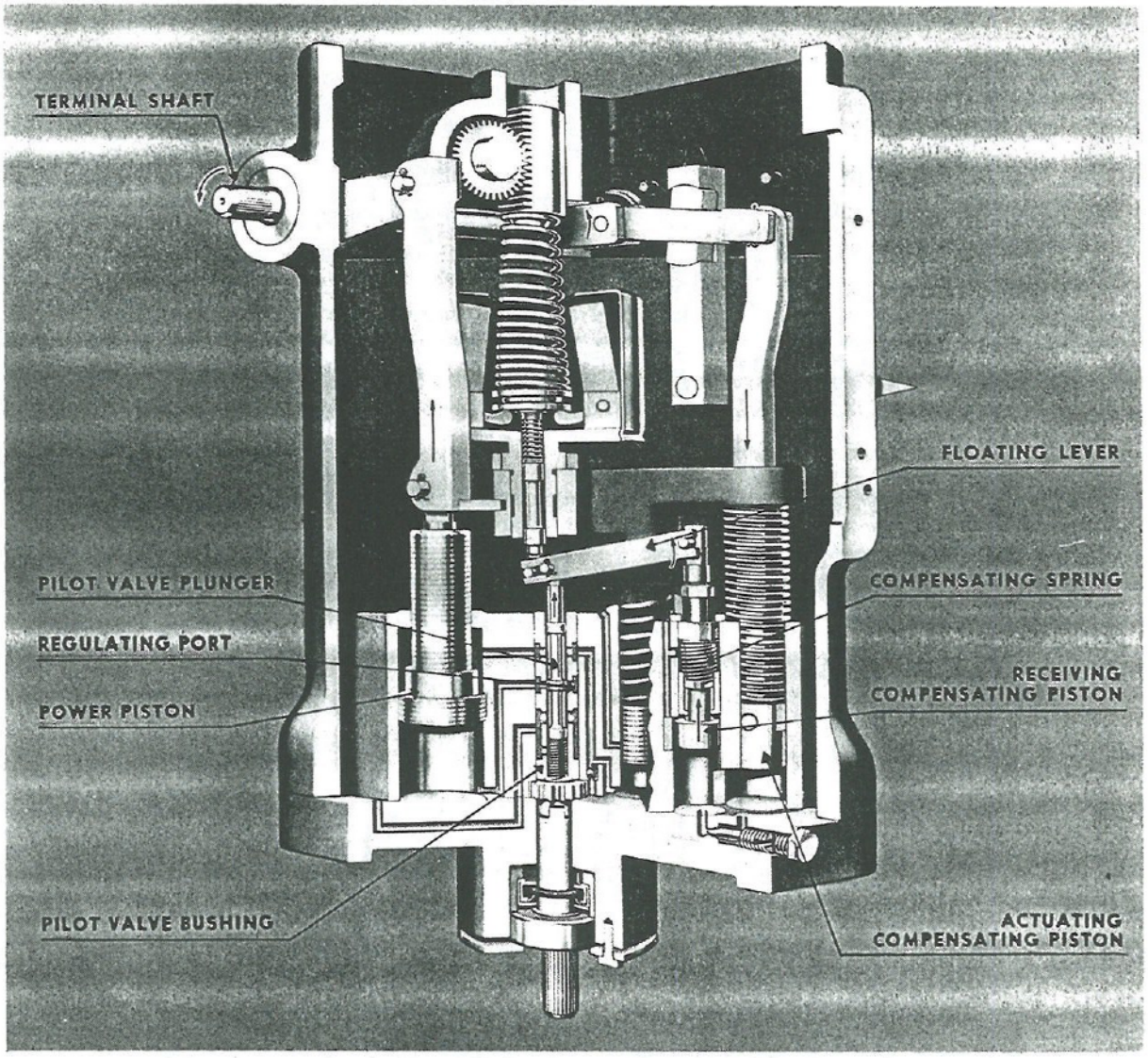

Fig. 50. Governor, Hydraulic, Operating to Increase Speed

below the piston as shown by the directional arrows.

f. In Fig. 50 it is shown that the pressure of oil under the power piston forces the piston upward. This exerts force on the piston rod which causes the terminal shaft to turn in a counter-clockwise direction. This rotation, transmitted through the fuel control linkage, causes the fuel control shaft to increase the amount of fuel the fuel injection pumps can deliver to the engine. The rotation of the shaft forces the short piece of jointed linkage upward. This action forces the longer end of the jointed linkage downward to push down the actuating compensating piston. The pressure created by the downward movement of this piston forces the receiving compensating piston upward to compress the compensating spring and raise the outer end of the floating lever as well as the pilot valve plunger. The movement of the power piston, actuating compensating piston, receiving compensating piston and pilot valve plunger continues until the

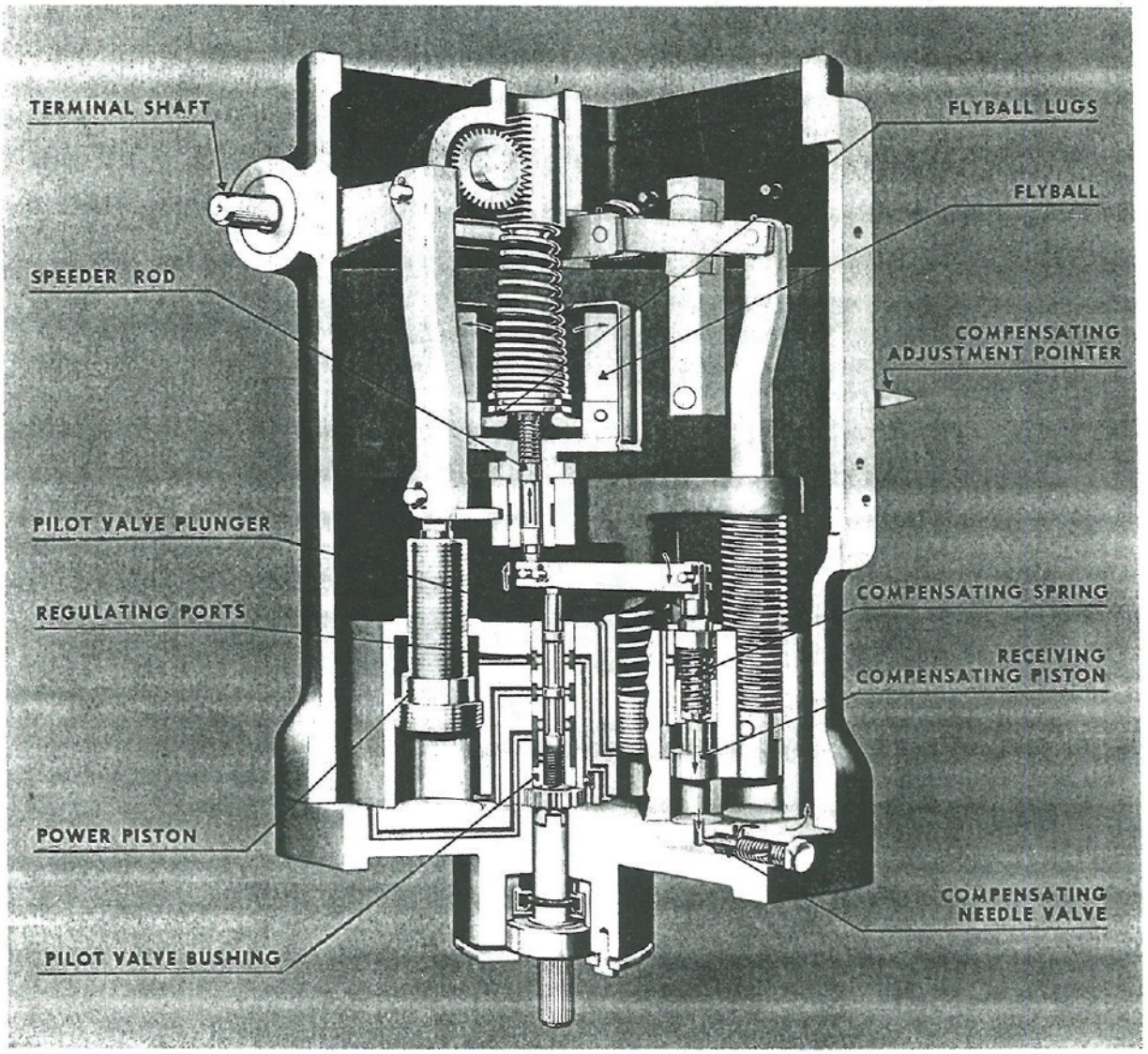

Fig. 51. Governor, Hydraulic, Operation at Normal After Compensating for Speed Decrease

land on the pilot valve plunger covers the regulating port. The equalized oil pressures above and below the power piston hold this piston stationary. The rotation of the terminal shaft is stopped in a position to increase the amount of fuel required to operate the engine at the desired speed under the increased load.

g. In Fig. 51 the governor is shown when the normal, or desired, engine speed is again resumed. The flyballs move outward to the normal position, and the flyball lugs compress the speeder spring, causing the speeder rod to move upward to the normal position. The receiving compensating piston is returned to the normal position by the compensating spring at the same rate as the speeder rod. This keeps the regulating port in the pilot valve bushing covered by the regulating land on the pilot valve plunger. The rate at which the compensating piston moves downward to the normal position is determined by the flow of oil out of

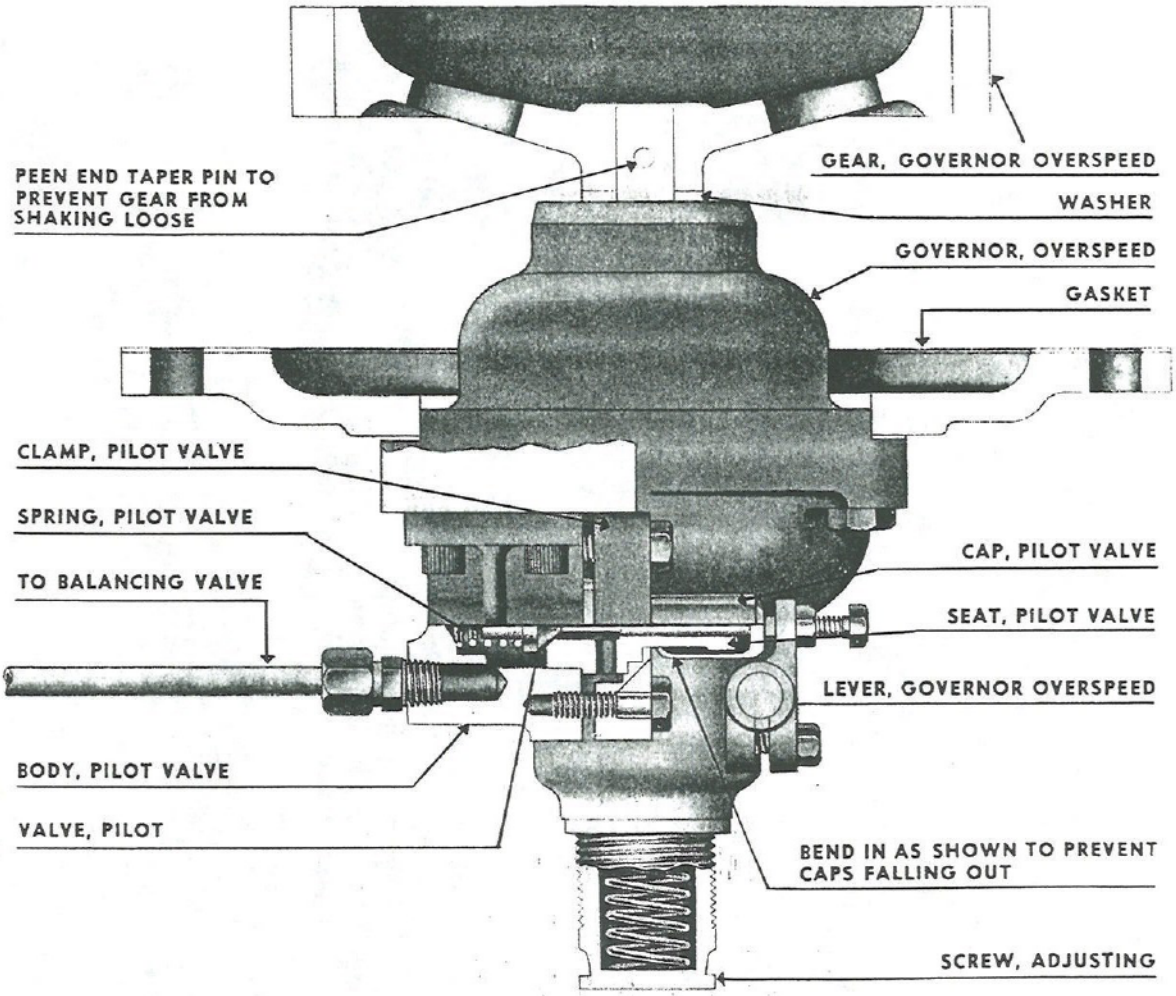

Fig. 52. Overspeed Governor

the receiving compensating cylinder to the sump through the needle valve. At the completion of the cycle, the flyballs, speeder rod, pilot valve plunger, and receiving compensating piston are in normal positions. The power piston is held stationary by the equalized oil pressure above and under the piston. Thus, the terminal shaft is held at a position which permits delivery of the amount of fuel required to maintain desired engine speed under the increased load.

58. OVERSPEED GOVERNOR. ***a.*** On Enterprise engines equipped with the hydraulic governor, an overspeed governor is installed. This governor is provided to protect the engine from excessive speeds in the event the hydraulic governor gets out of order. The overspeed governor is set so that it only operates if the engine reaches a higher speed than the maximum designed rating.

b. The overspeed governor system is shown in Fig. 44. Fig. 52 shows the overspeed governor. It is mounted on the front end of the engine and geared into the gear train. The governor is of the simple flyball type with the spring tension adjusted so that the flyballs will not move unless the engine attains an excessive speed. When the flyballs are set in mo-

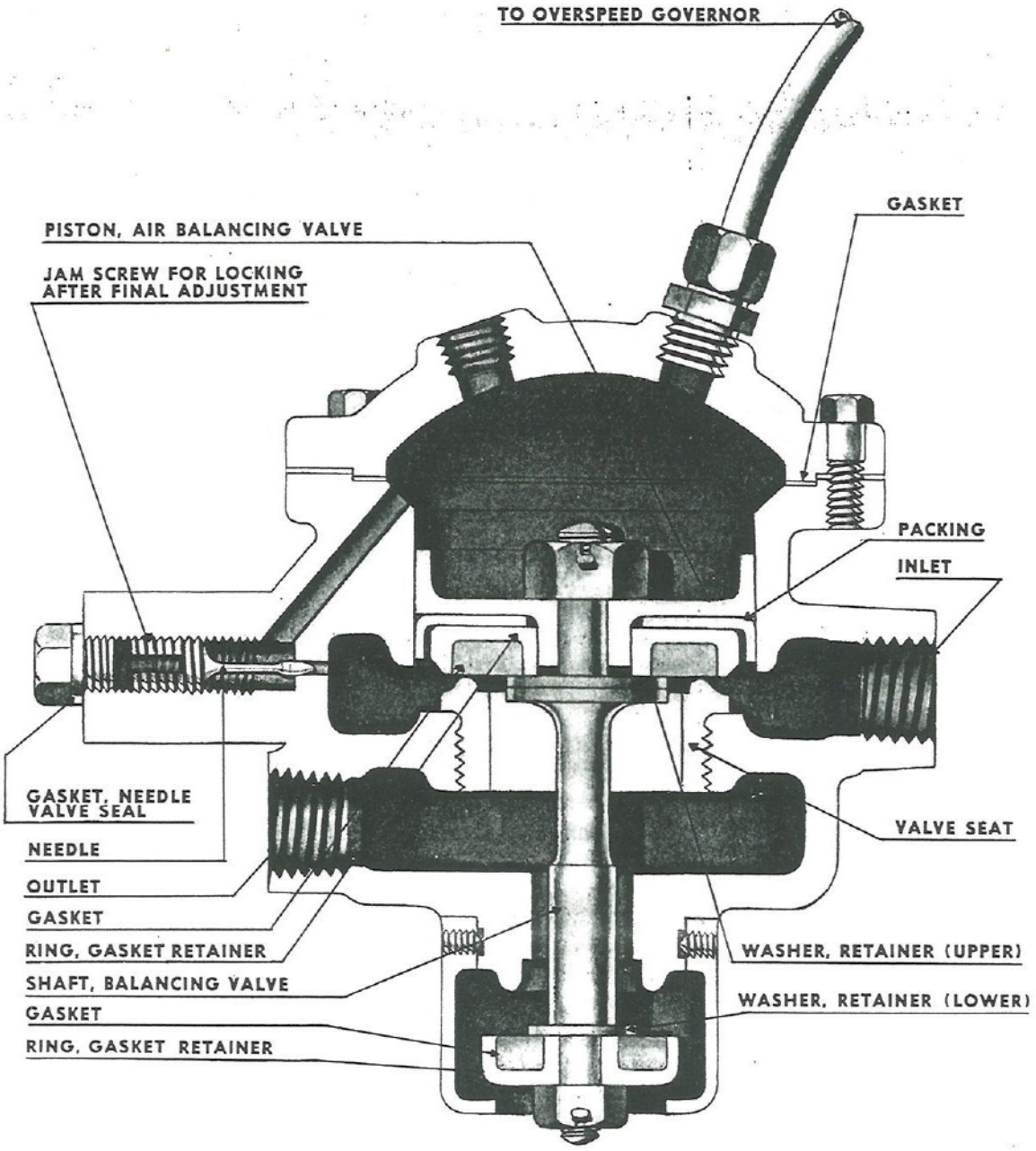

Fig. 53. Balancing Valve on Overspeed Governor

tion, they move the overspeed governor lever. As shown in Fig. 52 the end of this lever is fitted with a screw bolt which contacts the end of a spring loaded pilot valve enclosed in a housing located on the governor housing. If the engine attains an excessive speed, the fly-ball motion created inside the governor moves the lever. The lever then overcomes the spring pressure of the pilot valve and bleeds the air from the upper chamber of the balancing valve through the tubing.

c. In Fig. 53 the balancing valve is shown with the tubing leading to the pilot valve on the overspeed governor. The balancing valve, located on the housing of the reversing mechanism air motor, is continually under air pressure. However, the air pressure on both the top and bottom of the piston is equalized so that the piston remains stationary and the valve remains closed. The principle of the balancing valve is fully explained in par. 69. The equalized air pressure in the balanced valve is upset if the overspeed governor is put into operation. The movement of the overspeed governor arm, opening the pilot valve, drains off the air pressure from the top of the balancing valve piston. This opens the valve and the compressed air passes through the valve into the air header and enters the fuel tappet assemblies of the fuel pumps. The air pressure raises the tappets and prevents them from contacting the fuel cams. This stops delivery of the fuel to the engine. When the engine speed returns to below the maximum permissible, the overspeed governor stops and the spring pressure on the pilot valve closes this valve. This permits the air pressure in the upper chamber of the balancing valve to build up and close the valve.

SECTION VI
AIR INTAKE, AIR STARTING & EXHAUST, STARTING & MANEUVERING

59. GENERAL. In this section certain parts and subordinate systems necessary to start the engine and to coordinate the operations of the major systems are explained. In Sect. VII the starting and running of the engine is discussed but before the operator undertakes this activity, he must become acquainted with the mechanism and parts involved in the action.

60. CAMSHAFT. *a.* Although practically every part in the engine revolves on a shaft, there are only two main shafts. The crankshaft

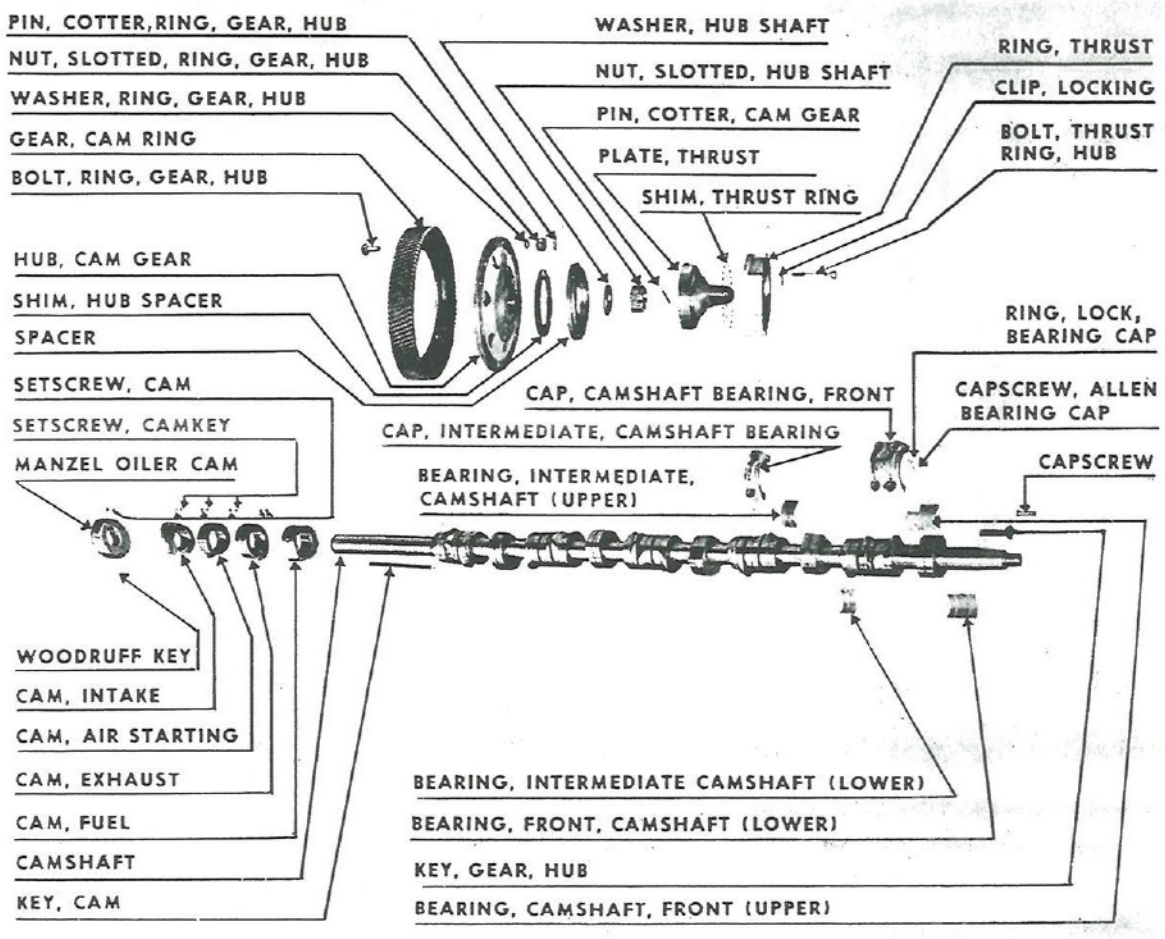

Fig. 54. Camshaft and Cam Parts

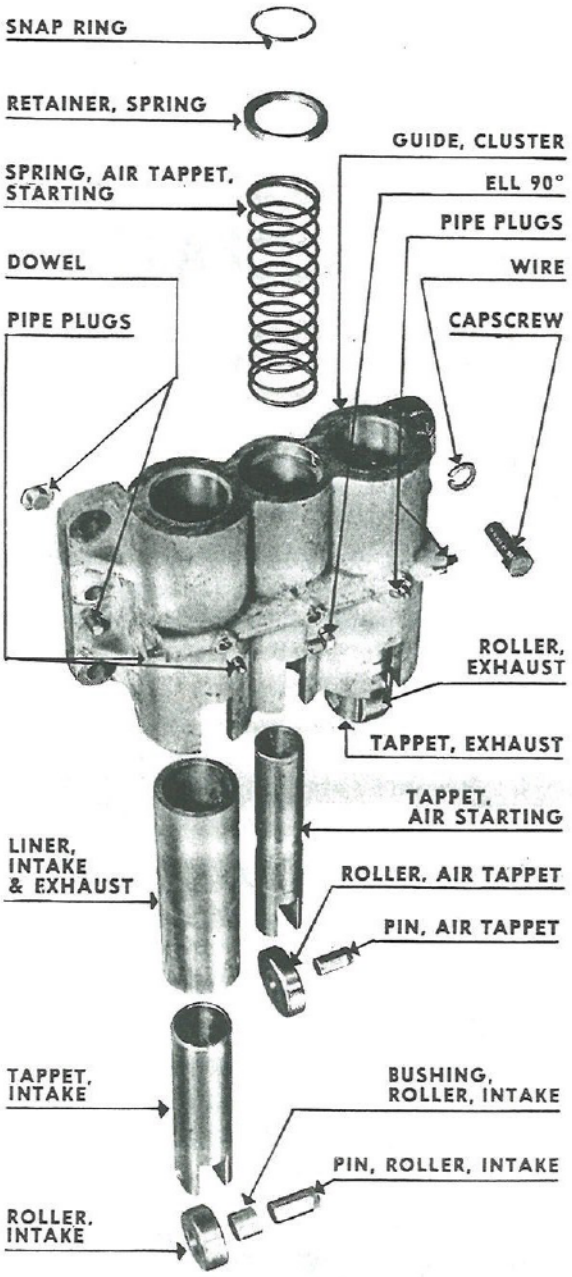

Fig. 55. Tappet Cluster Parts

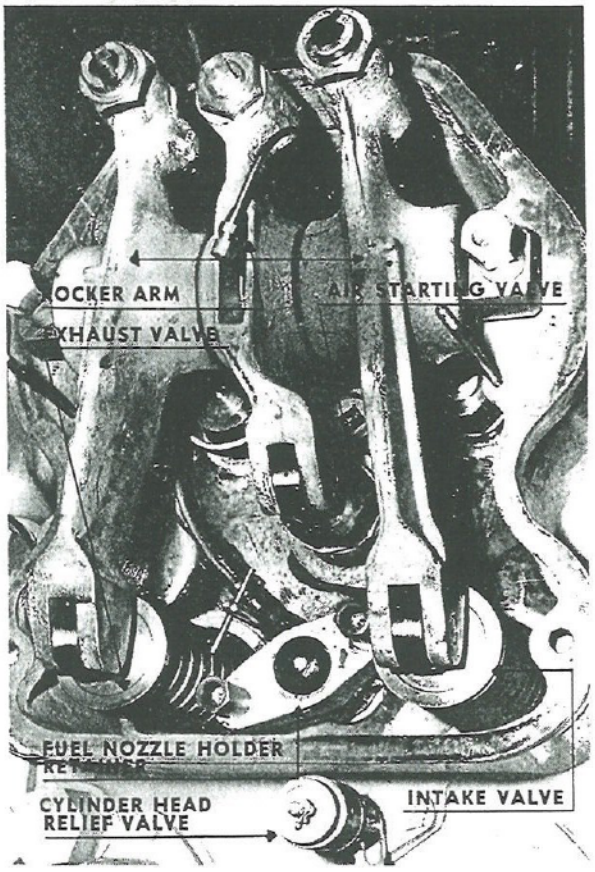

Fig. 56. Cylinder Head Complete

transmits the power developed by the power stroke of the piston to the propeller shaft. It is, therefore, a transmission shaft. The camshaft controls the time that each cylinder and cylinder valve operates. It can be considered as a regulatory shaft. It is located on the operating side of the engine, underneath the cylinder heads, and is hidden from view by covers. In Fig. 11, a portion of the camshaft is shown. It is operated from the crankshaft by a set of gears in front of the engine.

b. The camshaft is a straight shaft to which are attached a number of cams. These cams are round discs, with a nose or lobe on one side extending a considerable distance beyond the rest of the disc. The cams are securely fastened to the camshaft in their proper positions by setscrews. Fig. 54 shows a camshaft and cams, as well as other parts, disassembled. The cams are arranged on the camshaft to operate the air intake and exhaust valves, the fuel pump, and the air starting valves for each cylinder. In addition, a cam on the after end of the camshaft operates the Manzel oiler.

c. As the camshaft revolves, the lobes of the cams come into contact with the wheels or

rollers fitted into the ends of the tappets, as shown in Fig. 55. The tappets are fitted into a guide with separate holes or cylinders for each tappet. This is called a tappet cluster. The tops of the tappets are bored to receive a push rod. Therefore, when the lobe of the cam contacts the tappet, it is pushed upward and, in turn, it forces the push rod upward. When the camshaft revolves far enough, the lobe of the cam also moves and, with pressure released on the roller, the tappet returns to its original position. The tappet guide, through which the tappet must operate, is rigidly fastened to the engine block so that the tappet can move only up or down. Thus, through the use of the wheel, or roller, the circular motion of the camshaft is changed to a straight up and down motion.

d. The up and down motion of the push rods is carried up to the cylinder head where it is utilized to open and close the valves through the rocker arm assembly. The rocker arms are located inside the cylinder head, as shown in Fig. 56. They are permitted up and down movement by the rocker arm shaft. The push rods are secured to one end of the rocker arms by a cup and ball device. The other ends of the rocker arms are fitted with rollers which contact the stems of the valves. The disassembled parts of the rocker arm assembly are shown in Fig. 57.

e. This is how a valve, for example the exhaust valve, operates. The camshaft revolves until the lobe of the cam operating the exhaust valve comes into contact with the roller on the end of the exhaust tappet. The exhaust tappet is forced upward and raises the push rod. The push rod then raises one end of the rocker arm and forces the roller on the other end of the rocker arm down against the exhaust valve stem. The exhaust valve is then unseated, opening the valve. When the lobe of the exhaust cam no longer pushes against the tappet, the tension of the valve spring forces the rocker arm back to its previous position, and

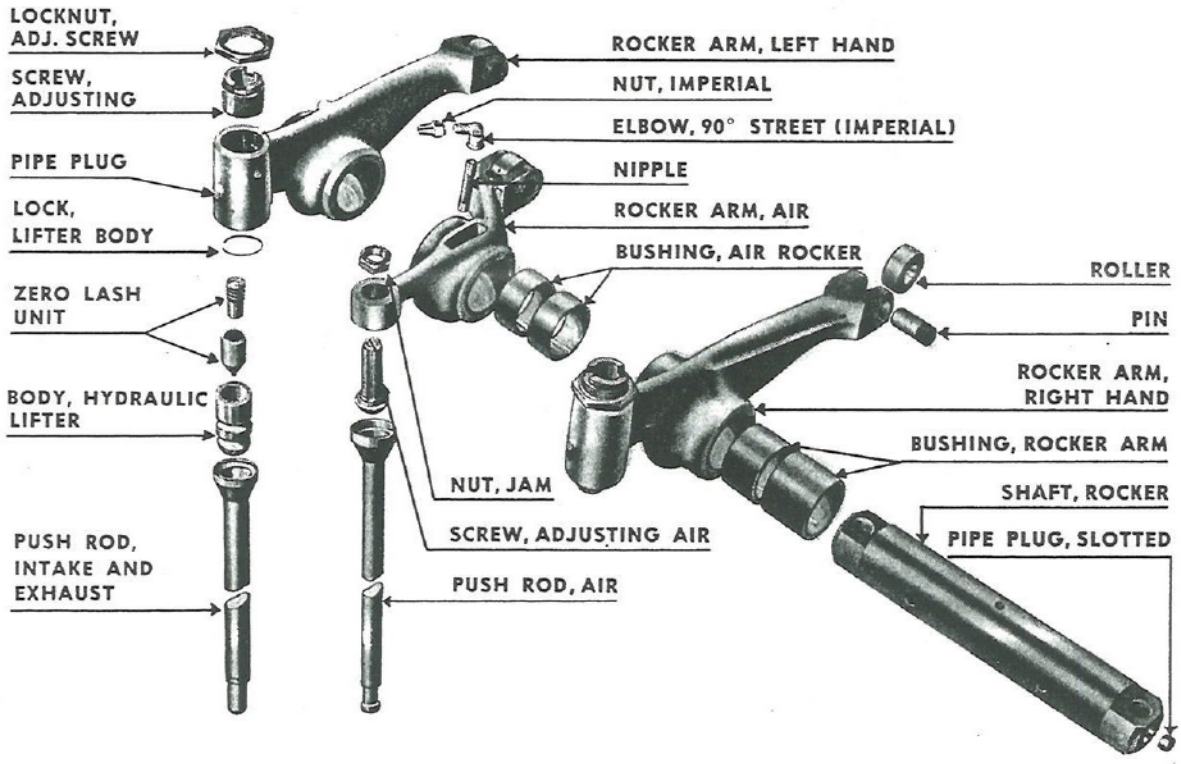

Fig. 57. Rocker Arm Assembly

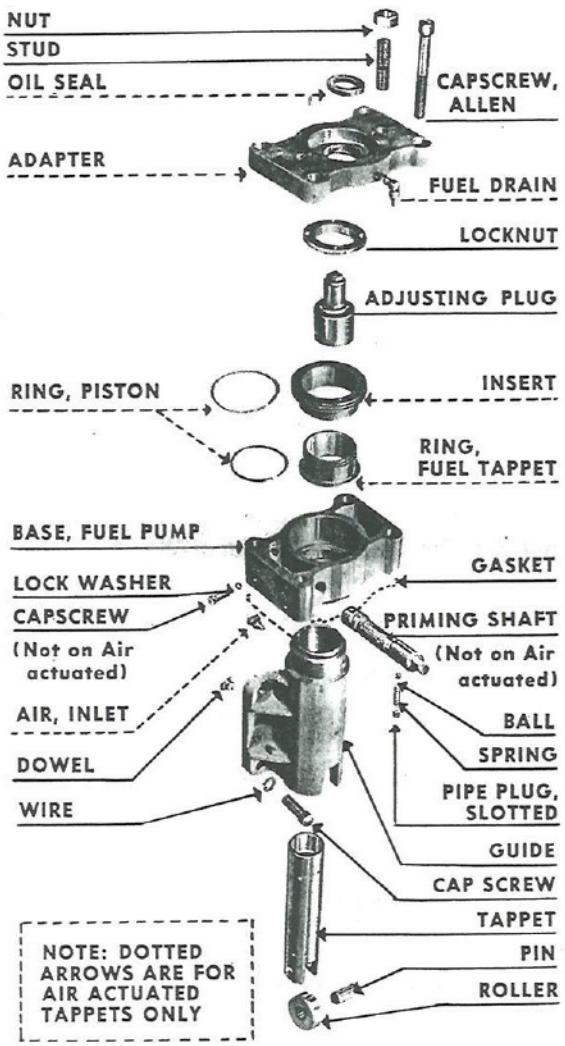

Fig. 58. Fuel Tappet Disassembled

the valve closes. In effect, the rocker arm is a teeter-totter with a constant pressure on one end at all times.

f. The fuel tappets are mounted directly over the camshaft and activate the fuel injection pumps which are mounted with their tappets in a common housing. A fuel tappet is shown disassembled in Fig. 58.

61. TIMING. All valves do not open at the same time. Engines have to be timed so that all the valves in one cylinder open at different times, and that the cylinders fire at different intervals. The proper operation of all the valves and all the pistons is done by timing. During the time the engine crankshaft makes two complete revolutions, the valves and fuel pumps in each cylinder operate once. The camshaft is geared to the engine in such a way that it makes one-half a revolution for every full revolution of the crankshaft. Thus, the camshaft only revolves once during the time the crankshaft is completing two revolutions. This difference in speed is necessary to afford the time required to open and close valves and to inject fuel for the four strokes of the piston. The actual spacing of time between the opening and closing of the valves and the injection of fuel is accomplished by fitting the cams on the camshaft in a staggered position, so that the lobes come up underneath the tappet cluster at different times.

62. REVERSING CAMS. When the engine is operating in the ahead position, the cylinders are firing in the following order 1-5-3-6-2-4. The crankshaft is turning in a clockwise direction. To reverse the engine, the firing order is changed to 1-4-2-6-3-5. Due to the arrangement of the cranks on the crankshaft, this results in the crankshaft turning in a counterclockwise direction. Since this changes the order of the valve openings and fuel intake for the various cylinders, another set of cams is used. In Enterprise engines the ahead and astern cams are made from the same piece of metal, but are forged and machined so that the lobes are in different position.

63. REVERSING MECHANISM. *a.* The Enterprise engines are reversed by moving the camshaft so that the "ahead" cams do not contact the tappets, and the "astern" do. This results in a change of the firing order, so that instead of cylinder No. 5 firing after cylinder No. 1, cylinder No. 4 will fire.

b. The reversing mechanism is located at the front end of the engine. It consists of a gear box and an air motor operating from the compressed air supply used to start the engine. Located on top of the reversing gear box, the air motor is fitted with a shaft and

gear which meshes with the large gear in the gear box. This large gear is fastened to a shaft so that when the gear moves, the shaft turns. The shaft is cut like the usual shaft except that just below the gear wheel a big collar, or shoulder of metal, is left. This collar is off balance. One side is closer to the center than the other. This is called an "eccentric" shaft.

c. The bushing that fits on this eccentric shaft is cut to provide for a strap that connects to the end of the camshaft. When the rotation of the engine is changed, the air motor starts. The gear turned by the air motor shaft turns the larger gear and eccentric shaft. This results in the camshaft either being pushed or pulled to place the desired set of cams underneath the tappet rollers. It is essential that the movement of the shaft stop at the exact moment the cams are in position, and in order to make this possible a set of gears operating a control lever shuts off the

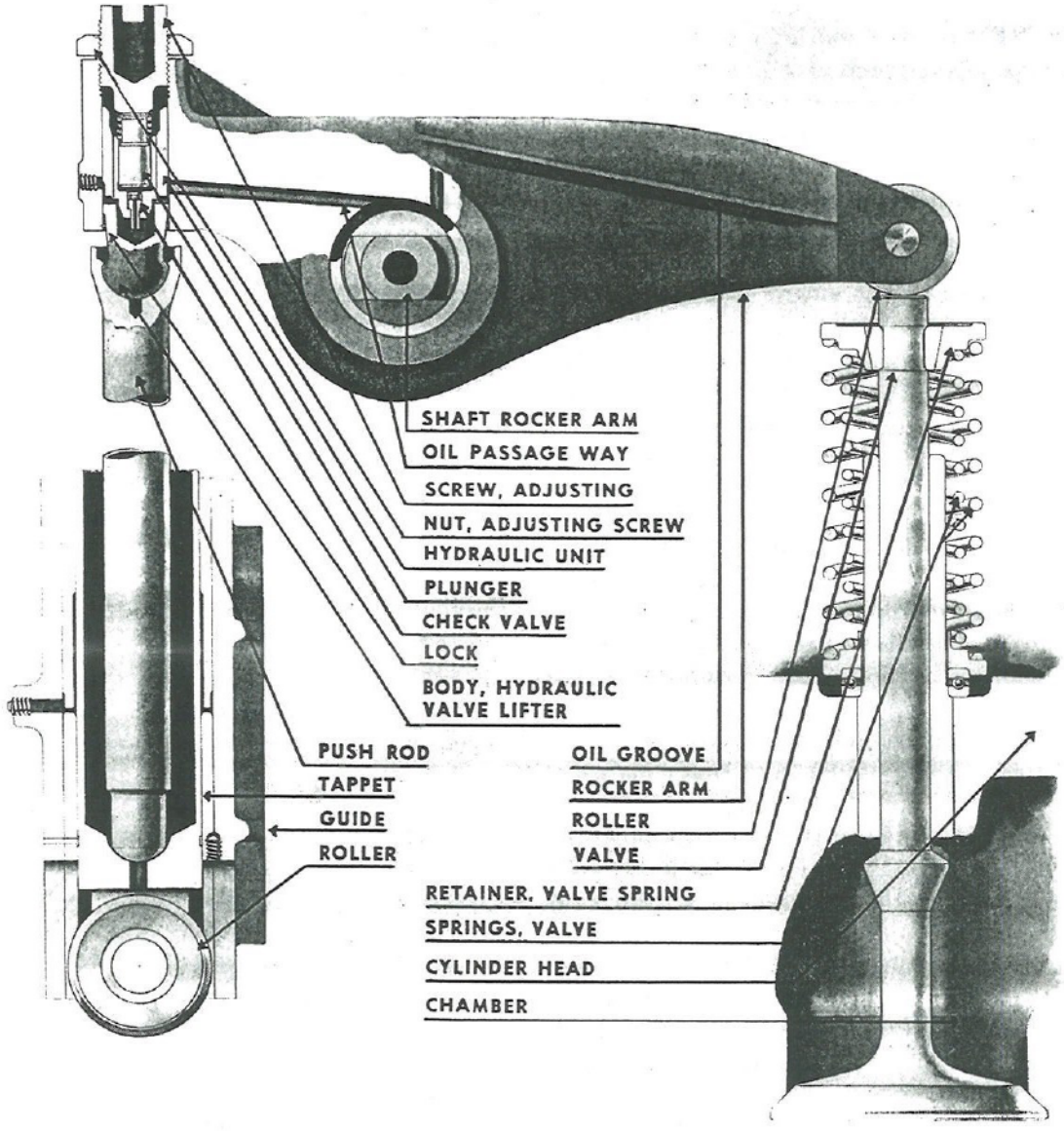

Fig. 59. Zero Lash Unit or Hydraulic Valve Lifter

supply of air to the air motor. However, all machinery set in motion attains a momentum which will carry on the action after the supply of energy is shut off. To prevent the momentum of the air motor from carrying the camshaft beyond the exact position required, a set of stops that contact the eccentric shaft strap are fitted into the bottom of the gear box. A detailed discussion of the reversing mechanism appears in Sect. XVII.

64. ZERO LASH UNIT. The parts of the zero lash unit are shown with the intake and exhaust valve push rod in Fig. 57. This unit is used on Enterprise engines to silence the action of the push rod, and to maintain an adequate adjustment at all times. The push rod is not solidly secured either to the tappet activating it or to the end of the rocker arm it moves. This is not possible because a limited sidewise movement accompanies the straight up and down motion. The zero lash unit insures that this necessary play is not allowed to slap. The entire unit is contained in the end of the rocker arm where the push rod is fitted. Oil under pressure goes into the zero lash unit, as shown in Fig. 59. This oil, conducted through the drilled rocker arm shaft into the hole drilled in the rocker arm, enters the zero lash unit and fills a chamber in the ball of the push rod connector. The oil then enters a passage and lifts a ball check valve at the upper end of the passage. It goes into a small cylinder and forces a piston up against the adjustment screw at the top of the zero lash unit. The piston is stopped at that point, since the adjusting screw is set. The upward thrust of the push rod increases the oil pressure in the cylinder, and this causes the check valve to seat and prevent the oil from escaping. The upward thrust of the push rod is thus cushioned by the compressed oil which is slowly forced out through the clearance between the piston and cylinder. The spring at the top of the zero lash unit is free to compress as the pressure increases. When the push rod stops exerting an upward thrust and starts downward, this spring expands and prevents clearance between the valve stem and the roller of the rocker arm. Only the intake and exhaust valves use the zero lash unit.

65. COMPRESSED AIR STARTING. The Diesel engine burns fuel with hot compressed air. The cylinders must compress the air. This makes it necessary to use some method of starting the engine in rotation until it is able to combust the fuel. As Enterprise engines are known as "full Diesels," starting is accomplished by injecting compressed air into the cylinders on the regular power strokes until the cylinders start firing. The principal units of the air starting system, in addition to the necessary piping and valves, are the compressor, compressed air storage tanks, the air starting control valve, and the air starting valves for each cylinder. Fig. 60 illustrates the air control system and shows the flow of compressed air from the compressor to the cylinders.

66. AIR COMPRESSOR. ***a.*** The air compressor is mounted on the rear end over the thrust bearing, and is driven by a "V" belt from the flywheel. The compressor has two cylinders, or is what is known as the "two-stage" type. Air first is drawn into a large cylinder which compresses it moderately. This moderately compressed air enters a smaller cylinder, where it undergoes a second compression that brings it up to maximum pressure. From the second cylinder the air is piped into the air storage tanks.

b. The compressor also is fitted with an unloading device that stops further compression when the tanks are filled. When the compressor is unloading, a loud whistling sound is made by the escaping air. This can be stopped by disengaging the clutch on the compressor. As illustrated in Fig. 60, the unloader is fitted on the top of the compressor. The unloader holds the suction valve of the compressor as long as the tank pressure is up to the limit. With the suction valve opened, air drawn into the compressor cylinder by the downstroke of the piston is forced out of the suction opening and into the atmosphere on

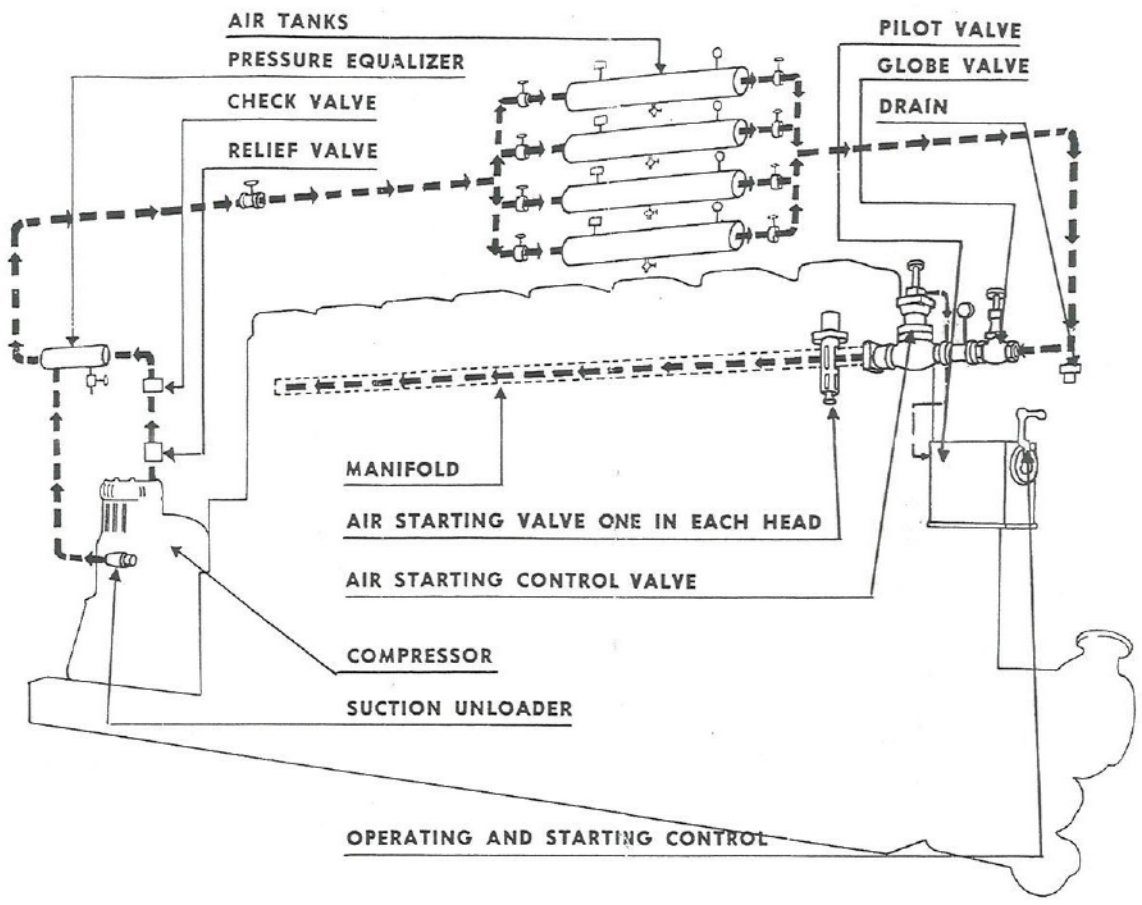

Fig. 60. Air Starting System

the upstroke. When the air pressure in the storage tanks drops below a fixed pressure, the unloader returns the compressor suction valve to its seat.

c. The unloader has a piston working against the air tank pressure at one end, and against an adjustable spring at the other. When the air pressure overcomes the spring tension, the piston is pushed back. The air pressure then passes to the tops of two flexible diaphragms located over the suction valves. When the air pressure forces these diaphragms down they press on pins which hold the valves off their seats and permit the air to escape. When the pressure in the air tanks drops below the minimum level, the spring in the unloader forces the piston shut and the diaphragms move to their normal positions. As they move, coil springs seat the valves and force the pins up. The suction valves then are able to seat and function. The tension of the unloader spring is set by turning a handle on one side. This handle either increases or decreases the pressure at which the unloader will operate. It is general practice to set this spring so that it will cause the unloader to operate when the pressure in the tanks is 250 pounds.

67. AIR STORAGE TANKS. In Fig. 60, four air storage tanks are shown in the system. Some engine installations have three of these tanks. Each tank is fitted with a spring-loaded safety relief valve to protect the tank

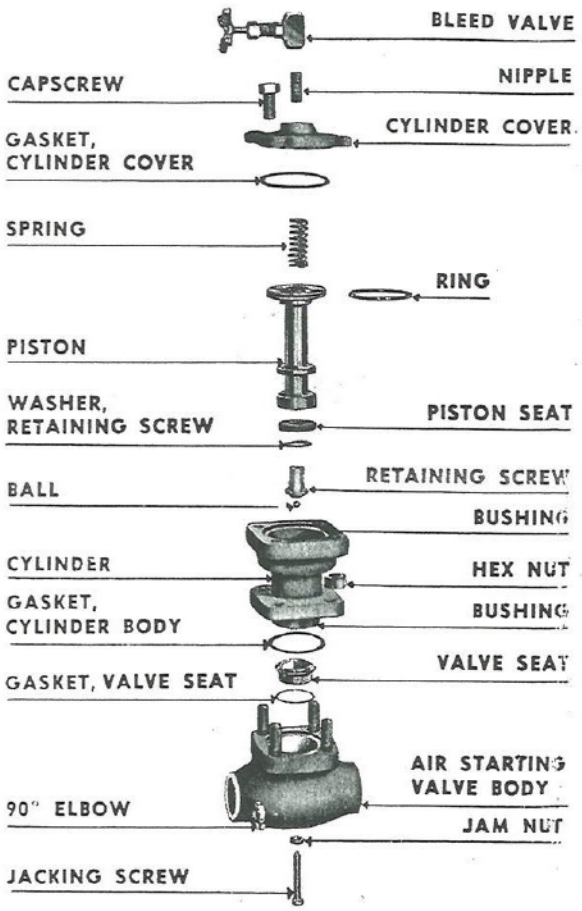

Fig. 61. Air Starting Control Valve Parts

against pressures above the safe maximum. A system of valves also permits the tanks to be used together or separately. The best practice is always to hold one tank in reserve up to maximum pressure for emergencies. The compressed air from the storage tanks is conducted by a line to the engine. This line is fitted with a drain to permit draining out water that will collect due to condensation of moisture. At the entrance to the system, a globe valve is installed in the line. This globe valve, or gate valve, should be kept tightly closed when the air system is not in use.

68. AIR STARTING CONTROL VALVE. a. When the operator is ready to start the engine, the globe valve is opened, and air under high pressure enters the air starting control valve on the front end of the engine, as shown in Fig. 60. This air takes the place of the force created by combustion when the engine is running. The full air pressure, therefore, has to "hit" the pistons instantly. Slow building up of the air pressure inside the combustion chamber would not give the full, immediate force exerted on the piston similar to the combustion of fuel. The air starting control valve used is often referred to as a "balanced" valve.

b. The air starting control valve, disassembled, is illustrated in Fig. 61. The only two moving parts are the piston and the spring. The spring keeps the valve seated when compressed air is not entering the valve. The piston is drilled lengthwise through the center with a small hole. When the globe valve is opened to admit air to the system, the compressed air rushes into the body of the valve and starts to exert upward pressure on the piston. Before the piston can be unseated, however, air escapes to the upper section of the cylinder through the hole in the piston. This air, trapped between the upper end of the piston and the piston cover, or head, exerts as much downward pressure on the piston as the upward thrust on the bottom of the piston. This equalizes the pressure, or results in a "balanced" valve.

69. PILOT VALVE. The pilot valve is connected to the top of the air starting control valve, as shown in Fig. 60. It connects to the control valve by means of the valve fitting shown at the top of the control valve in Fig. 61. The function of the pilot valve is to "bleed" the air from the top chamber of the air control valve and permit that valve to supply air into the starting air manifold. As explained, the control valve is kept balanced. The pilot valve has a larger opening than the hole through the piston. The pilot valve is a simple stem valve, and is kept seated by the air pressure from the upper chamber of the control valve. When the engine is started, the control lever pushes the stem on the pilot valve down,

unseating the valve. This unbalances the air pressure in the control valve, and causes the piston to be thrust upward. The compressed air then rushes into the starting manifold. The moment pressure is released from the stem of the pilot valve it snaps shut, and the control valve closes. In this manner, a precision control is exerted over the flow of compressed air into the system.

70. AIR STARTING VALVE. a. Each cylinder is served with a separate air starting valve. The compressed air leaving the air starting control valve is conducted to the starting valves in each cylinder through an air jumper, or manifold. In Fig. 56, the air starting valve is shown installed in a cylinder head. It is arranged so that a roller on the end of a short rocker arm serves this valve alone. The other end of the rocker arm is secured to a push rod which goes down to a tappet operated by an air starting cam on the camshaft. This cam is timed to open the air starting valve on the regular power strokes of the cylinder. However, when the air starting system is not in use, the tappet, push rod, and rocker arm that open the air starting valve do not operate.

b. The parts of the air starting valve are illustrated in Fig. 62. At the bottom of the valve, the body is turned down to permit it to fit into a hole drilled in the cylinder head. The stem type delivery valve is seated against the end of the valve body. The greater part of the valve length, containing a lower and upper set of air ports, is enclosed in the engine by the starting air manifold. A rubber sealing ring at the top and a copper gasket at the bottom stop the compressed air from escaping around these connections. At the top of the valve, above the tapped ears, an outer and inner piston are located. The inner piston fits against the top of the valve stem. In the illustration, the valve is shown expanded. The expansion gap is shown extended, and it can be seen that when the valve is expanded, the entire top, or cap, of the valve is pushed upward. When not expanded, the cap drops down into the housing and this gap is closed.

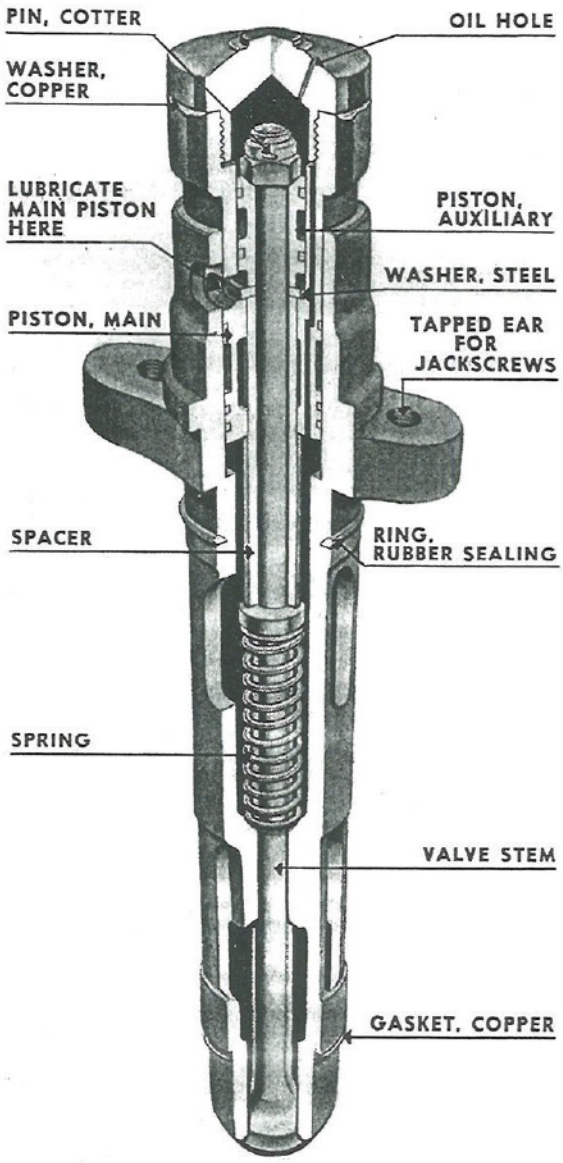

Fig. 62. Air Starting Valve Cut Away

c. Briefly, the air starting valve operates as follows: Air from the manifold enters the upper ports and exerts pressure on the bottom of the outer piston, or cap, forcing it upward. Its travel is limited on contact with the washer which is bolted to the valve stem just below the inner piston. The upward motion extends the valve contacting the rocker, and this causes the air tappet to be forced down

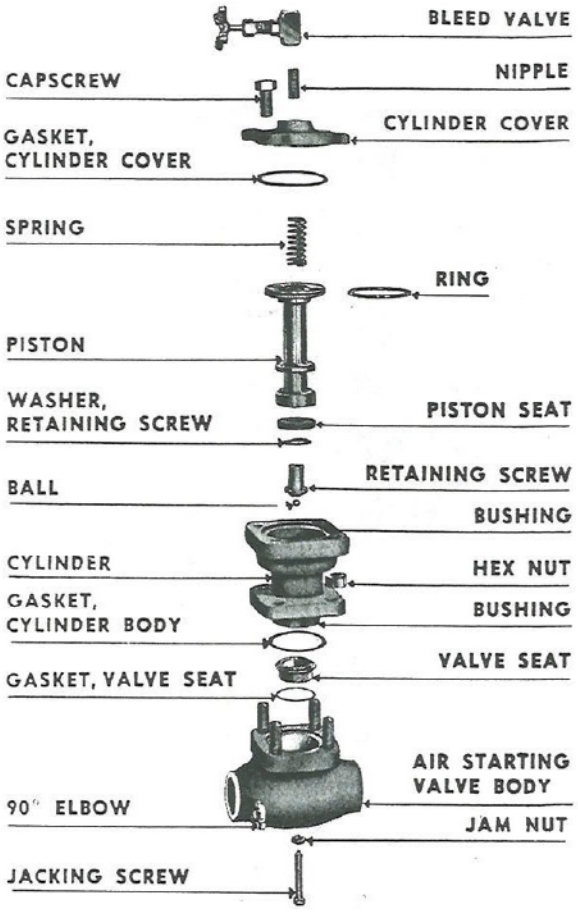

Fig. 61. Air Starting Control Valve Parts

against pressures above the safe maximum. A system of valves also permits the tanks to be used together or separately. The best practice is always to hold one tank in reserve up to maximum pressure for emergencies. The compressed air from the storage tanks is conducted by a line to the engine. This line is fitted with a drain to permit draining out water that will collect due to condensation of moisture. At the entrance to the system, a globe valve is installed in the line. This globe valve, or gate valve, should be kept tightly closed when the air system is not in use.

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b. The air starting control valve, disassembled, is illustrated in Fig. 61. The only two moving parts are the piston and the spring. The spring keeps the valve seated when compressed air is not entering the valve. The piston is drilled lengthwise through the center with a small hole. When the globe valve is opened to admit air to the system, the compressed air rushes into the body of the valve and starts to exert upward pressure on the piston. Before the piston can be unseated, however, air escapes to the upper section of the cylinder through the hole in the piston. This air, trapped between the upper end of the piston and the piston cover, or head, exerts as much downward pressure on the piston as the upward thrust on the bottom of the piston. This equalizes the pressure, or results in a "balanced" valve.

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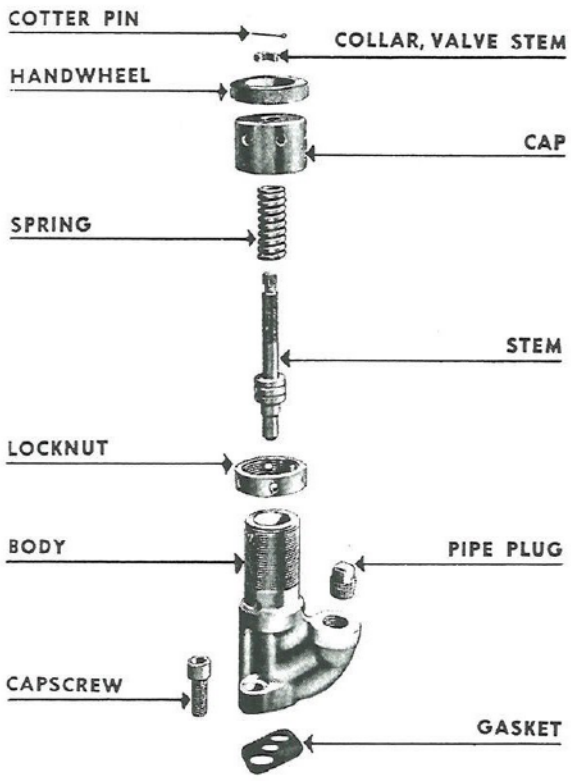


Fig. 64. Relief Valve Parts

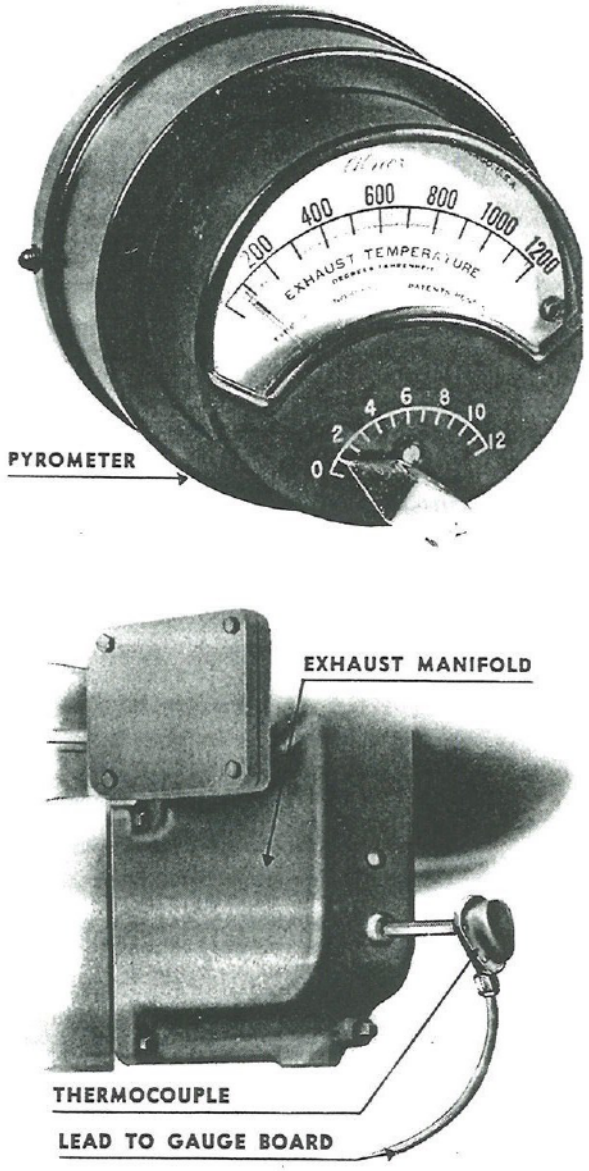


Fig. 65. Pyrometer Gauge and Thermocouple Installed on Manifold

the cylinders and leads them through a silencer. The silencer is a chamber with baffle plates which break up the pulsations of the exhaust and cause the gases to escape in a steady stream. The exhaust manifolds of the six-cylinder engine are fitted with water jackets to reduce the temperature of the exhaust.

73. PRESSURE GAUGES. Since insufficient or excessive pressures may lower the engine's operating efficiency and result in damage, pressure gauges are installed to aid the operator in seeing to it that accurate pressures are maintained. Gauges are located in the lubricating oil system, the fuel oil system, the jacket water system, the sea water system, and the starting air system.

74. TACHOMETER. This gauge shows the number of revolutions being made by the engine per minute, or what is known as the RPM. Critical and excessive speeds are indicated in red.

75. REVOLUTION COUNTER. While the tachometer shows the number of revolutions being turned, the revolution counter records the number that have been made during any de-

sired period. This record is of value as an aid to navigation, since it may be used to compute the speed and number of nautical miles traveled during a stated period.

76. PYROMETER. The pyrometer records cylinder temperatures that are too high for the ordinary thermometer. A thermocouple installed in the exhaust part of each cylinder is connected by wires to the pyrometer gauge on the gauge board, as shown in Fig. 65. Thermocouples react to heat changes, and these changes are transmitted to the gauge. The gauge is fitted with a selector switch so that it may be shifted to show the temperature in the exhaust port of any cylinder.

SECTION VII
ENGINE CONTROLS—STARTING ENGINE

77. ENGINE CONTROLS. Engine controls are located on the front end of the engine on the starboard (right) side. In Fig. 66 the control handle, throttle lever, and gauge board are shown. The gauge board carries most of the essential instruments with the exception of the fuel oil pressure gauge. This gauge is located at the rear of the engine where the fuel transfer pump is installed. Fig. 66 shows the engine controls when they are used for operation from the engine room. In some installations a series of chains and cables are connected with sprockets to extend the controls to the pilot house or some other place on the ship.

78. CONTROL HANDLE. ***a.*** In Fig. 67 a close-up view is shown of the control handle in neutral position. There are four other positions —the starting and running positions for both ahead and astern operations. The control handle moves the camshaft to put either ahead or astern cams into position, and also set the air starting system in operation.

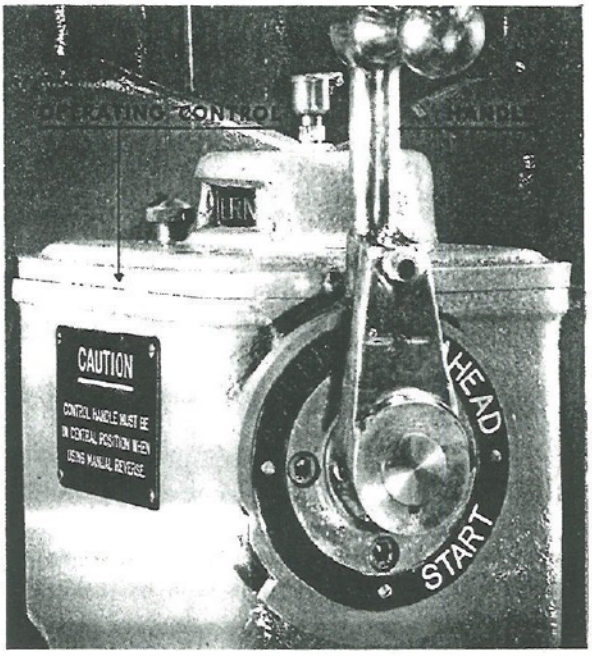


Fig. 67. Control Handle in Neutral

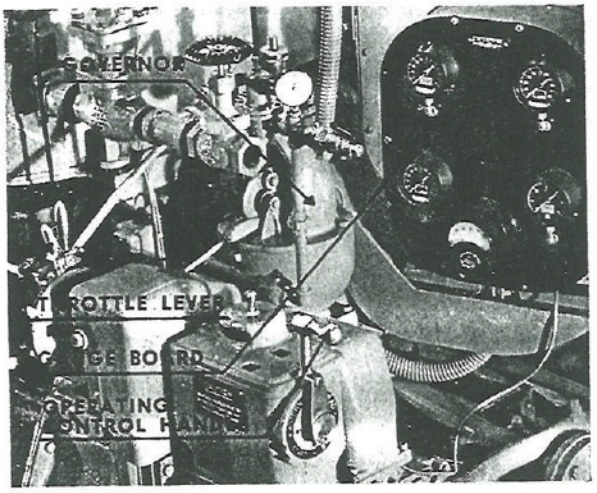


Fig. 66. Operation Controls and Gauge Board

b. To start the engine, the control handle is turned smartly down to the first notch in the desired direction, either ahead or astern, as indicated on the direction plate. It is necessary to move the handle smartly to avoid losing compressed air. When the handle is in running position, the camshaft is shifted into the proper position. This is accomplished by a cam on the control handle inside the control box which contacts the ears of a spindle connected

to the gear of the reversing mechanism. There are two ears on this spindle. If the engine is being started in the ahead position, and the camshaft is already in this position, the cam will pass this ear. If the camshaft is not in the proper position for the desired direction, the cam will contact one of the ears, and the ear will start the air motor on the reversing gear mechanism operating to shift the camshaft. In the meantime, the ear will prevent the control lever from being pushed on any further until the camshaft is moved. Another cam on the shaft of the control handle pushes against a lever and roller connected to the fuel pump control shaft, preventing the pumps from sending fuel into the engine. When the camshaft is shifted, the ear passes by the cam and the fuel control shaft is unlocked. The position of the camshaft appears in letters at the window located on top of the control box.

c. With the camshaft in position, the control handle can be pushed down to the bottom notch, or the starting position. The handle has to be pushed down hard to overcome a spring tension. A cam on the handle shaft then operates a lever which bleeds the pilot valve, permitting air from the air starting control valve to enter the engine. As soon as the engine starts firing, the handle is released and is returned to the running position by the spring.

79. THROTTLE LEVER. The throttle lever is shown in Fig. 68. It is mounted on a notched quadrant and has a grip handle which permits the throttle to be set at any notch. The governor controls the amount of fuel injected into the cylinders, and the throttle sets the amount of fuel the governor can deliver as explained in the discussion of the governors in Sect. V.

80. BEFORE STARTING THE ENGINE. Before starting the engine, the operator must be familiar with all its parts and how each functions. He also must know the location of every valve, adjusting handle, and other control. Therefore, before starting the engine, a definite inspection routine should be followed. This routine should become so well established in the mind of the operator that it becomes second nature.

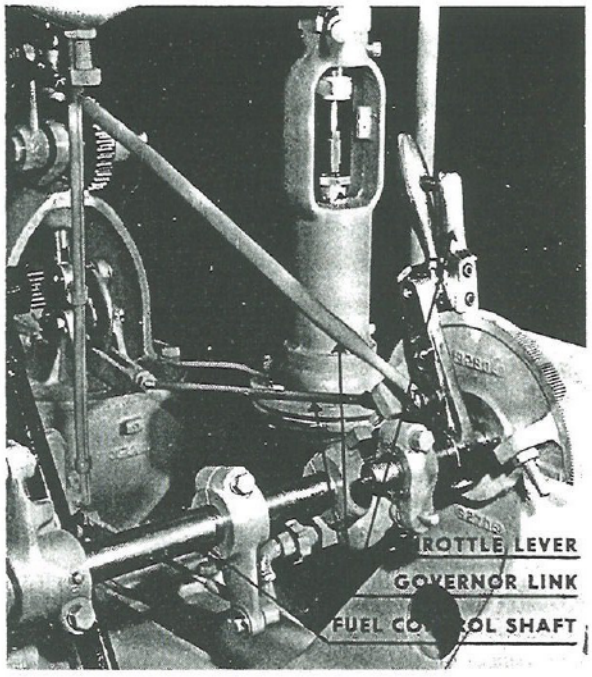


Fig. 68. Throttle Lever Controlling Governor

81. INSPECT ENGINE JACKET WATER SYSTEM. The inspection should start at the centrifugal pump supplying the jacket water system. Examine this pump to be certain all connections are tight. Be sure the valve in the discharge line is open. Follow the discharge pipe line to the jacket water cooler, or heat exchanger, and be sure the valves are set to direct the flow of jacket water into the cooler and not through the by-pass. Examine the exposed piping for leaks. Follow the piping back to the inlet on the engine and compare thermometers, replacing those that are damaged. Look at the holes on the exhaust manifold side of the engine just above the side door covers to see if any water is coming out of the cylinder liners. On top of the engine check the connections of the pipe line to the surge tank and see that both valves are open one-quarter of a turn. Check the quantity of water in the surge tank, and if not half full admit more water by opening the valve in the fresh water supply line connected to the suction side of the pump.

Be certain the valve at the surge tank on the pipeline leading back to the engine is open. Examine the temperature control valve in the by-pass system. If all these items are in correct working order, the jacket water cooler system is ready to operate.

82. INSPECT RAW WATER SYSTEM. Start at the sea chest. If the sea chest is arranged so that it can be blown out with air pressure, this should be done. Remove any dirt, debris, vegetation, or other matter that may be collected in the raw water strainers, replacing the strainers when finished. Open the sea valve admitting raw water into the system. This valve should always be closed when the engine is not in operation. Look at any additional valves between the sea chest and raw water pump, making sure that they are open, and that the piping is secure and not leaking. Be certain that the by-pass valve between the suction and discharge lines is closed. Inspect the valves to and from the lubrication oil cooler and the valve into the jacket water cooler, being certain they are open.

83. INSPECT LUBRICATING OIL SYSTEM. If the engine has been idle for a time, remove a side cover from the engine and check the amount of oil collected in the engine sump. This is important since additional oil that is not needed may have been added to the system, and if this is the case the lubricating oil storage tank will overflow when the engine is started. If the sump contains a considerable quantity of oil, pump it dry with the hand pump. When finished pumping, be sure the valves leading to and from the hand pump are closed. Always inspect the lubricating oil service tank. Open the drain at the bottom of the tank and allow any water, dirt, etc., to escape, then close the valve SECURELY. Check the quantity of oil in the tank. If it is below the normal mark, add new oil from the lubrication oil storage tank. Then be sure that the valve from the tank into the system is open. Inspect the filters, open the drains to allow any collected foreign materials to escape, then close the valve securely. If filter elements seem to be clogged, remove the covers and inspect them, replacing the filter elements if necessary. Be sure the control handle of the four-way valve indicates that the lubricating oil will travel through the filter and not through the by-pass. Check the control handle of the four-way valve on the engine to be sure that the oil will pass through the lubrication oil cooler and not through the by-pass. Be sure that the valve in the lubricating oil cooler is open. Remove the coarse mesh from the sump strainer and wash it out thoroughly. Do the same to the discharge strainer. Be sure the Manzel oiler has sufficient oil. Turn the crank on the left end of the shaft three or four times.

84. INSPECT FUEL SYSTEM. Open the drain of the fuel oil accumulator tank to allow any water, dirt, etc., to escape. Then close the valve securely. Be sure that the valves to and from the pumps are open. Drain out any dirt that has collected in both the scraper type filter and the absorbent type filter. If the absorbent type filters seem to be dirty or clogged, shut off the fuel to the engine and replace them with new elements. Turn on the fuel again. If the filter elements have been changed, the entire fuel system must be bled of air.

85. INSPECT AIR STARTING SYSTEM. If the ship is equipped with an auxiliary air compressing system, the system should be checked according to the manufacturer's instructions. It should be started if the pressure in the air storage tanks is below 250 pounds. Examine the regular air compressor, and be sure that the lubricating oil in the compressor is up to the proper level, adding oil if necessary. Be certain that the air compressor clutch is disengaged and that the "V" belts are tight so they will not slip when the compressor is started. Drain the water out of the air storage tank to be used. Drain the main air supply line to the engine of water through the drain valve located at the engine.

86. INSPECT ENGINE. Open the safety relief valves on each cylinder to allow any compres-

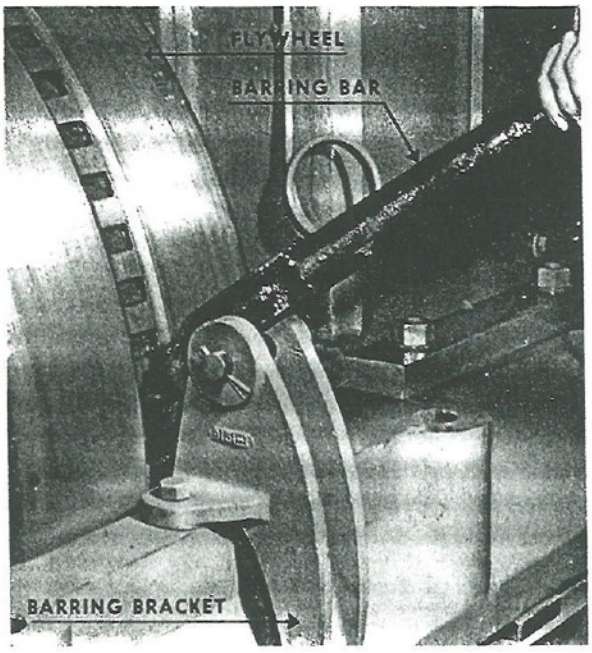


Fig. 69. Barring Engine

sion to escape. Use the jacking bar and device shown in Fig. 69 to bar the engine over at least three complete revolutions, watching the relief valves for any signs of water. If the engine bars over freely and no water comes out of the safety relief valves, the engine is ready to run. CAUTION: Do not forget to remove the jacking bar or disengage the barring device and close the relief valves.

87. INSPECT TURBOCHARGER. Be sure that the valves admitting water to the turbocharger cooling system are open. Fill the turbocharger water jacket with water before starting. Inspect the lubricating oil tank, filling it to the middle of the gauge range with clean 2-104B lubricating oil. Fill the housing of the lubricating oil filter with oil. If the oil line has been broken, or the engine idle for some time, the lubricating oil pump must be primed. This is done by opening the upper half of a plate located on the front of the silencer. A priming plug is located on the suction line on the left side of the pump. Pour in oil, directing the flow toward the pump, and also fill the suction line down to the check valve. Replace the plug securely. If the oil and water systems are in order, the engine may be started.

88. STARTING THE ENGINE. Open the valve admitting high pressure air to the engine's air starting system. Be certain that everything from the flywheel to the shafting box at the end of the shafting is clear. Advance the throttle, or speed control lever, on its notched quadrant to one-fourth open. Push the control lever in the desired direction. Be sure the indicator shows the camshaft is in the correct position before attempting to press the handle down to the starting position. Release the handle as soon as the engine starts firing. The engine is now in operation. The first few minutes after starting is a critical time, and further inspections should be made immediately to determine if all parts are actually functioning as expected.

89. GAUGE BOARD. ***a.*** The gauge board carries the instruments which record the functioning of the various systems. The usual set of instruments consists of: 1, air pressure gauge; 2, lubricating oil pressure gauge; 3, fuel oil pressure gauge; 4, raw water pressure gauge; 5, jacket water pressure gauge; 6, tachometer; 7, pyrometer; and 8, revolution counter. NOTE: The fuel oil pressure gauge is usually not mounted on the gauge board, but is located at the fuel oil header pipe near the fuel transfer pump. The moment the engine starts firing, give undivided attention to the gauge board. Again a regular routine must be established.

b. The first concern is the pressure of the lubricating oil indicated by the gauge installed to record this fact. From this gauge, the eyes should pass quickly to the fuel oil pressure gauge. The fuel oil pressure should be not less than 5 pounds and not more than 20 pounds. At low engine speeds the pressure will be approximately 8 pounds. If the pressure of the fuel oil falls below the limit, the pumps may become airbound and the engine will stop.

c. The jacket water circulating pressure gauge should read from 5 pounds to 15 pounds, depending on the engine speed. If the tachometer pointer indicates a speed in red, lower the speed until the indicator is in black. The raw water pressure is to be inspected next. This gauge should show a pressure from 3 pounds to 15 pounds, depending on the engine speed.

d. The pyrometer must be used to ascertain if all cylinders are firing. Check the air pressure in the storage tanks, and if the pressure is below 250 pounds engage the compressor clutch to build up the pressure of the storage air. The inspections should be made in the order given here.

e. If any of the gauges do not record the correct pressures, shut down the engine immediately and determine the cause of the trouble. See Sect. XXIV, TROUBLE SHOOTING, for corrections of low and high pressure.

f. As soon as the engine is started, run it at low speeds until checking the lubricating oil pressure of the turbocharger. The pressure is set at the factory for 15 pounds at full load, and if the pressure does not show about 7 pounds within twenty seconds after the turbocharger rotor has attained a speed from 2000 to 4000 rpm., stop the engine and investigate the cause.

g. Every drip tube in the Manzel oiler should be delivering two drops of oil per stroke.

90. INCREASING ENGINE SPEED. a. The engine must be allowed to run for about ten minutes before speed is increased. This gives time for the lubricating oil to warm up and flow more freely to lubricate the various working parts. During this time, the operator should make a complete check of the engine operations. At the end of ten minutes, move the throttle up on the quadrant until the desired speed is attained. Avoid operation in the range of critical speeds.

b. The turbocharger speed, or the speed of the blower, is controlled by the engine. When the engine is under a heavy load, the impulse rate of the exhaust gas and the temperature of the gas are increased. The turbine fan revolves faster, and this, in turn, runs the rotor at a higher speed. The speed of the rotor is indicated by a tachometer on the turbocharger. Under normal conditions the turbocharger rotor on the six-cylinder engine should run at the rate of 10,300 revolutions per minute. The maximum rotation speed is 16,000 rpm. Normal rotor speed on the eight-cylinder engine is 9200 rpm. and the maximum speed is 12,500 rpm. The engine load must be reduced if these speeds are exceeded.

c. An exhaust gas temperature at the turbine inlet for continuous operations under normal conditions should be 880° F and may go up to 1000° F under full load operation. A temperature of 1100° F may be allowed for not more than 15 minutes. If temperatures exceed these limits, reduce the load on the engine.

d. The temperature of the lubricating oil entering the turbocharger lubricating system should not exceed 160° F and not over 180° F at the drain. If the temperatures exceed these limits, reduce engine load and look for stoppage or leakage in the turbocharger lubricating system.

e. The lubricating oil pressure at maximum operating speeds should be 15 pounds. If the pressure exceeds this limit, the lubrication relief valve in the turbocharger is not functioning properly and should be examined. A decrease not due to speed variations is probably caused by faulty action of the relief valve, stoppage of the system, or clogging of the filter element. Normal lube oil pressure is 5 to 7 pounds at 2000 to 4000 rpm.

f. The temperature of the cooling water at the point where it leaves the turbocharger should not exceed 180° F. The water temperature also should not rise more than 25° F when the engine goes from normal running speeds to full loads.

91. DECREASING ENGINE SPEED. Lower the throttle lever on the quadrant until the desired speed is reached.

92. STOPPING THE ENGINE. Move control handle to the neutral stop position. Do not attempt to stop the engine by reducing the throttle setting.

93. REVERSING THE ENGINE. Move the control handle in the direction of the desired rotation. When the indicator shows the new direction of rotation, press down on the handle and the engine will start. When in ahead running, wait until the engine stops before pushing the control lever into the astern position. Whenever the direction of the engine rotation is reversed, the engine goes through the same operations as when originally started. For a brief interval the engine stops until started again by pushing the control handle down in the desired direction. This is important to remember.

94. MANUAL EMERGENCY REVERSING. In the event that the air motor-driven reversing mechanism fails to function, the engine can be reversed manually. PLACE THE CONTROL HANDLE IN THE NEUTRAL POSITION. Insert a bar in the capstan located directly beneath the reversing mechanism. Rotate the capstan until it contacts the stop within the reversing mechanism, and start the engine in the normal way. This capstan is provided solely for emergency operation. Find the cause of the air motor failure as soon as possible and correct it.

95. THE LOG. Equally important as any tools provided for the operation and maintenance of the engine is the ENGINE ROOM LOG. Fig. 70 is a sample log sheet. The log is printed and ruled to provide for uniform entries. This log, like any other tool, is only of full benefit when properly used. Complete and accurate entries in the log record the operations of all parts of the engine so that even the slightest failures will point immediately to the mechanism not operating efficiently. The log also records the efficiency of the engine by providing a comparison of fuel consumption over different periods of time. The log also is the only means in which a relief watch operator can learn how the engine has been functioning, and from it obtain a warning of any suspected mechanism which should have his close attention while on duty. Everything concerning the operation of the engine should be recorded in the log. Adequate and accurate entries are necessary.

96. FUEL NOZZLES. Look at the exhaust stack occasionally to determine if the fuel nozzles are operating properly. If smoke is seen in any quantity at normal load and rated speed, the nozzle may be clogged or stuck. If the engine is overloaded, the exhaust will be smoky but this will not necessarily indicate fuel mechanism trouble. The operator must determine the cause of the smoke.

97. RAW WATER DISCHARGE. Glance over the side of the ship where the raw water system discharges to determine the functioning of this unit.

ENGINE ROOM LOG

Engineer	Date	1 Hr.	2 Hr.	3 Hr.	4 Hr.
Time					
Engine R.P.M.					
Pressures					
Lubricating Oil					
Fuel Oil					
Starting Air					
Jacket Water					
Sea Water					
Temperatures					
Jacket Water In					
Jacket Water Out	#1 Cylinder				
" " "	#2 "				
" " "	#3 "				
" " "	#4 "				
" " "	#5 "				
" " "	#6 "				
" " "	#7 "				
" " "	#8 "				
" " "	Combined				
Exhaust	#1 Cylinder				
"	#2 "				
"	#3 "				
"	#4 "				
"	#5 "				
"	#6 "				
"	#7 "				
"	#8 "				
Thrust Bearing					
Turbine Exhaust					
Turbine R.P.M.					
Lube Oil Filters	Service				
Lube Oil Service Tank Level	"				
Fuel Oil Filters	"				
Remarks					

Fig. 70. Typical Engine Room Log

SECTION VIII
ENGINE SPECIFICATIONS AND CLEARANCES

SPECIFICATIONS

Number of cylinders:	
DMQ-36	6
DMQ-38	8
Bore	16 inches
Stroke	20 inches
Maximum rated speed	280 RPM (revolutions per minute) (6 cyl.) 275 RPM (8 cyl.)
Displacement	4021.2 cubic inches per cyl.
Horsepower at maximum rated speed	1000 BHP (Brake Horsepower) (6 cyl.) 1200 BHP (8 cyl.)
Firing order ahead (6 cyl.)	1-5-3-6-2-4
Firing order astern (6 cyl.)	1-4-2-6-3-5
Firing order ahead (8 cyl.)	1-4-7-3-8-5-2-6
Firing order astern (8 cyl.)	1-6-2-5-8-3-7-4
Advance, or fuel timing (6 cyl.)	Injection set 6 inches on the flywheel before top dead center
Advance, or fuel timing (8 cyl.)	Injection set 6 inches on the flywheel before top dead center
Weight of one cylinder head	Approx. 1050 lbs.
Weight of one piston and connecting rod	1000 lbs. (approx. with rings)
Lubricating oil pressure	Pressure system 25 to 28 lbs. per sq. in.
Lubricating oil quantity in engine system	100 gals.
Lubricating oil temperature from engine	130° to 140°; 160° maximum
Lubricating oil temperature from cooler	110° to 125° full load
Jacket water pressure at pump discharge	3 to 15; 30 pounds maximum
Jacket water temperature at pump discharge	130°
Jacket water temperature out of engine	140° to 150°; 180° maximum
Jacket water temperature out of supercharger	140° to 160°; 180° maximum
Fuel oil pressure at transfer pump	10 to 15 lbs.
Starting air pressure	250 pounds
Reversing mech. air pressure	125 pounds
Lubricating oil	2-104B for use in temperate zone
Fuel oil:	
Viscosity, Saybolt Universal Viscosimeter at 100 deg. F	Visc. SSU @ 100° F. 38-40 Sec.
Gravity deg.	@ 60° F. A. P. I. 33.0
Water content and sediment	%/ vol-trace
Cetane rating	47
End point	700° F.

TABLE OF CLEARANCES

Valves

Exhaust Valve Clearance in Guide	.0055" - .007"
Replace guide if clearance exceeds .020" - .025"	
Inlet Valve Clearance in Guide	.0035" - .005"
Replace guide if clearance exceeds .020" - .025"	
Air Starting Valve Clearance in Cage	.015"
Main Piston in Cage	.002" - .004"
Replace piston if clearance exceeds .015"	
Auxiliary Piston in Main Position	.002" - .004"
Replace worn parts if clearance exceeds .015"	

Rocker Arm

Radial Clearance on Shaft	.002" - .004"
Replace rocker arm bushings if clearance exceeds .010"	
Roller on Pin	.0005" - .0025"
Replace pin and roller if clearance exceeds .010"	

Tappets

Tappet in Guide	.005" - .007"
Replace with new tappet guide liner if clearance exceeds .015" - .020"	
Tappet Roller on Pin	.0015" - .0030"
Replace pin and roller if clearance exceeds .012"	
Roller Pin in Tappets	.000" (Press Fit) - .0013"
Roller in Forks of Tappet	.006" - .008"
Roller to Side of Slot in Guide	.005"

Fuel Tappet

Tappet in Guide	.003" - .005"
Roller in Forks of Tappet	.006" - .008"
Roller Pin in Tappet	.005" - .009"
Roller in Guide	.006" - .008"

Air Tappet

Roller in Fork	.004" - .007"
Roller Pin in Tappet	.0005" - .0015"
Roller in Guide	.005"
Tappet in Guide	.005"

Camshaft Bearings

Clearance on Camshaft	.0025" - .0055"
Replace shells if clearance exceeds .010"	
Thrust Clearance	.010"
Replace thrust brg. if clearance exceeds .030"	
Thrust Brg. is first from Gearcase	

Connecting Rod Bearings

Clearance on Crankshaft	.012" - .014"
Replace if clearance exceeds .025"	
Side Clearance between Bearing Shoulder and Crank must not measure over	.008" - .010"
Replace shells if clearance exceeds .020"	

Main Bearing

Clearance on Crankshaft	.010" - .012"
Replace if clearance exceeds .025"	

Piston

Piston in Liner (Skirt Clearance)	.014" - .016"
Replace liner if diameter of bore at any point exceeds 16.055"	
Piston Pin In Piston	Light Driving Fit at 70° F
Piston Pin in Connecting Rod Bushing	.0065" - .0075"
Replace bushing if clearance exceeds .015"	

Top of Piston to Top of Cylinder Block ..... .830" - .840"
Adjust by means of compression shims between foot of connecting rod and bearing

Piston Rings

Gap Clearance
Sealing Rings ..... .040" - .055"
Top Compression Ring..... .040" - .060"
Second Ring ..... .025" - .040"
Oil Rings ..... .025" - .040"
Side Clearance in Groove
Top Two Rings..... .006" - .0085"
All Other Rings..... .004" - .0065"

Lubricating Oil Pumps

End Clearance of Gears..... .002" - .003"
Radial Clearance of Gears in Housing ..... .002" - .004"
Backlash in Gears..... .004" - .006"
End Clearance of Drive Shaft .004" - .007"
Adjust by removing shims under thrust washer if clearance exceeds .010"
Bushings — Radial..... .001" - .003"
Replace bushings if clearance exceeds .010"

Timing Gears

Backlash
Crankshaft Gear to Idler Gear .003" - .004"
Idler Gear to Water Pump Gear ..... .001" - .002"
Idler Gear to Camshaft Gear... .002" - .003"
Idler Gear to Lube Pump Gear .001" - .002"
Camshaft Gear to Governor and Tachometer Driven Gear ..... .001" - .002"
Main Governor Drive to Main Governor Driven Gear..... .001" - .002"

Idler Gear Bearing

Radial Clearance ..... .004"
Fit new bushings if clearance exceeds .010"
Thrust Clearance ..... .010"
Adjust by removing shims under thrust washer if clearance exceeds .015"

Centrifugal Water Pump

Clearance of bushings on impeller shaft ..... .003" - .0045"
Replace bushings if clearance exceeds .015"
Thrust clearance, measured between gear and bushing ..... .008" - .010"

Fuel Transfer Pump

Eccentric crank clearance on bushing ..... .003" - .005"
End clearance of eccentric crank ..... .003" - .006"
Clearance of plunger in body... .002" - .005"

Thrust Bearing DMQ-36

Type—Kingsbury "GH" special
Size—19"
RPM—300
Maximum operating temperature.....160° F
Journal Clearance ..... .011"
Clearance between thrust shoes and thrust collar..... .019"
Required water flow through lube oil cooler.....1 - 2 gals. per min.

Thrust Bearing DMQ-38

Type—Kingsbury "GF"
Size—21"
RPM—275
Maximum operating temperature.....160° F
Journal Clearance ..... .012"
Clearance between thrust shoes and thrust collar..... .021"
Required water flow through lube oil cooler.....3 - 4 gals. per min.

Compressor

Bore, low compression 5¼
Stroke, low compression 3½
Bore, high compression 3
Stroke, high compression 3½
Safety valve set at ..... 110 pounds
Unloader set at ..... 250 pounds
Lubricating oil grade ..... SAE 20
Self contained gear type lubrication oil pressure system

Compressor Clearances

Connecting Rod Bearings
  Total wear on both shells should not exceed ..... .005″

Piston Rings
  On low pressure piston, maximum ..... .008″
  On high pressure piston, maximum ..... .006″

Piston Pin Bushings
  Light driving fit

Crankshaft
  Main bearings Timken
  Thrust clearance ..... .010″

Compression
  Remove or add shims between crankcase block and cylinder block until piston crown, at dead top center, is flush with top of cylinder block

Lubricating Pump
  Thrust clearance, maximum .005″

Turbocharger for DMQ-36

1000 BHP at 280 RPM ..... continuously
Size BF-34
Serial No. ..... 1064—1083
Inlet air pressure ..... 8.4 lb. per sq. in. absolute
Inlet air volume (calculated) ..... 2580 cu. ft. per. min.
Blower discharge pressure, approx. ..... 4.15 lb. per sq. in.
Approximate blower speed ..... 10,300 RPM
Exhaust gas temperature at turbine inlet ..... 880° F
Exhaust gas pressure after turbine ..... 5 inches of water maximum

Maximum conditions not to be exceeded in operation of turbocharger:

Blower speed: 16,000 RPM

Exhaust gas temperature at turbine inlet:

1020° F continuously; or 1100° F for 15 minutes

NOTE: Exhaust gas temperature at turbine inlet will differ from exhaust gas temperatures at cylinder head elbow.

Above temperature limitations are required by the turbocharger turbine material.

Turbocharger arrangement:

Number of exhaust leads from engine: 2

Shaft arrangement: Horizontal

Turbocharger Clearances

		Maximum Limit
Rotor axial movement or end float with surface oiled	.012″ - .015″	.025″
Journal Bearings		
Inner shaft diameter	1.495″ - 1.494″	
Inner bearing bushing I. D.	1.4980″ - 1.4985″	
Outer shaft diameter	1.245″ - 1.244″	
Outer bearing bushing I. D.	1.2475″ - 1.2480″	
Clearance on diameter, dry, inner	.003″ - .0045″	
Clearance on diameter, dry, outer	.0025″ - .004″	

Turbocharger Clearances

		Maximum Limit
Labyrinth Ring (Piece #176)		
Clearance on diameter over impeller	.038″ - .046″	
Labyrinth Ring (Piece #175)		
Clearance on diameter over impeller	.038″ - .046″	
Radial clearance between turbine blade I. D. and nozzle ring, measured on blade tip angle cold with rotor toward nozzle ring	.047″ - .060″	
Oil Baffle Bores		
Threaded I. D.	2.010″ - 2.011″	2.025″
Bore projection inside diameter	1.759″ - 1.761″	1.770″

Turbocharger for DMQ-38

1200 BHP at 275 RPM.....continuously

Size BF44

Serial No.....564 to 577 and 611 to 616 inclusive

Inlet air pressure.....9.9 lb. per sq. in. absolute

Inlet air volume (calculated).....3900 cu. ft. per min.

Blower discharge pressure, approx.....4.35 lb. per. sq. in. gauge

Approximate blower speed.....9200 RPM

Exhaust gas temperature at turbine inlet.....878°

Exhaust gas pressure after turbine.....4 inches of water maximum

Maximum conditions not to be exceeded in operation of turbocharger:

Blower speed: 12,500 RPM

Exhaust gas temperature at turbine inlet:

1020° F continuously; or 1100° F for 15 minutes

NOTE: Exhaust gas temperature at turbine inlet will differ from exhaust gas temperatures at cylinder head elbow.

Above temperature limitations are required by the turbocharger turbine material.

Turbocharger arrangement:

Number of exhaust leads from engine: 4

Shaft arrangement: horizontal

Turbocharger Clearances

		Maximum Limit
Rotor axial movement or end float, with surface oiled	.014″ - .018″	.025″
Journal Bearings		
Shaft diameter.....	1.870″ - 1.869″	
Bushing I. D.....	1.8740″ - 1.8745″	
Clearance on diameter, dry.....	.004″ - .0055″	
Labyrinth Ring (Piece #176)		
Clearance on diameter over impeller.....	.038″ - .046″	
Labyrinth Ring (Piece #175)		
Clearance on diameter over impeller.....	.038″ - .046″	
Clearance between end of turbine blade and nozzle ring with rotor shifted toward nozzle ring.....	.054″ - .070″	
Oil baffle bores		
Threaded bore I. D.	2.509″ - 2.511″	2.525″
Smallest bore I. D.	2.196″ - 2.198″	2.210″

SECTION IX
ADJUSTMENTS, TIMING, AND GENERAL MAINTENANCE

98. MAINTAINING OPERATIONS. If the engine is properly maintained it should not be necessary to shut it down frequently for repairs. At the end of this section there is a schedule of routine maintenance operations. This routine should be followed carefully. Do not tamper with the engine when it is running satisfactorily.

99. KEEP THE LOG CURRENT. The engine room log must be kept accurately and completely up to date at all times the engine is running. Engine breakdowns seldom happen instantaneously, but are built up slowly with various symptoms warning of impending trouble. The log should contain every bit of information on the engine's performance. A watch by watch comparison of these notations will show quickly if some part of the engine is starting to function poorly. A slight increase in operating temperature may not be important, but if in succeeding watches the temperature continues to climb, it is apparent that serious trouble is developing which must be corrected before it causes major damage. A typical log is shown in Fig. 70.

100. TIMING THE ENGINE. ***a.*** Normally the engine is always in time. If the gears in the front end of the engine that keep the camshaft and crankshaft in proper time are removed,

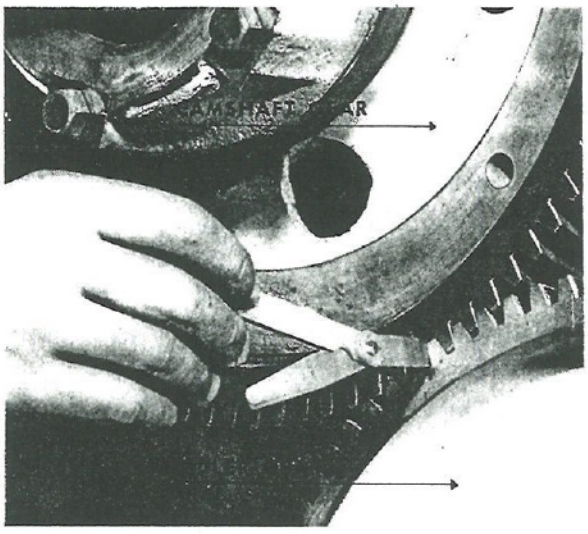


Fig. 71. Measuring Camshaft Gear Back Lash for Timing Adjustment

mark the teeth of each gear with a center punch, stamping in a row of dots on each gear so that on reassembly the two gears can be lined up in the same position.

b. The gears should function without attention for many hours. Occasionally one of the gears may become stripped or worn out, making replacement necessary. After replacement, it will be necessary to re-time the engine. If the gears are not stripped but thought to be worn excessively, check the backlash with a feeler gauge as illustrated in Fig. 71. If the clearance between the teeth exceeds the maxi-

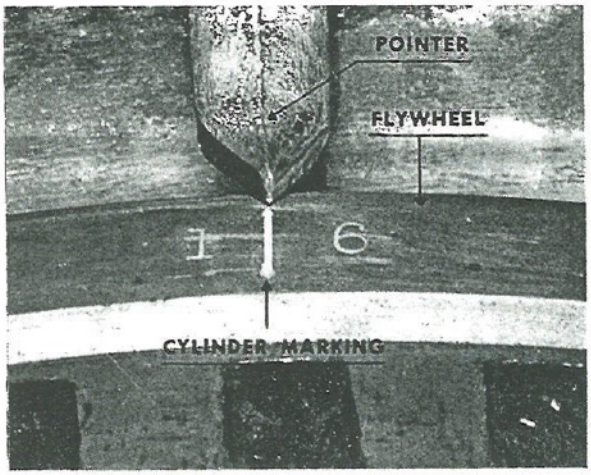


Fig. 72. Flywheel Pointer

mum clearance listed in the table of clearances in Sect. VIII, replace the gears. There are three gears in this group, the large one on the front end of the camshaft, the idler gear that meshes into it which is of equal size, and the smaller gear meshing into the idler gear on the front end of the crankshaft. The outer set of nuts secures the gear ring to the gear wheel. In replacing the gears, it is usually only necessary to remove the gear ring and install a new one.

c. Bar the engine over until the flywheel pointer is directly on the line stamped with the numerals 1 and 6, as shown in Fig. 72. Remove the idler gear from its shaft and push or pull the camshaft until the roller of the fuel tappet for No. 1 cylinder divides the fuel cam evenly, as shown in Fig. 73. Remove the rocker arms on all cylinders to relieve the pressure on the camshaft. Rotate the camshaft until the master key that holds the cams in position on the camshaft for No. 1 cylinder is exactly on top of the shaft. Use a square and rule to be sure the key is exactly on top, as illustrated in Fig. 74. When the legs of the square are perfectly flush on the side of the engine block and on the top of the keyway the camshaft is in correct position and time.

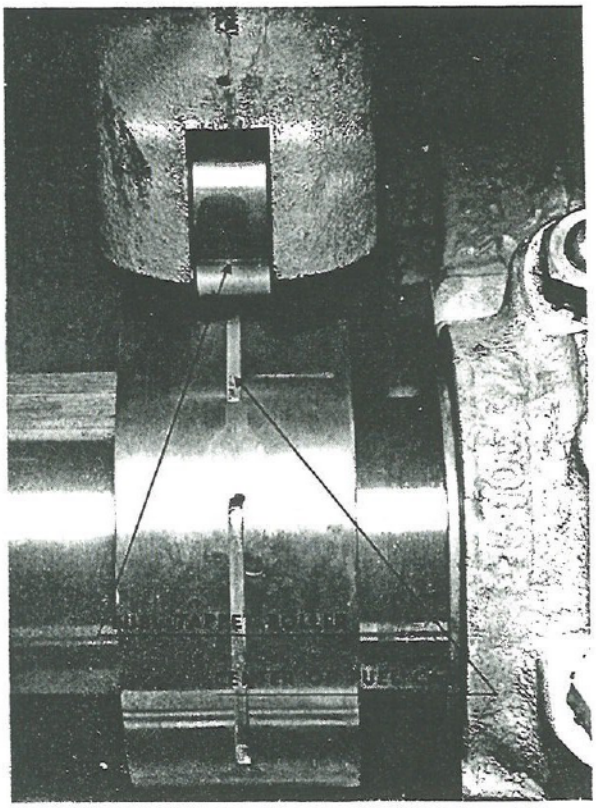


Fig. 73. Fuel Tappet on Fuel Cam Center

101. FUEL PUMP TIMING. ***a.*** The fuel pumps do not operate from a push rod, but directly from the fuel pump tappet. The fuel pump and its tappet are assembled together with the pump fitting over the top of the tappet. The fuel pump timing must be exact. If the pumps inject fuel into the cylinders too late or too early, poor engine performance will result. Before adjusting the fuel tappet, however, the engine must be in the proper position.

b. The cranks of the engine crankshaft work in pairs. If one piston is on top dead center, the other piston paired with it will also be on top dead center. The pairs that work together are 1 and 6, 2 and 5 and 3 and 4. Bar over the engine until the line between the numerals 1 and 6 is exactly opposite the flywheel pointer. About eight inches on each side of this line coat the flywheel with white lead,

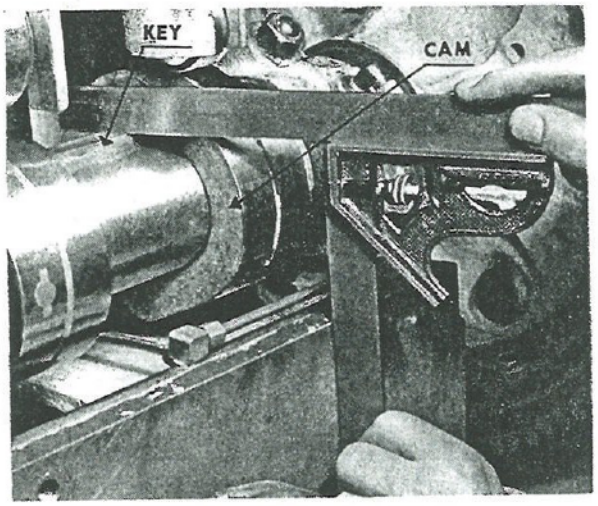


Fig. 74. Camshaft Key Measurement

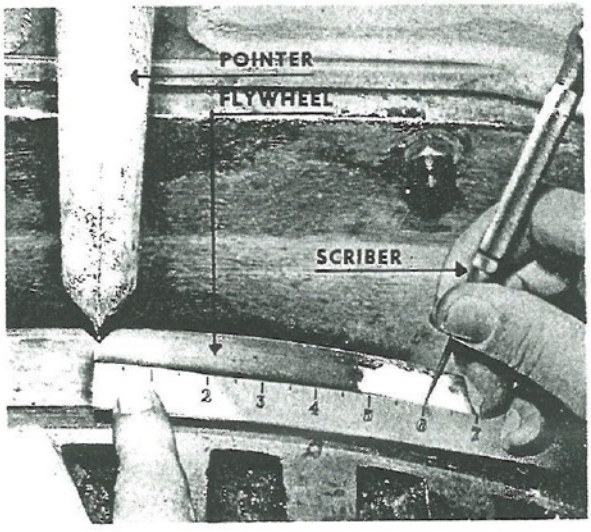


Fig. 75. Marking Off Timing Liner on Flywheel

white paint, or some other substance that will stick, for about an inch. With a flexible steel ruler that will bend to the contour of the flywheel, measure off 6 inches on both sides of this line, as shown in Fig. 75, and scratch lines through the white lead. Repeat this operation for each pair of numerals on the flywheel.

c. Remove the camshaft cover to expose the entire camshaft, and be sure the camshaft is

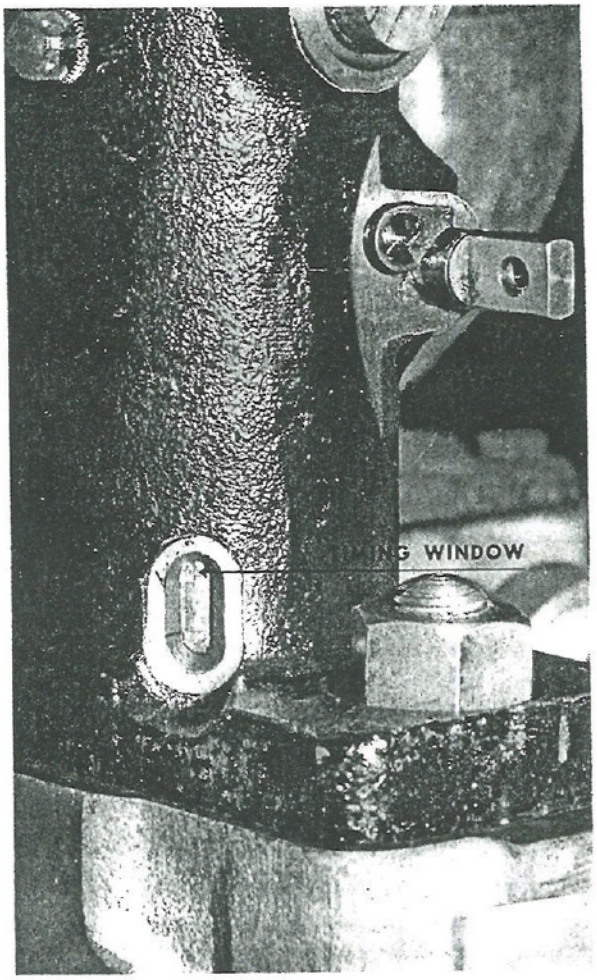


Fig. 76. Timing Window on Fuel Pump

in the ahead running position by checking with the indicator on the top of the control handle box. Bar the engine over until the flywheel pointer is exactly opposite the line marked out 6 inches ahead of the engraved line between numerals 1 and 6.

d. Look at the fuel pump serving No. 1 cylinder and find the timing window, as shown in Fig. 76. On the lower left edge of the window a deep line is engraved. A similar line is on the plunger of the pump. If these two lines meet to form one straight line, the pump is timed for port closing. This means that the pump is at rest but ready to start into operation on the

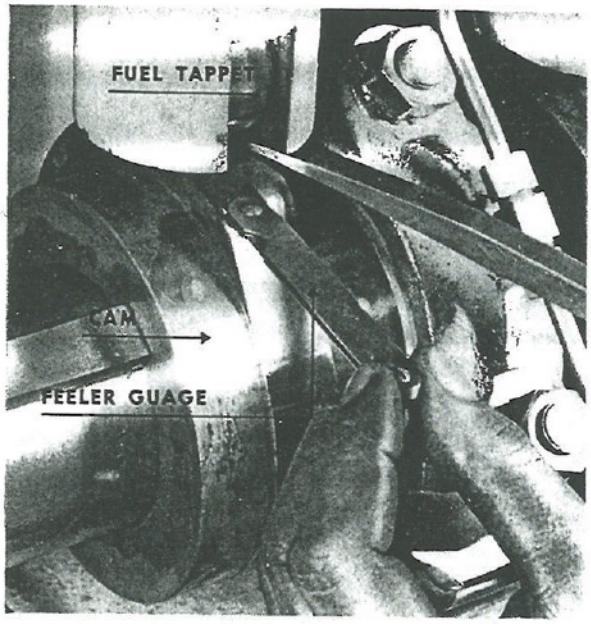


Fig. 77. Fuel Roller on Fuel Cam Lobe

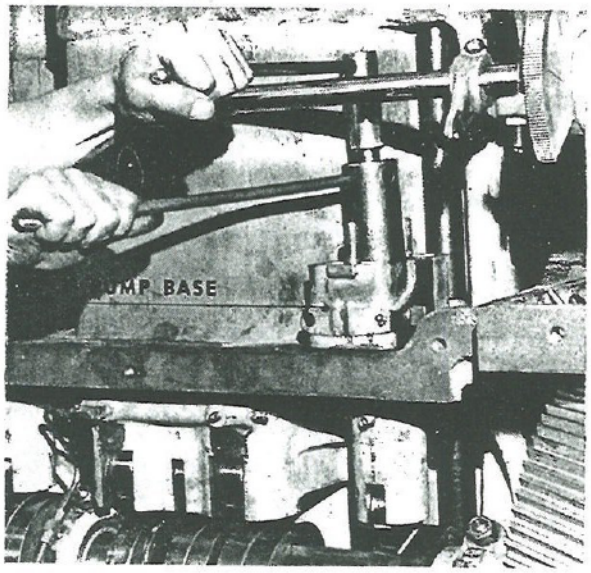


Fig. 78. Adjusting Fuel Pump Tappet

next movement of the engine. The tappet roller is still on the base circle of the cam, but almost on the start of the rise of the lobe. The position of the roller on the cam is shown in Fig. 77.

e. If the line on the plunger is higher than the line on the side of the window, the tappet is too long. If the plunger line is below the line on the window, the tappet is too short. Measure the distance between the two lines. Remove the tubing on the pump, if it is not already off, and take off the two nuts as shown in Fig. 76, that hold the pump on the tappet base. The adjusting plug on the tappet is now available. A half turn on the tappet plug is approximately equal to 1/32nd of an inch in the tappet window. Therefore, divide the distance found between the two lines in units of 1/32nd of an inch and turn the tappet adjustment either up or down the half turns needed to close the distance between these lines. The method of adjusting is illustrated in Fig. 78. Before replacing the fuel pump over the tappet, measure the distance from the top of the tappet base to the top of the adjusting plug. If the pump is in time, this distance should be exactly 1.97 inches. Adjust until this distance prevails and replace the pump over the tappet. If the lines in the window meet, the fuel pump for No. 1 cylinder is in time for ahead running.

f. Since the Enterprise engine is direct reversible, the pump must also be timed for astern operations. Set the camshaft into the astern running position and bar the engine over in the direction the crankshaft rotates when operating in reverse and watch the timing lines in the fuel pump window. Stop barring as soon as they meet. Look at the flywheel, and if the flywheel pointer is exactly opposite the line scratched on the flywheel 6 inches behind the timing mark for Nos. 1 and 6 cylinders, No. 1 fuel pump is in time for astern operations as well as ahead operations. In fact, for astern timing the distance will be correct if it is ⅛ of an inch shorter than the 6-inch mark. If it is less than this, or more than 6 inches, however, the camshaft is unbalanced and must be balanced before timing the rest of the fuel pumps.

102. TO BALANCE CAMSHAFT. a. Bar the engine over until the flywheel markings and pointer show that Nos. 1 and 6 cylinders are on top dead center. The master cam key for No. 1 cylinder should be facing upward. Remove the fuel pumps and fuel pump tappet assemblies from No. 1 and No. 6 cylinders. With a square and ruler, measure the distance be-

tween the engine shelf on which the fuel pumps are located and the tip of the fuel cam, as illustrated in Fig. 79, at both the No. 1 and No. 6 cylinders, as these two are located on extreme ends of the camshaft. The two measurements will vary, indicating positively that the camshaft is out of balance.

b. At the front end of the engine loosen the nuts that secure the cam gear ring to the cam gear hub, as illustrated in Fig. 80, and rotate the shaft in the direction required to balance the camshaft. When the camshaft is balanced to approximately even measurement, check again with a square and rule, using this time a feeler gauge under the rule to obtain the exact measurements, as illustrated in Fig. 81. When this is done, the camshaft is balanced. Resecure the nuts on the camshaft gear ring, replace Nos. 1 and 2 fuel pumps and tappets, and proceed to time the fuel pumps in the proper firing order.

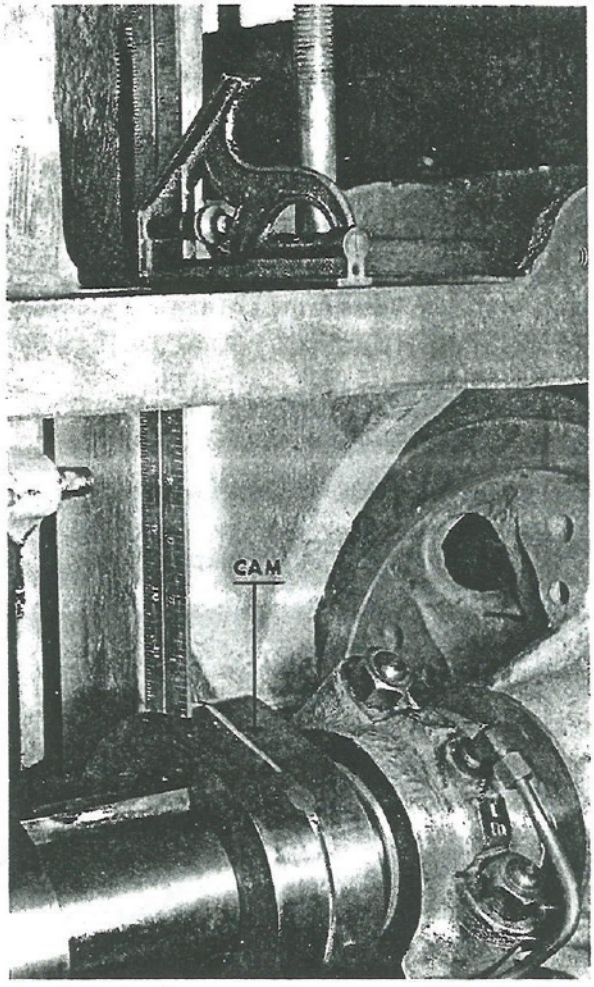


Fig. 79. Camshaft Balancing

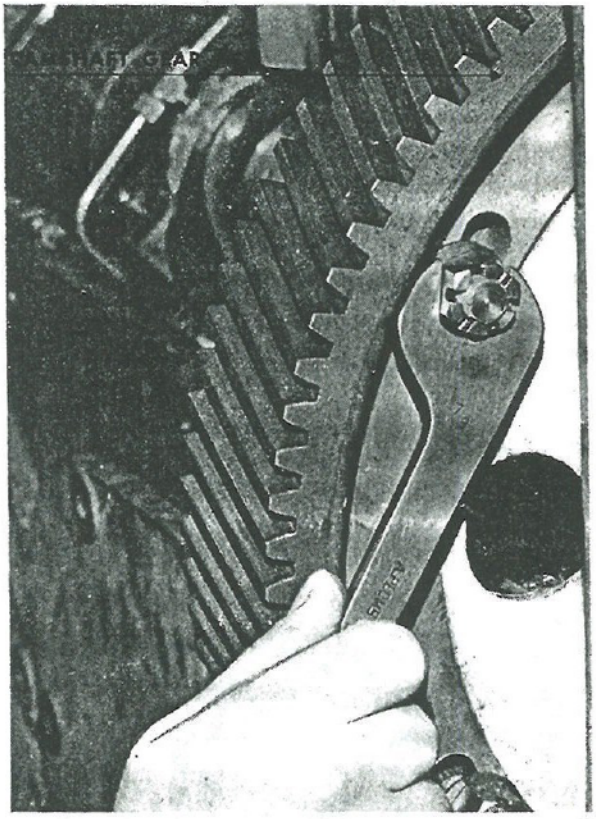


Fig. 80. Camshaft Gear Ring Loosening

103. FIRING ORDER. *a.* If the camshaft is balanced, the fuel pumps need only to be timed for ahead operations; the astern timing will be adjusted automatically. It is when the balance of the camshaft is unknown that the astern timing must be checked. With the camshaft balanced, as explained, the operator is only concerned with the ahead timing.

b. The timing of the fuel pumps arranges the sequence in which the cylinders will receive a charge of fuel to ignite for the power stroke. As already explained, when the flywheel marking 1 and 6 is opposite the flywheel pointer, those two cylinders which work in

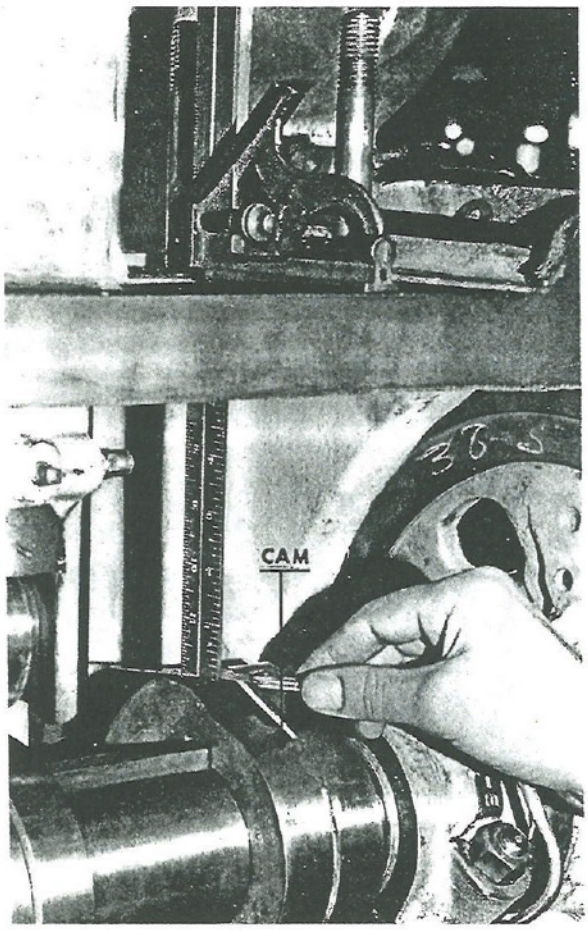


Fig. 81. Camshaft Balancing to Exact Measurements

pairs, are on top dead center. However, two cylinders cannot be firing at the same time. When No. 1 cylinder is ready to receive a fuel charge, No. 6 cylinder, also at top dead center, is at the end of the exhaust stroke.

c. The ahead firing order in the Enterprise engine is 1-5-3-6-2-4. Therefore, after No. 1 fuel pump is timed for ahead operation, bar over the engine in the ahead rotation until the line marked 6 inches in front of the cylinder marking for Nos. 2 and 5 cylinders on the flywheel is opposite the flywheel pointer. Go to No. 5 fuel pump and time it in the manner already described. When finished, bar the engine over in the ahead rotation until the marking on the flywheel 6 inches ahead of the marking for cylinders 3 and 4 is opposite the flywheel pointer. Now time No. 3 fuel pump. When completed, bar over the engine in the same direction until the line 6 inches ahead of the marking for Nos. 1 and 6 cylinders is again opposite the flywheel pointer and then time No. 6 fuel pump. When completed, bar the engine over to the same mark used in timing No. 5 pump, but this time adjust the No. 2 pump. When completed, bar over the engine until the flywheel reaches the marking used to time No. 3 fuel pump and proceed to adjust No. 4 fuel pump. When this is completed all fuel pumps are timed for ahead operations and with the camshaft in balance are also timed for astern running.

104. TIMING AIR INTAKE AND EXHAUST VALVES AND ADJUSTING. The timing of the air intake, air starting, and exhaust valves is correct when the camshaft is in time with the crankshaft. The procedure for timing the camshaft is explained in par. 103. These valves require adjusting, however.

105. ADJUSTING ZERO LASH UNITS. Zero lash units secure the push rods to the rocker arms operating the intake and exhaust valves. They require adjustment occasionally. Zero lash units depend on oil pressure for opera-

Fig. 82. Adjustment of Zero Lash Unit

tion, and if adjusted when the engine is shut down, or when the lubricating oil is cold, the adjustments will not be true when the engine warms up. Before making the adjustment, have the engine running at normal temperatures and then cut the engine speed to about 1/3 speed. Remove the cylinder bonnet to expose the head. Screw down on the adjusting nuts, as shown in Fig. 82, until the valve starts to hold slightly open. Then unscrew or back off the adjustment one whole turn and lock the adjustment with the locking nut.

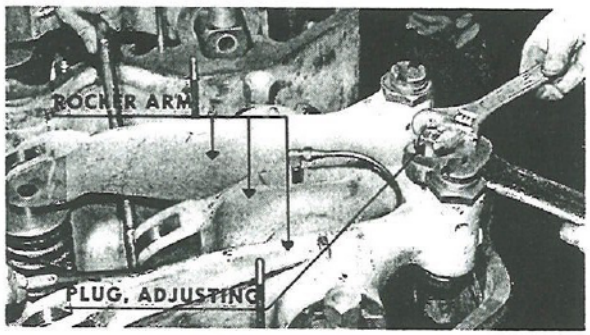


Fig. 83. Adjusting Air Starting Rocker Arm

106. REPAIRING ZERO LASH UNIT. *a.* Normally, the adjustment screw will remedy any difficulty experienced with a zero lash unit. If, after adjusting, the zero lash still does not function properly after having been adjusted, disassemble the unit.

b. Disconnect the rocker shaft and the lubricating line and remove the rocker shaft stud nuts. Lift the rocker shaft until the lifter units clear the push rods and remove the lifter units and take off the rocker assembly. Remove plunger from the zero lash unit cylinder and wash all parts thoroughly with solvent, dry-cleaning. Be sure that the hole feeding oil to the unit is clear. If the spring is broken, or has lost its elasticity, replace it. If the plunger or the cylinder is worn, it will be necessary to replace both of them, as the plunger and cylinders are ground at the factory to permit the proper oil escape. Be sure that the plunger fits into the cylinder freely, but without looseness. Hold the unit in a vertical position, release the spring from the counterbore in the cylinder, and pull the plunger out as far as possible. If the plunger kicks back repeatedly, it indicates that considerable air is retained and the unit is in good condition.

c. When satisfied that the unit is in working order, wipe off the plunger with a dry, soft cloth, replace in cylinder, and assemble lifter in lifter body. Replace unit in rocker arm, reinstall the rocker arm assembly, and tighten the stud nuts.

d. Adjust the zero lash unit by backing off the adjusting screw about two turns and barring over engine until the piston is ready to start the firing stroke. Tighten up the adjusting screw until the plunger rests against the bottom of the cylinder. At this time the roller on the rocker should contact the valve stem. Back off the adjusting screw one full turn, and the zero lash unit will be in proper adjustment. It may run noisily for the first five to fifteen minutes after the engine is started due to air in the zero lash cylinder.

107. ADJUSTING AIR STARTING VALVES. The air starting valves are easily adjusted in the head while the engine is shut down. However, do not attempt to adjust an air starting valve if both the intake and exhaust valves on the cylinder are closed. If they are both closed, bar over the engine until one of the valves is open. Lift the upper piston or the expanding cap of the valve. Either use a screwdriver to pry this expanding cap up for its full expansion, or screw in the bleeding valve on the air starting control valve just enough to permit sufficient air pressure to enter the cylinder heads and expand the air starting valves. Be careful that the supply of compressed air admitted is less than that required to start the engine rotating. When the piston, or expanding cap of the air starting valve is up, insert a feeler gauge of .030 between the rocker roller and the top of the air starting valve. Screw down or up on the tappet adjustment, as illustrated in Fig. 83, until there is a definite pull on the feeler gauge when it is pushed in or out. Lock the adjustment.

No. 7033

WAR DEPARTMENT LUBRICATION ORDER

WAR DEPARTMENT
WASHINGTON 25, D. C., 26 AUGUST 1944

ENGINE, DIESEL, MARINE TURBOCHARGED

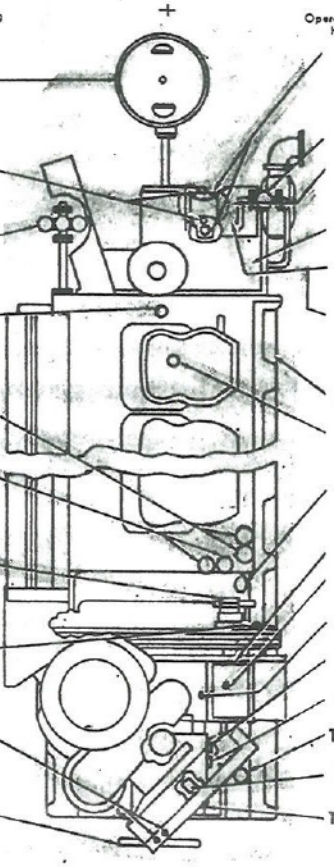
(ENTERPRISE DMG 38, DMQ 36, DMQ 38)

For detailed information, refer to TM 55-1106 for DMG 38, TM 55-1105 for DMQ 36 and DMQ 38.

Clean fittings before lubricating. Reduce intervals under severe operating conditions.

Requisition replacement Lubrication Order from the Commanding Officer, Montgomery Transportation Corps Depot, Montgomery, Alabama

To clean parts use SOLVENT, dry-cleaning or OIL, fuel, Diesel. Dry before lubricating.



		Lubricant	Operating Hours
1	*Lube Oil Filter* Drain sediment. Every 200 hours renew element		8
3	Air Motor One shot. Clean and repack every 6 months	CG	50
8	*Lube Oil Strainer* (See Note 3)		50
12	Engine Breather Cap Clean, dry and oil breather element	OE	50
13	*Fuel Oil Strainers* Turn handle 1 full turn (See Note 3)		4
2	*Fuel Oil Filters* Drain sediment. Every 200 hours renew element		25
5	Compressor Shaft Pulleys One shot. Clean and repack every 6 months	CG	8
6	Compressor Idler Pulleys Clean and repack every 6 months	CG	8
9	Turbo Charger Lube Oil Fill and Level. Check level	OE	8
	Air Cleaners (See Note 2)	OE	500

		Lubricant	Operating Hours
25	WP Seawater Pump (On port side on DMQ 36 & DMQ 38) Turn cups down 1 full turn, refill as needed		11
50	*Lube Oil Strainer* (See Note 3)		8
8	OE Governor & Fuel Control Shafts. 6 to 8 drops		3
8	OE Governor Linkage. 6 to 8 drops		3
8	OE Starting and Reverse Controls (DMG 38). 6 to 8 drops		
50	CG Starting and Reverse Controls (DMQ 36, DMQ 38). One shot. Clean and repack every 6 months		
200	*Crankcase & Sump Tank* Drain excess moisture and sludge		
8	OE Air Starting Valve. 6 to 8 drops in oil cup and on top of caps and outer piston		7
4	OE Fuel Oil Transfer Pump (Hand oiling points)		14
50	*Compressor Oil Drain* Drain and refill		4
8	OE Compressor Fill & Level. Check level		4
50	OE Compressor Breather Cap. Clean, dry and oil breather element		4
8	OE Thrust Bearing Fill & Level. Check level		10
500	*Thrust Bearing Drain* Drain and refill		
1200	*Turbo Charger Lube Oil Filter* Renew element		9
300	CG Tachometer Cable and Drive Gear		
1200	*Turbo Charger Lube Oil Drain* Drain and refill		9

NOTES

1—LUBE OIL SERVICE TANK—Check level hourly. Drain water and sludge from trap daily. Drain and fill every 500 hours with OE.

2—AIR CLEANERS—Remove and wash cleaners and cleaning element. Dry and oil. Drain excess oil and replace.

3—STRAINERS—Daily drain sediment. Remove and clean element and case every 50 hours.

KEY

ARMY LUBRICANTS	UNITS SERVICED	ALL TEMPERATURES
OE—OIL, engine	Crankcase Compressor All Other Points	SAE 30, or Navy Symbol 9250
CG—GREASE, general purpose	All Points	No. 1, or Navy Symbol 14L9
WP—GREASE, water pump.	Water Pump	WP, or Navy Symbol 14L11

Copy of this Lubrication Order will remain with the equipment at all times; instructions contained therein are mandatory and supersede all conflicting lubrication instructions dated prior to 26 August 1944.

By Order of the Secretary of War:
G. C. Marshall, Chief of Staff.

Official:
J. A. Ulio, Major General,
The Adjutant General.

NO. 7033 [NOT TO BE REPRODUCED in whole or in part without permission of the office of the Chief of Transportation.]

Data based on inspection of Production Model

Fig. 84. Lubrication and Service Chart

108. FUEL NOZZLE ADJUSTMENT AND MAINTENANCE. The fuel nozzle must open and close at the proper times to insure the delivery of a measured quantity of fuel at the exact time. In routine service, three things on the fuel nozzles require attention. The small holes in the tip, if clogged, must be cleaned out with fine piano wire to permit full delivery of fuel. The nozzle check valve must seat perfectly to prevent the escape of fuel as pressure is developed. If not in perfect condition, replace the check valve and seat. Repair is not recommended. The edge filter in the fuel nozzle should be clean and serviceable, and, if damaged, replaced. The spring tension of the check valve spring should be adjusted so that the valve will not open until 2300 pounds has developed. The bleeder ball valve should be examined to see that it seats correctly. The method of performing this operation is explained in Sect. XV.

109. SERVICING ROUTINE. a. For the convenience of the operator, as a ready reference, the servicing points are shown in Fig. 84 for both the six-cylinder and eight-cylinder engine. Refer to Fig. 84 for the location of the service points and in Figs. 85, 86 and 87 these points are illustrated in close-up views. Refer to WDLO #7033 for proper lubricants to use.

b. Other routine and periodic servicing, not illustrated, is set down in the following table:

HOURLY SERVICE

Turn handles on knife blade scrapers.

Read all instruments and make proper notations in engine log.

Check oil level in lubricating oil service tank. Feel side covers on engine for excessive heat.

FOUR-HOUR SERVICE

Check water level in surge tank.
Inspect pump glands.

EIGHT-HOUR SERVICE

Check oil level in Manzel oiler, adding new oil when required.

24-HOUR SERVICE (Daily)

Drain lubricating oil service tank until clean oil shows.

Clean sea chest.

200-HOUR SERVICE (30 Days)

Inspect crank case sump for excess of water, drain oil from sump if considerable amount of sludge or water is present.

Remove camshaft covers and inspect tappets and rollers. Check tappet clearances with feeler gauge with rollers on low part of cams.

300-HOUR SERVICE

Disconnect the flexible shaft to the turbocharger tachometer at both ends and remove the inside cable. Apply a light film of grease CG to the inside cable, using only enough lubricant to coat with a thin, even film. Replace the inner cable in the outside covering.

500-HOUR SERVICE (60 Days)

Clean heat exchanger tubes with stiff brush. Flush water jacket.

Inspect sea water pump for dirt and sand damage.

Drain oil from lubricating system, replacing with new oil.

Disconnect the right angle drive section from the turbocharger tachometer and from the flexible cable. Remove the ⅛-inch plug on the side of the gear housing, and apply only enough light grease to wet the gear teeth as the shaft is slowly turned. Too much lubrication may ruin the tachometer.

1500-HOUR SERVICE (Semi-Annually)

Remove one or more pistons and inspect for wear of pistons or rings, replacing as necessary.

Remove one or more valves and inspect for pitting, warping, or wear.

Inspect valve lifting mechanism.

Remove cover on timing gear case and test backlash with feeler gauge, making necessary adjustments or replacements.

Inspect camshaft bearings with feeler gauges.

Check clearance on one or more connecting rod bearings and main bearings.

Test backlash of all gears with feeler gauges.

Inspect lubricating oil cooler for corrosion, and clean if necessary.

Examine cylinder liner walls for hump or ledge above top of piston travel.

Examine bolts holding engine to bed. If loose, tighten and check alignment between flywheel and thrust bearing shaft.

Clean off accumulations of dirt on turbocharger impeller and diffuser.

3000-HOUR SERVICE (Annually)

Overhaul and completely clean engine, replacing parts not meeting specifications or clearances.

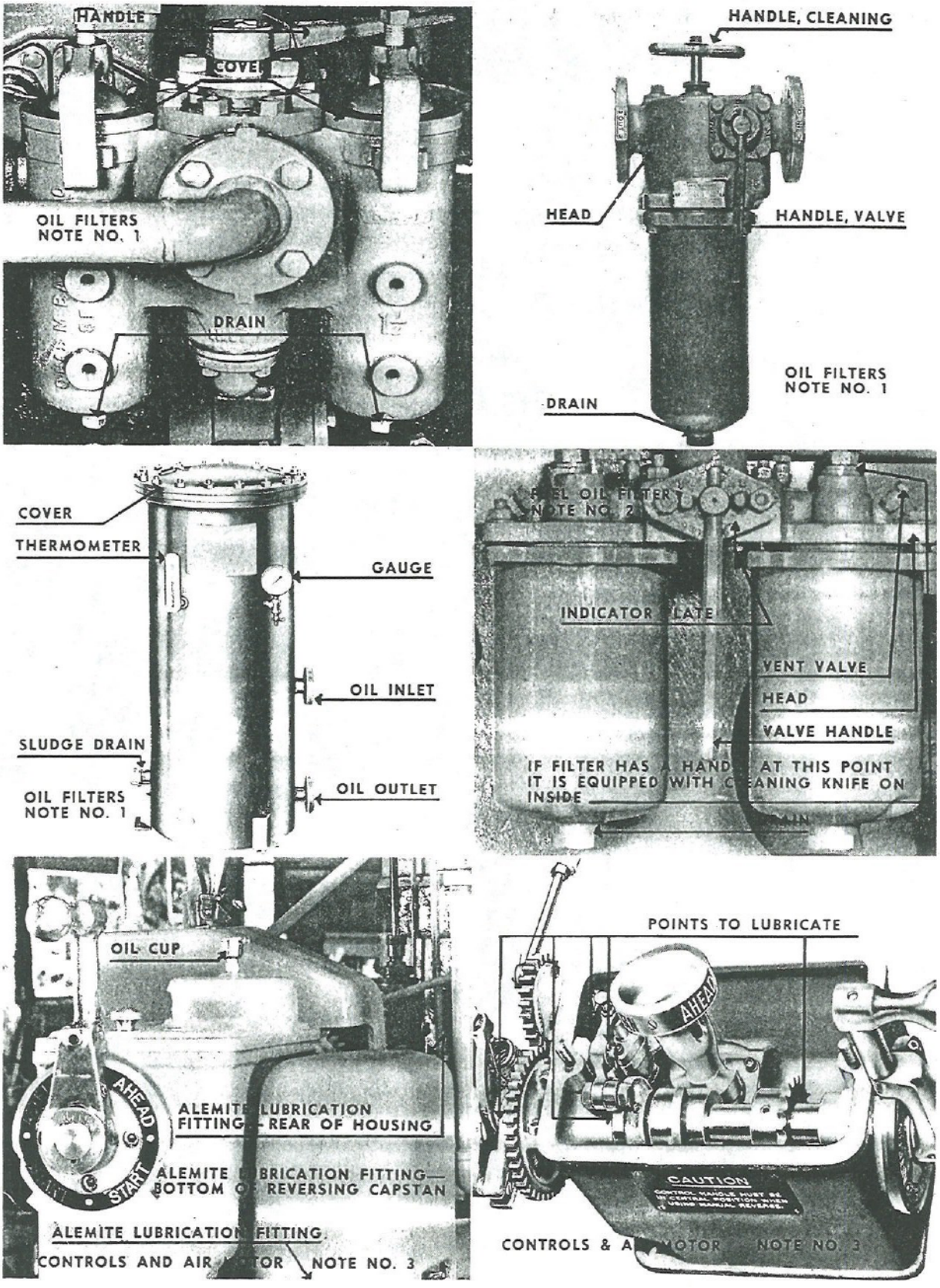


Fig. 85. Localized Views of Service Points

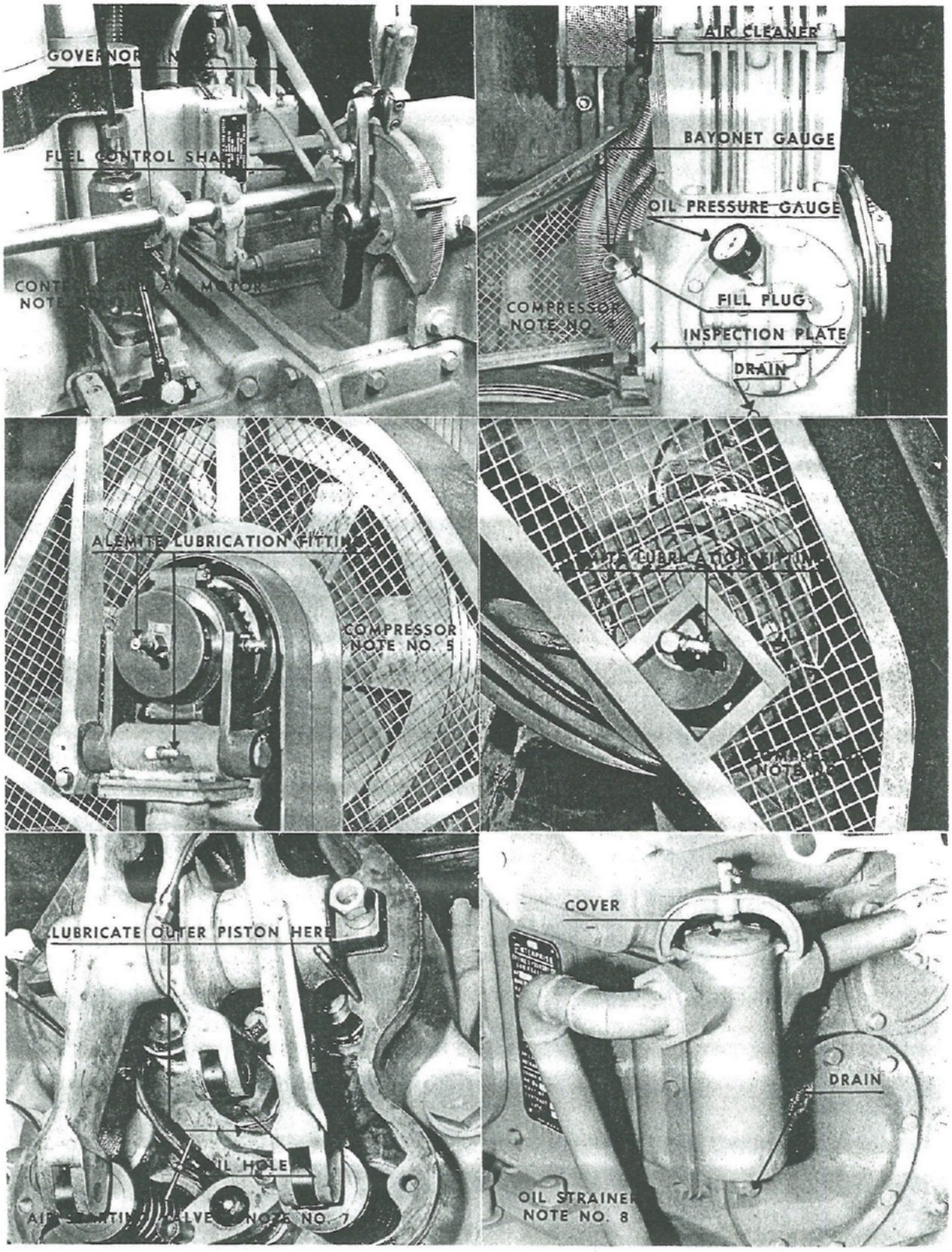


Fig. 86. Localized Views of Service Points

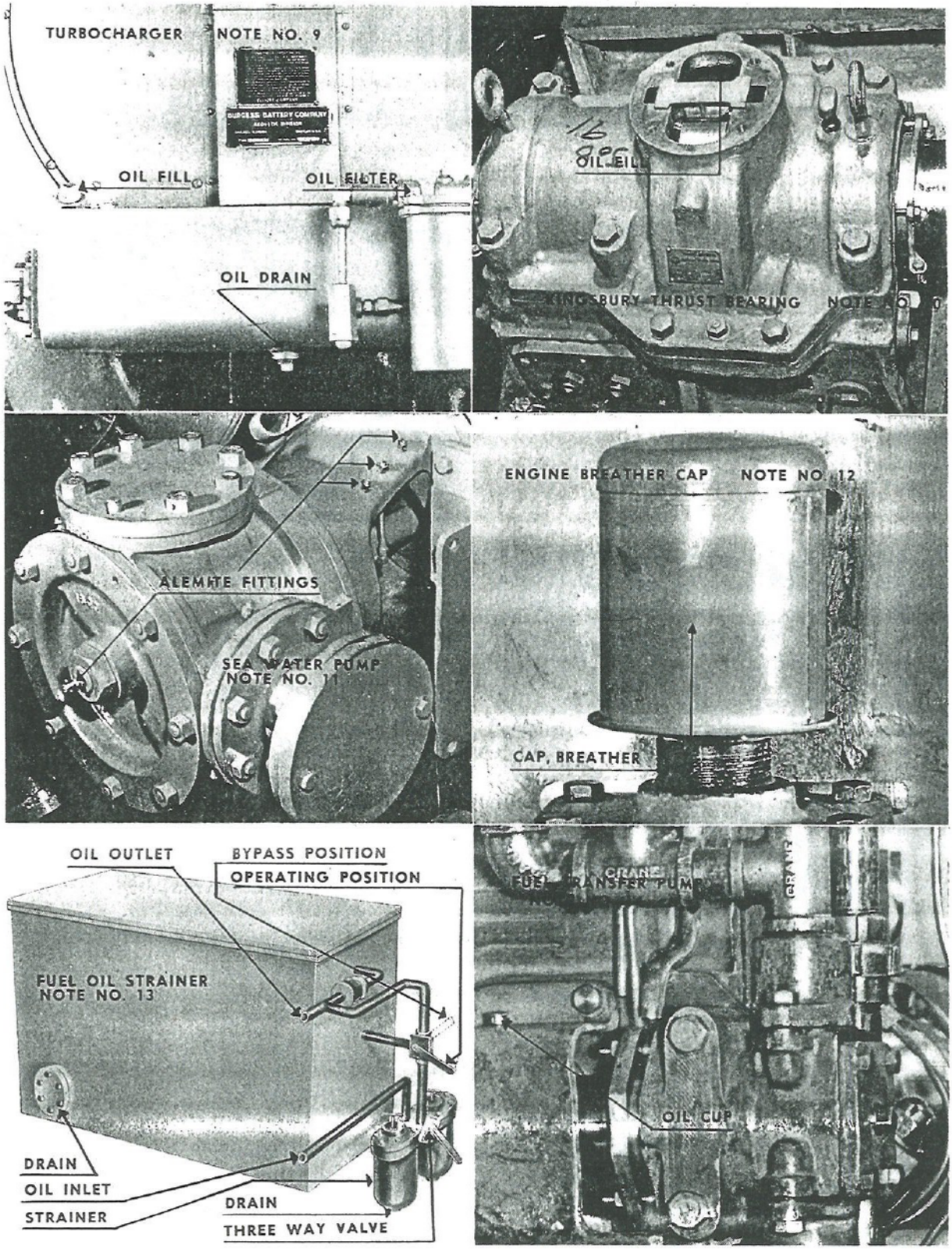


Fig. 87. Localized Views of Service Points

SECTION X
CYLINDER HEAD AND VALVES

110. GENERAL. Starting with this section, instructions will be given on the repair and replacement of the various engine parts.

111. REPAIR OF CYLINDER HEAD PARTS. Many repairs can be made to cylinder head parts without removing the cylinder heads. These parts include the valve springs, air starting valve, fuel nozzle, relief valves, and rocker arm parts, as shown in Fig. 88.

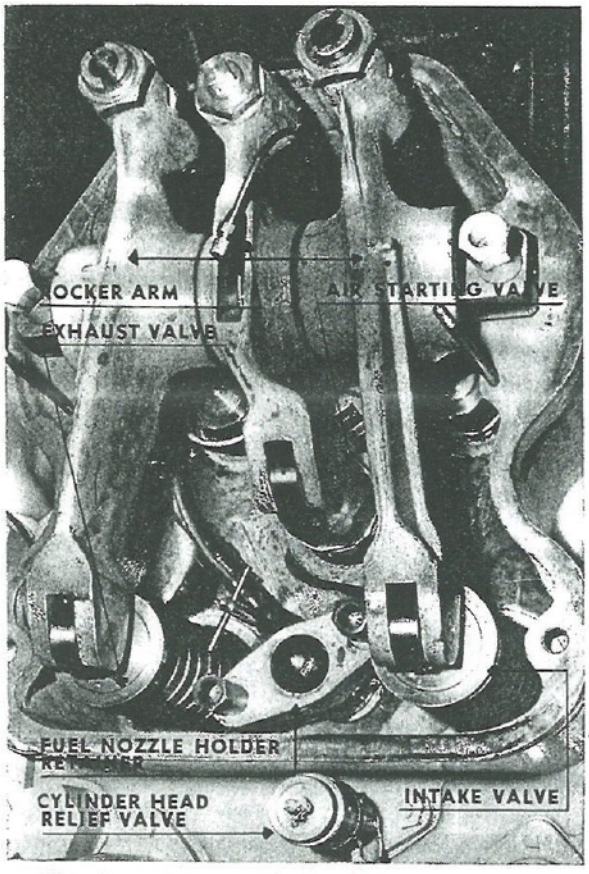


Fig. 88. Cylinder Head with Bonnet Removed

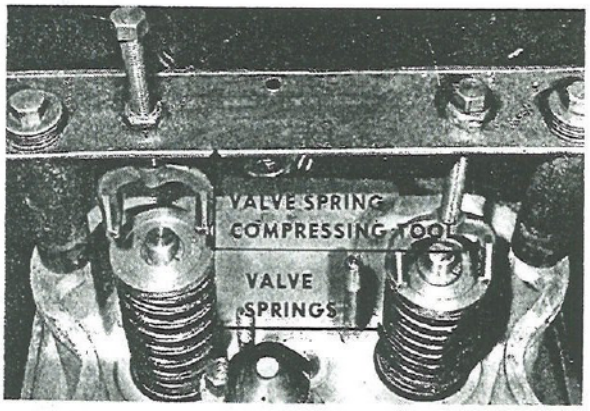


Fig. 89. Valve Spring Removal Tool

112. REPLACING VALVE SPRINGS. If a valve spring breaks, bar the engine over to top dead center. Then remove the rocker arm assembly by loosening the two securing nuts located at each end of the rocker shaft and disconnecting the lubrication oil tubing line. This will hold the valve in the cylinder head while the spring is replaced. CAUTION: during this operation do not bar the engine over since, if this is done, the valve may drop into the cylinder and require the removal of the head to retrieve it. Place the valve compressing tool on top of the cylinder head, as shown in Fig. 89, and tighten the two bolts that secure the tool to the cylinder head. Be sure these bolts are tight before starting to compress the spring, otherwise a serious accident may result. Turn the compressing screw until the valve keepers

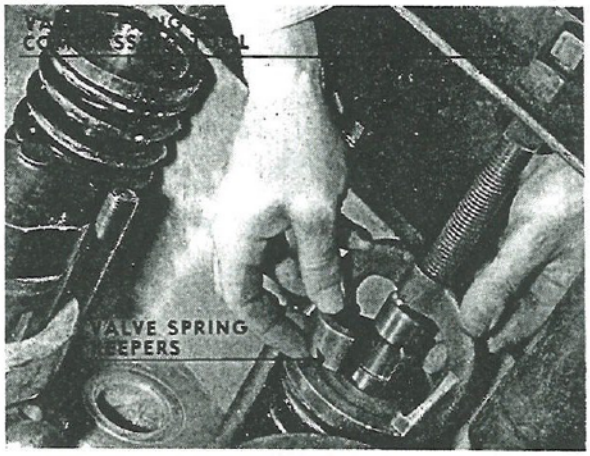


Fig. 90. Removing Intake and Exhaust Valve Spring

are free, and then remove them. If the valve and spring both compress as much as a half-inch, tap the spring retainer with a light hammer which will jar the spring loose. Turn the compressing screw to release the pressure and clear the valve spring. It will then be free for removal. Replace with a new spring and compress it. Insert the valve keepers, as shown in Fig. 90, making certain that they are correctly installed before loosening the compressing tool. When satisfied that the keepers are in proper position, loosen the compressing tool and remove it. Replace the rocker arm assembly and secure it. Replace the lubricating oil tubing and tighten the connections to complete the job.

113. REMOVING AIR STARTING VALVE. *a.* Remove the rocker arm assembly, as already instructed. Take off the retaining collar by removing the two securing nuts. Place two set-screws into the tapped ears of the air starting valve and tighten up on them to jack the valve off its seat, as shown in Fig. 91. Lift out the valve.

b. With the valve out, find the copper sealing gasket which may be either in the sealing

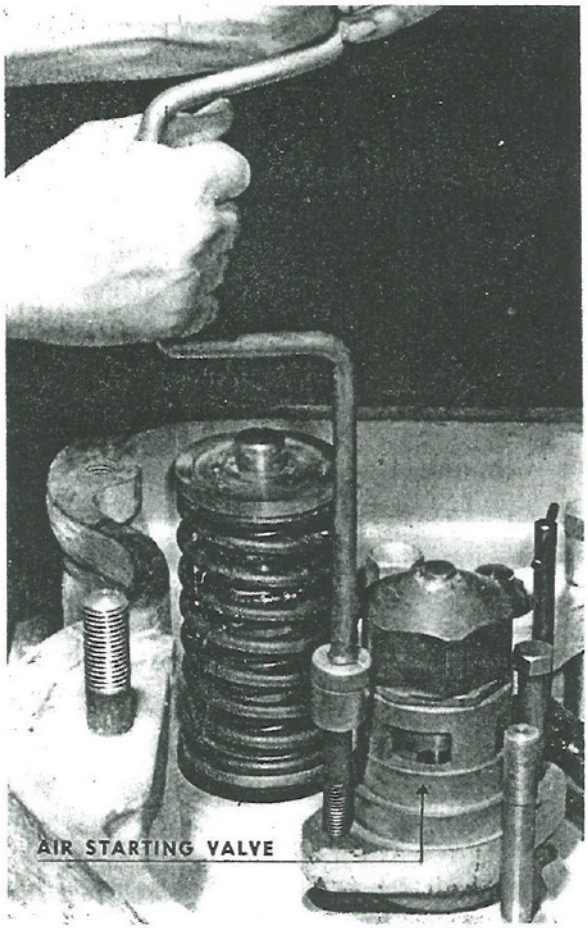


Fig. 91. Removing Air Starting Valve

shoulder of the gasket or the corresponding sealing shoulder in the head. If in the head, fish it out with a piece of wire hooked on one end. This gasket must be replaced with a new one before refitting the valve in the head. While the air starting valve is out of the head, be careful that nothing drops into the cylinder.

c. To disassemble the air starting valve, place the valve in a vise. Bend the copper locking washer on the cap until it no longer locks the cap. Use a monkey wrench to hold the brass upper piston while removing the piston cap with another wrench. Remove the cotter pin and nut from the valve stem. The valve is now disassembled by hand. When the upper

piston is removed, the lower piston will come out with it. The valve will drop out. The spring and valve guide is removed by taking the valve body out of the vise and turning it upside down. Remove the rubber sealing ring just below the ears of the valve. To save time and needless work, it is advisable to replace all gaskets, sealing rings, cotter pins, etc., with new ones, making sure spares are available before discarding the old ones. The parts of the air starting valve, disassembled, are shown in Fig. 92.

114. EXAMINATION OF AIR STARTING VALVE PARTS. a. Wash all parts well so that defects are easily seen. There are only three major causes of trouble in a valve. Check first the sealing rubber ring and gasket, the valve and seat, and the actuating pistons and sleeve. Inspect the valve seating. Place the valve into the body, and replace the brass valve guide. Put a little blueing on the valve and then drop on its seat. Rotate the valve back and forth a few times, then remove the valve and check the transfer of the blueing to the seat. If blueing is seen at all points of the seat, the valve fit is correct. If the blueing is not on all parts of the seat, the valve should be ground to a new seat. A valve grinding compound is used for this purpose. If the seat looks as though much grinding is necessary, reface the valve in a lathe and ream the seat, using a 45° reamer and lathe cutting angle. The valve guide must be in position, and must be used in both grinding or reaming to hold the seat true. Note at this time that all valves of the poppet type are seated in the same manner. Both valve and seat are cut to a definite angle and ground by compound to an absolute seat, then checked with blueing for perfection.

b. Inspect the upper and lower pistons of the air starting valve in the following manner. Examine the piston and its rings, replacing any that are broken. Stuck valves are a common cause of valve failure. Be sure rings are free in their grooves and that the grooves are clean. If there are any burrs on the piston that would cause sticking, remove them. Check the

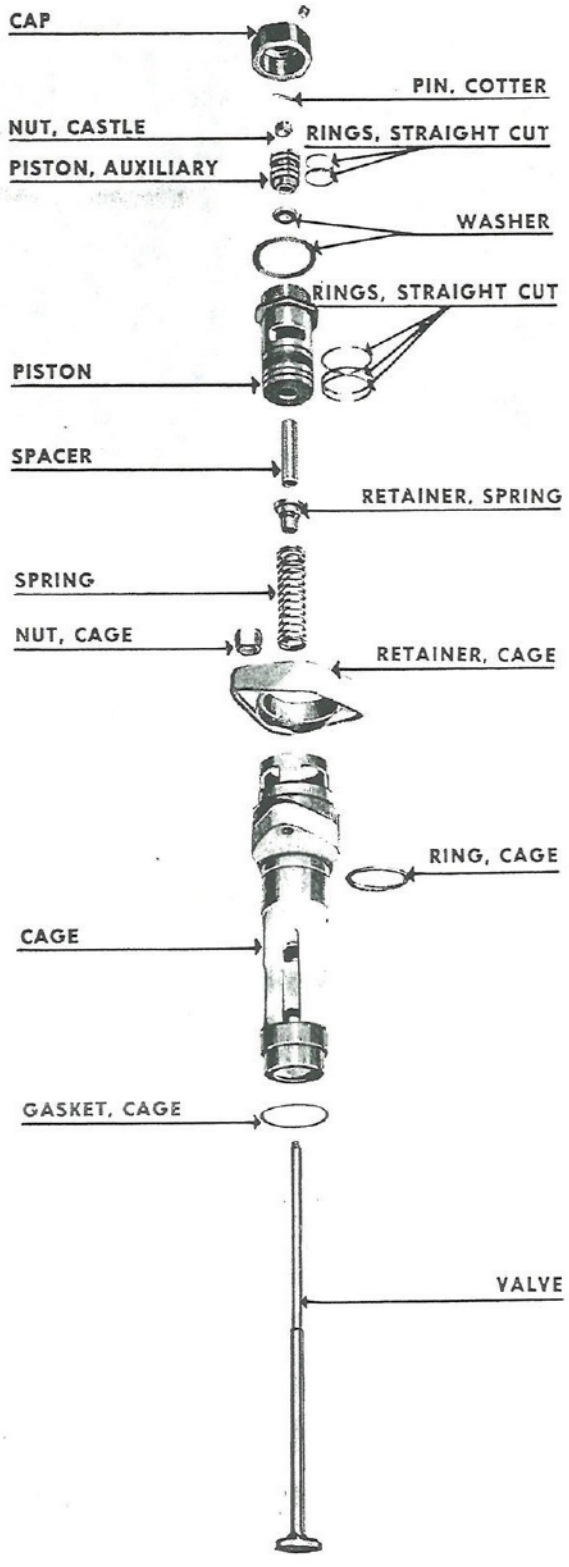


Fig. 92. Air Starting Valve Parts

inside cylinder walls of the valve body for burrs, removing any that are likely to stick the piston. Make the same inspection of the cylinder walls of the inner piston. When all parts are in proper working condition, the valve is ready for reassembly.

c. Place the spring and guide into the valve body, then replace the valve. When the valve is in place, install the outer piston. The drilled hole in the piston must be clean. Use a piece of wire to tie the rings closed so that the piston will enter the cylinder without hanging up on the rings. The inner piston is installed in the same manner. Put a little oil on all moving parts as they are reassembled. When both pistons are assembled in the valve body, replace and secure the nut on the valve, replacing the cotter pin. If the old copper cap locking washer is in good condition it may be re-used. Replace it on the top of the outer piston and replace the cap, screwing it down securely and bending the washer to lock the cap. Replace the old rubber sealing ring with a new one, using a very light film of cup grease over it to aid in sliding into the valve. Place a new copper sealing gasket on the sealing shoulder of the valve, making it stick there with a little cup grease. Remove the jacking screws used in lifting the valve, and re-insert the valve into the head. Replace and tighten the retaining clamp and nuts. If the sealing ring has been displaced, or can be seen, remove the valve and, if necessary, use a new rubber sealing ring. Start all over again. When finished, install the rocker arm assembly as previously directed.

115. REMOVING A NOZZLE. Disconnect the high pressure fuel line and the bleeder tubing. It is not necessary to remove the rocker arms for this operation. Remove the two nuts securing the retaining collar and lift the nozzle out. If the nozzle will not lift easily, pry it up gently. With the nozzle removed, find the nozzle sealing copper gasket. It may be on the sealing shoulder of the nozzle, but if it is found in the nozzle housing in the cylinder head retrieve it with a piece of stiff wire. Except in an emergency, the operator should not attempt to repair the nozzle, but replace it with a spare. Put a new copper sealing gasket on the spare nozzle, sticking it in place with a little cup grease, and insert it into the head. Replace the high pressure line and drain the tubing. Replace the retaining collar and tighten up the nuts.

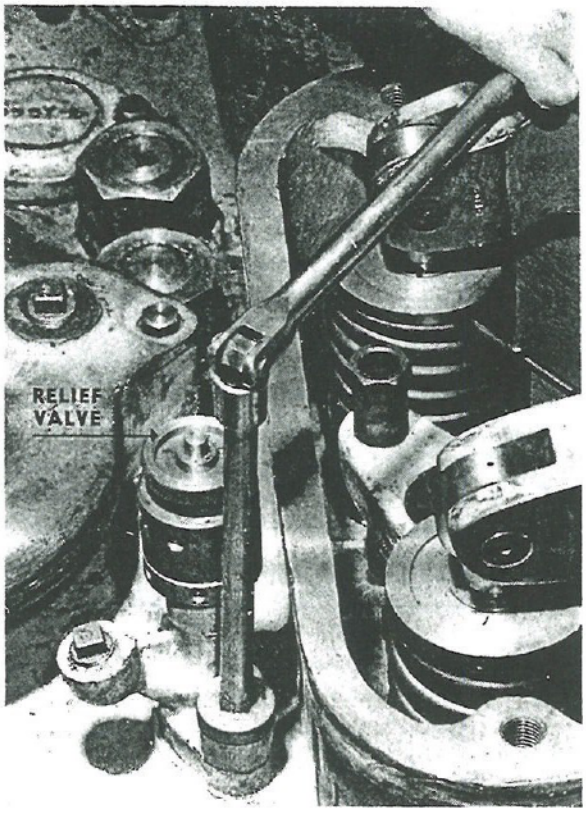


Fig. 93. Removal of Relief Valve

116. SAFETY RELIEF VALVE. To remove the safety relief valve, take off the rocker arm assembly and remove the two capscrews securing the valve with the special offset wrench, as shown in Fig. 93. Do not attempt to repair a safety relief valve, but install a spare, using a new gasket. Return the defective valve to the factory for repairs.

117. REMOVING INTAKE AND EXHAUST VALVE. *a.* The cylinder head must be removed. Drain the jacket water from the engine before disconnecting the air intake elbow and ex-

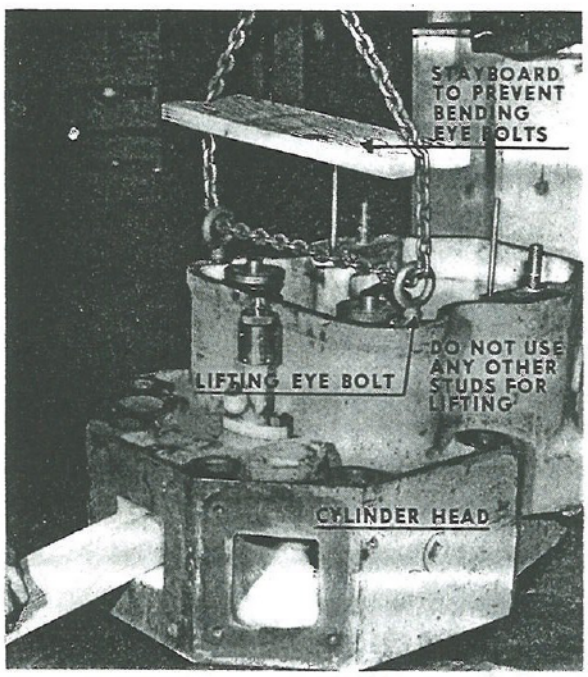


Fig. 94. Lifting Cylinder Head Off Engine

haust manifold from the cylinder head. Remove the water pumper pipe feeding cylinder head water to the exhaust manifold. Remove the nozzle, then disconnect the high pressure fuel line from the fuel pump. The air starting and relief valves need not be removed unless desired. Take out the cylinder head nuts. Disconnect the nozzle drain header pipe from each cylinder, and either loosen and push to one side of the engine, or remove entirely.

b. To raise the cylinder head, insert two eye-bolts with threaded stems into the threaded holes on the cylinder head as shown in Fig. 94. Run a chain or rope through the eye-bolts and hold it apart with a notched stay or spreader board, as shown in Fig. 94. Attach the hoisting equipment to this sling and raise slowly. In hoisting it is always best to use a rope to attach the part to the hoist. In this way, if the part holds firm and refuses to move, is held by some forgotten bolt or other cause, the rope will break before the hoist can damage the engine. Set the cylinder head down deck so that the inside of the cylinder head faces up. When the cylinder head is removed it is generally good practice to reseat the valves so that all parts are overhauled at the same time.

118. TO REMOVE VALVES. Place the valve spring compressing tool on the cylinder head in the same manner as shown in Fig. 89. With the valve retainers removed, lift out both valves. Wash the valves thoroughly, using a wire brush on the stems and heads if those parts are heavily coated with carbon. Insert the valve into the head. The exhaust and intake valves are plainly marked on their heads. If the markings are obscured by carbon, the valves can be identified by the fact that the exhaust valve has a gas defection on its stem while the stem of the intake valve is plain, as shown in Fig. 95. Be sure the right valve is in the proper port. Measure the valve stem diameter and the inside diameter of the valve with a suitable gauge, and if there is more than normal clearance between them, remove the guide or guides and replace the new ones. The guide is also illustrated in Fig. 95.

119. REPLACING VALVE GUIDES. Remove the valve guides by placing the cylinder on a hydraulic press and pressing the old guides out. If a press is not available, tap them out with

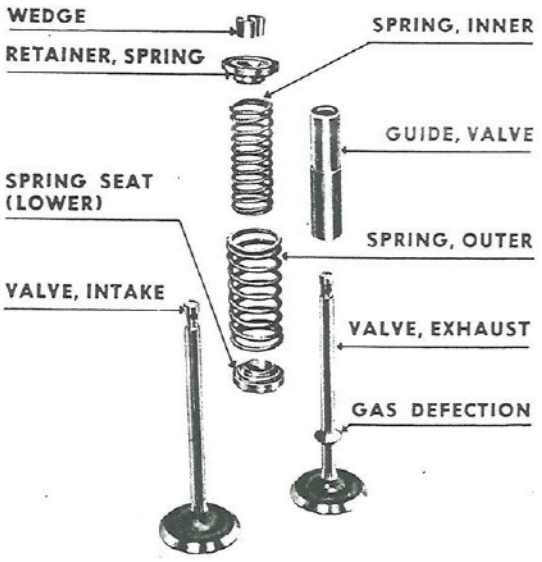


Fig. 95. Intake and Exhaust Valve Parts

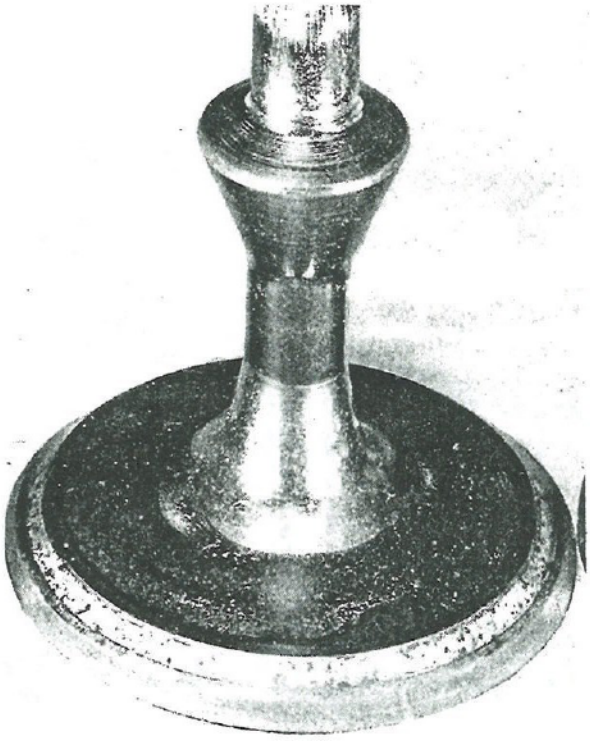


Fig. 96. Badly Worn Valve in Need of Repair

a heavy bronze bar. When the guides are out, clean their housing holes. Examine the new valve guide, removing any burrs that might prevent it from entering the head. Use a thin coat of white lead diluted with lubricating oil on the new guide to make installation easier, and press into the head. If the valve guides are worn to the extent that they require replacement, the valves will have to be refaced and

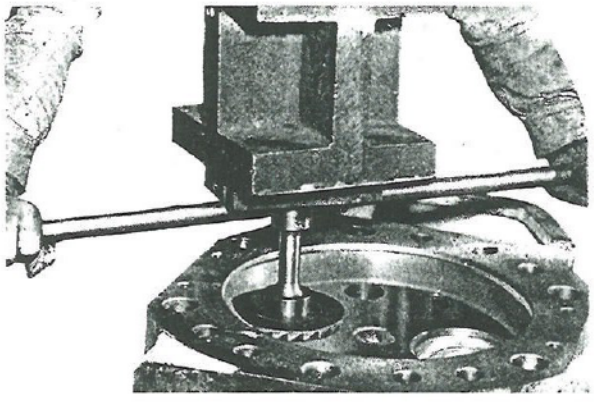


Fig. 97. Reaming Intake and Exhaust Valve Seats

Fig. 98. Application of Grinding Compound to Valve

the seats reamed. It is not practical to try reseating the valves if the guides are badly worn. A perfect seat is impossible since the valve will never seat twice in the same place. Replace valves when the seating edge or shoulder is burned badly or the valve warped. A warped valve will not hold its seat long.

120. GRINDING VALVES. If the valves or their seats are pitted or worn, a good seat is not being made. Fig. 96 shows a pitted valve in need of repair. If the seats are in need of repair, ream them out with a 45° reamer in the manner shown in Fig. 97. If the seat is reamed, or if the seat is in good condition but old valves are refitted to the seat, or new valves installed, they have to be ground down to fit. Put blueing on the edge of the valve, insert the valve into its seat, and rotate the valve. Then inspect the seat. If the valve has not transferred blueing to all surfaces of the seat, it must be ground down to fit. Coat the edge of the valve with grinding compound, as shown in Fig. 98, and insert the valve into its proper seat. Rotate it with the valve grinding tools, as shown in Fig. 99. After a time, take out the valve, thor-

oughly remove all the grinding compound and check again with blueing. Repeat this process until the valve seats perfectly.

121. REASSEMBLING THE CYLINDER HEAD. **a.** Always put a little oil on the working surfaces of the parts as they are reassembled. Before replacing the cylinder head, remove the old cylinder head gasket and clean all exposed surfaces. On the top of the cylinder block wipe off any carbon that may have fallen onto the upper cylinder walls. Mix some powdered graphite and lubricating oil, coat both sides of the new gasket, and set into place. Hoist the cylinder head back onto the engine, as illustrated in Fig. 100, and lower it, placing a new gasket coated with the graphite mixture between the head and the exhaust manifold. Finish lowering the head. Line up the cylinder head to the exhaust manifold by tapping the side of the cylinder head. Start all the exhaust manifold securing capscrews but do not tighten them at this time. The head is now properly aligned to the exhaust manifold.

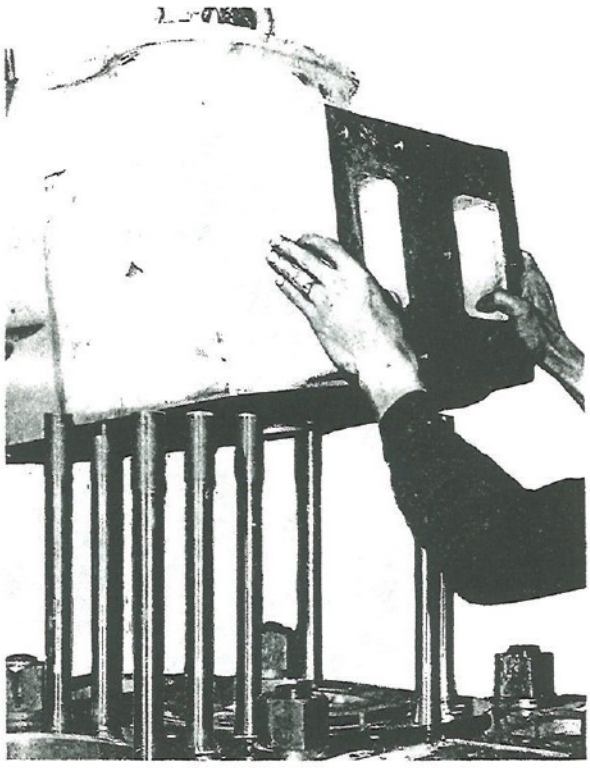


Fig. 100. Replacing of Cylinder Head

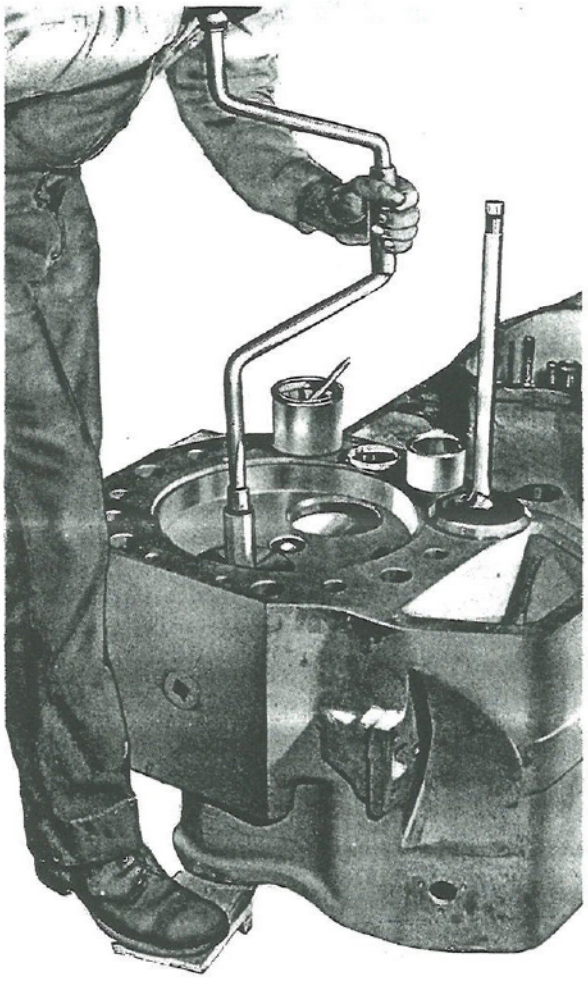


Fig. 99. Grinding Intake and Exhaust Valve

b. Replace the cylinder head washers and nuts, running all the nuts down on the threads. Tighten up the nuts correctly so that the head will be square to the engine block and no stress developed by using the order of tightening as illustrated in Fig. 101. Start at the nut marked 1 in the illustration, then tighten nut 2, and follow in rotation through to nut 8. This method tightens opposite nuts, and this results in pulling the head down evenly. The cylinder head should be tightened securely, and this usually requires the combined efforts of two strong men pushing on the end of a six-foot bar.

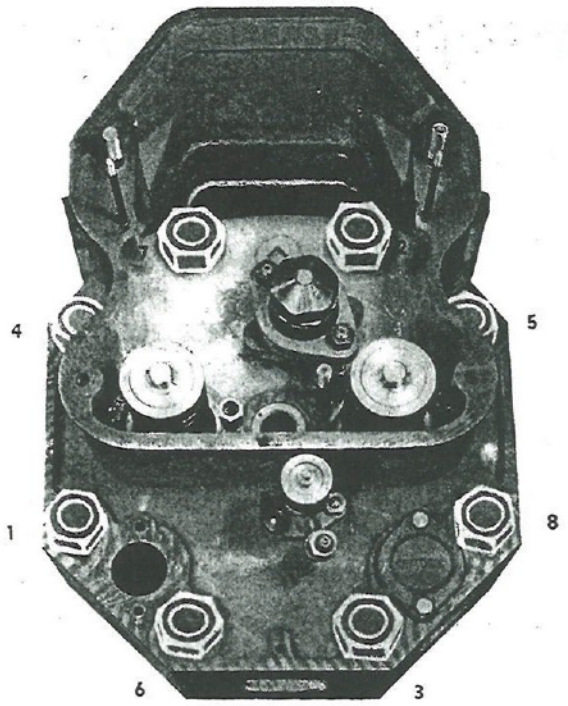


Fig. 101. Tightening Nuts of Cylinder Head

c. After the cylinder head is tightened, tighten up the exhaust manifold nuts. Secure the exhaust manifold and air intake elbow. Replace the water jumper connecting the cylinder head to the manifold, and fill the engine with water. If there are no leaks, re-assemble the various parts to the head. When completed, relieve the engine compression by screwing down all the safety relief valves and barring the engine over. Make at least two complete turns, and if no water comes out of the safety relief valves it is safe to operate the engine.

SECTION XI
PISTON, CONNECTING ROD, AND LINER DISASSEMBLY, AND ASSEMBLY

122. PRELIMINARY CAUTION. Before starting the disassembly of any part of the engine, be sure that the globe valve on the front end of the engine which supplies air to the air starting system is turned off. This will eliminate possible serious injury to the operator and damage to the engine.

123. ENGINE MARKINGS. *a.* Before the moving parts of the engine are taken apart, it is essential that the marking system used to identify them be thoroughly understood. The markings are of vital importance when performing repair work. All parts of an engine do not wear to the same degree in the same period. Even connecting rods, which presumably work together performing the same amount of work and which are identical in measurements when installed, will differ in measurements after extended operations. To match up these parts, it is essential that they be re-installed in the same places. The markings make this possible.

b. All markings start from the front end of the engine. The front cylinder is No. 1 cylinder, the next one No. 2, and on down the line to the last cylinder. Each component part of every cylinder, such as cylinder heads, connecting rods, and pistons, is stamped with the number of the cylinder it fits.

c. Many of these parts also are marked to show which side they face. Thus a piston, being round, can be installed in the same cylinder and still not be properly placed because the sides have been reversed. This is taken care of by a second system of markings. The engine has two sides, the exhaust manifold side and the camshaft side. The cylinder number is stamped twice on the side of the parts facing the exhaust manifold side. One side of the piston for the No. 1 cylinder is stamped 1-1, indicating this side must always face the exhaust manifold side.

d. Connecting rods also are marked for the proper cylinder. Large numerals are stamped on the bearing box to correspond with numbers stamped into the bolts that are fitted into the holes in the box. The nuts also carry the number of the bolt they are to be placed on.

e. The connecting rod and the main bearing shells are enclosed with caps. To prevent the caps from being reversed when re-installed, the numbers on them must be placed on the camshaft side of the engine. Camshaft bearing caps are stamped with the cylinder number, starting from the front of the engine, and with a corresponding number stamped in the section holding the lower bearing shell.

124. TO REMOVE PISTON AND CONNECTING ROD. *a.* Bar the engine over until the flywheel indicator points to the desired cylinder number stamped on the flywheel. The piston

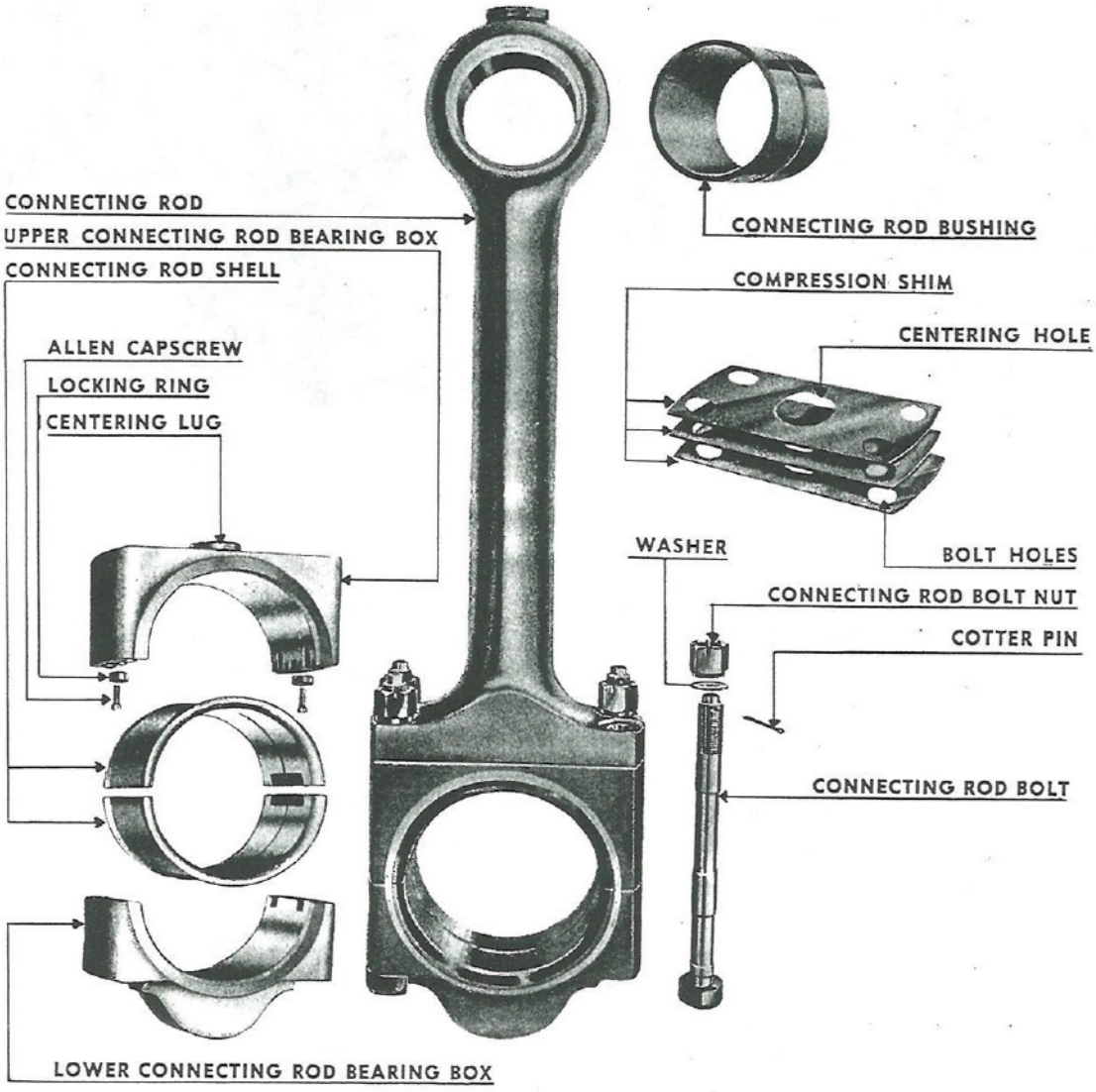


Fig. 102. Connecting Rod and Bearing Disassembled

in this cylinder is now at top dead center. Remove the cylinder head, as explained in Sect. X, and remove the side covers that permit access to the bottom of the connecting rod attached to this piston. Take care that no dirt, rags, or other material get into the engine.

b. The connecting rod is shown in Fig. 102 without the piston which is connected to the top of the rod. There are four bolts securing the connecting rod to the bearing box. Remove the cotter pins and loosen the nuts. Place a plank or board underneath the bearing box to hold the lower half of the box from dropping into the base of the engine, and remove the bolts. Lift out the lower half of the bearing box.

c. The disassembled piston is shown in Fig. 103. Threaded holes are located on the top of

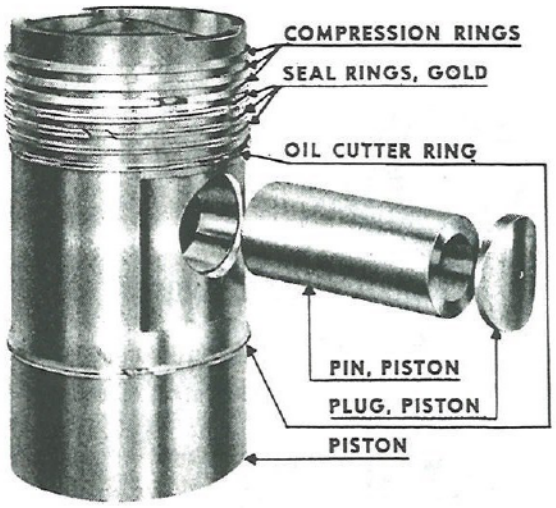


Fig. 103. Piston with Piston Pin Removed

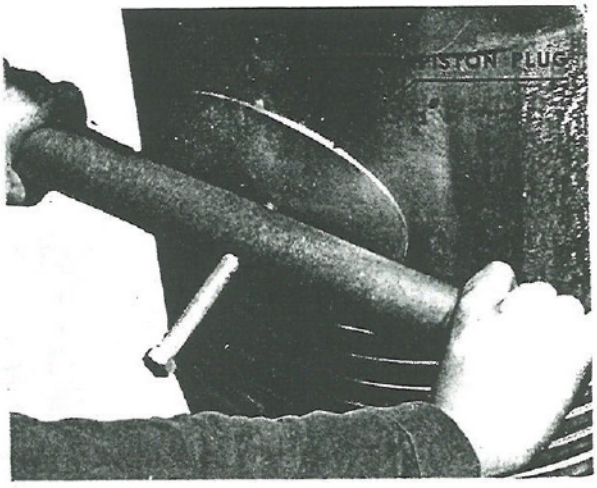


Fig. 104. Removal of Piston Plug

the piston. The set of tools has a strap with a welded ring in the center and bolt holes on each end. Secure the strap to the piston with the bolts to hold the combined weight of the piston and connecting rod. Attach a rope to the ring to protect the engine from damage in case the parts hang up while being hoisted, and fasten the rope to a chain hoist or block and tackle. While the piston is being raised one man must hold the upper half of the bearing box until there is enough clearance to remove it from the engine along with the compression shims. Guide the foot of the connecting rod to keep it from swinging and marring the inside of the liner when the assembly is hoisted out of the engine. When the piston is out of the engine be careful not to scratch its surface.

125. TO REMOVE PISTON FROM CONNECTING ROD. In Fig. 103 the piston is shown taken apart. The piston pin fits into the bushing in the eye on the upper end of the connecting rod to secure the piston to the rod. The piston pin is hollow, but the openings on both sides are closed with piston plugs, as illustrated. Take out the small screw that is threaded into the bottom edge of the piston plug and the piston pin opening. In the center of the piston plug a threaded hole is located. Use a piston strap or piece of pipe or bar drilled in the middle and insert a ½-inch N. C. capscrew about three inches long and screw the capscrew into the threaded hole in the piston plug. Sharply slide the piston strap or bar out against the head of the screw to force out the piston plugs. This method is illustrated in Fig. 104. With both piston plugs out, place a piece of wood against the piston pin and tap out with a hammer, taking care to hold up the connecting rod to prevent it from falling over and damaging the piston. With the piston pin driven out, lift the connecting rod out of the piston.

126. TO REMOVE THE PISTON RINGS. Handle the piston rings with care as their edges have been honed to razor sharpness by rubbing against the cylinder walls. Starting where the ring is split, slide four pieces of thin brass shim stock behind the ring and space them out evenly around the piston. The ring can then be lifted off. Repeat the process on the balance of the rings, taking them off the top of the piston with the exception of the lowest ring, an oil

scraper, which is removed from the bottom. The rings are replaced in the same manner.

127. TO REMOVE THE CYLINDER LINER. a. Each cylinder is fitted with a tubular lining of wear resistant metal in which the piston operates. The liners, as well as the piston rings, wear down from constant usage. This causes loss of compression.

b. Completely drain the engine of water to prevent jacket water from getting into the cylinder when the liner is removed. Cover the crankshaft to keep out dirt and other foreign material.

c. The lines from the Manzel oiler also must be removed. On the camshaft side of the engine remove the camshaft covers and the tappet cluster on the outside of the block at the location of the cylinder from which the liner is to be pulled. Remove the compression coupling on the end of the copper oiler tube with a crescent wrench. Be sure to take off the ferrule type washer and put in a safe place. The compression coupling is fitted on a ⅜-inch pipe nipple. This nipple is fitted with a threaded nut and washer that holds packing against the engine around the nipple. Remove the threaded nut with a crescent wrench and also remove the washer and packing. The end of the nipple is milled flat. Apply a crescent wrench to this flat surface and unscrew the nipple as it is threaded into the liner. When unscrewed from the liner, the nipple can be lifted out. Repeat this procedure on the exhaust manifold side of the engine. On the exhaust side, the oiler connection is easily accessible from the outside of the block without removing any units from the engine. The set of tools includes two liner pulling plates, or discs of flat metal cut to the outside measurements of the liner and drilled in the center. Place one of these plates on top, and insert through the hole the long liner puller bolt which has a ring head. Fit the second liner puller plate at the bottom of the liner with the lower end of bolt inserted in the plate hole. Tighten up with the nut provided. Attach a block and tackle or chain hoist to the ring on the liner puller bolt and pull the liner out of the engine, as shown in Fig. 105.

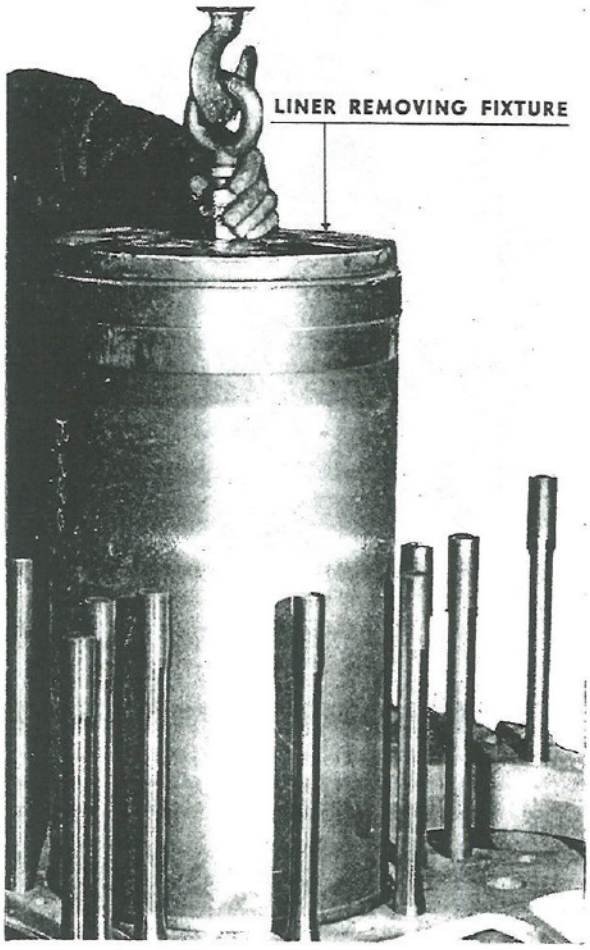


Fig. 105. Pulling Liner from Block

128. REPLACEMENT AND REPAIRS. Consult the tables of clearances in Sect. VIII, and check the parts against the allowable clearances in the table to determine the advisability of replacements. Common sense must be used to decide whether or not to replace a part. As an example, if a cylinder liner has worn .035 of an inch and the table of clearances states that a new liner should be installed when the old one is worn .040 of an inch, it is apparent that the liner can only wear another .005 of an inch before a replacement will be necessary. Therefore, while the engine is down, it is good sense to replace the liner before reassembling the

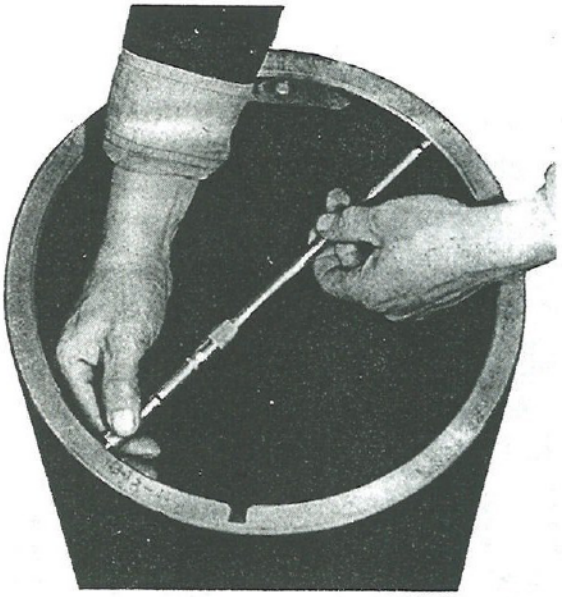


Fig. 106. Measuring Bore of Liner

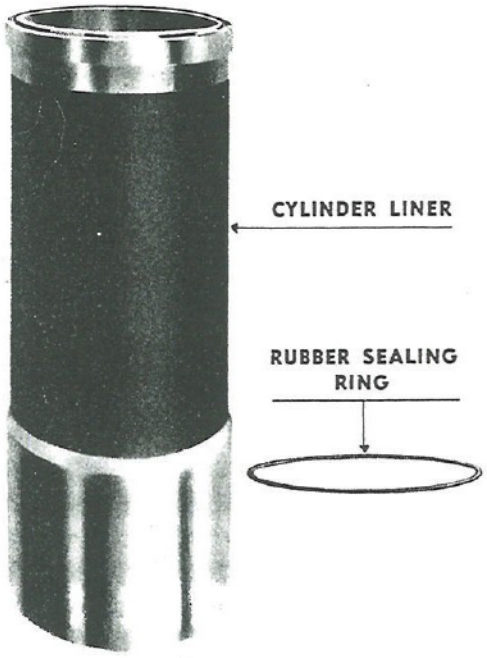


Fig. 107. Cylinder Liner and Rubber Sealing Rings

engine to avoid repetition of the same work in the near future. Measure the wear in the liner with an inside micrometer, as shown in Fig. 106. This is called making a bore measurement.

129. TO REPLACE LINER IN ENGINE. *a.* A liner removed from its place in the cast cylinder block is shown in Fig. 107. The rubber sealing rings which hold back the jacket water that is circulating through the passages in the block are fitted into the block near the bottom of the cylinder liner. Remove the used rubber sealings rings in the bottom portion of the block. Make sure that all pieces of the rings are removed. Clean thoroughly the grooves they fit into and grease them with cup grease, glycerine, or soft soap. They will help to hold the new rubber sealing rings in place. Stretch each new rubber ring slightly and fit into the grooves, as shown in Fig. 108. When both rings are in place, grease the outside of the sealing rings as an aid in sliding the liner past them. Prepare the cylinder by cleaning thoroughly on the inside, washing with a cleaning solvent if necessary.

b. Near the bottom of the liner the hole that is used to bolt the piston strap when a piston

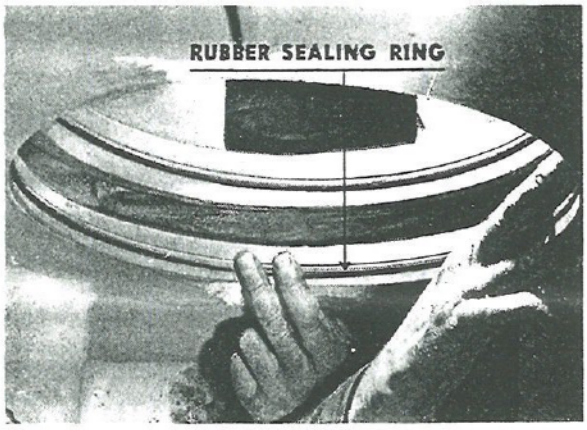


Fig. 108. Installing Liner Sealing Rings

is hung up for connecting rod bearing inspection must be plugged. Cut a wooden plug, and drive it until it is tight. Cut off the plug flush to the liner, using a file if necessary to dress the plug down so that it is smooth to the touch. Coat the outside lower part of the liner lightly with grease, glycerine or soft soap to help it slide past the rubber sealing rings.

Fig. 109. Installing Liner in Block

c. Put the liner puller plates back in the same manner as when the liner was pulled out of the block. Hoist the liner over the engine and lower it into the engine. Make sure that the plugged hole faces the exhaust side of the engine, and that it is square to that side. Holding the liner in this position, as illustrated in Fig. 109, lower until the liner will not slide down any further. Hoist it up slightly and straighten, then examine the liner as it enters the block. If the liner is entering the sealing chamber correctly, continue to lower. When the liner starts into the sealing chamber the rubber sealing rings will prevent it from falling into place. Tap the top plate of the liner puller plate with a heavy piece of brass until the liner is down in place. Occasionally look to see if the liner is passing the sealing rings. If a rubber sealing ring is squeezed out of place, lift the liner out, replace the rubber sealing ring if necessary, and try again.

d. When the liner is seated in place, holes must be drilled to accommodate the Manzel oiler fittings. Replace the packing gland in the block and insert in it a bushing that will fit a 19/32" drill to support the drill bit. Through the packing gland and bushing drill a hole with the 19/32" drill in the liner, as illustrated in Fig. 110. When the hole is drilled, use a 3/8"

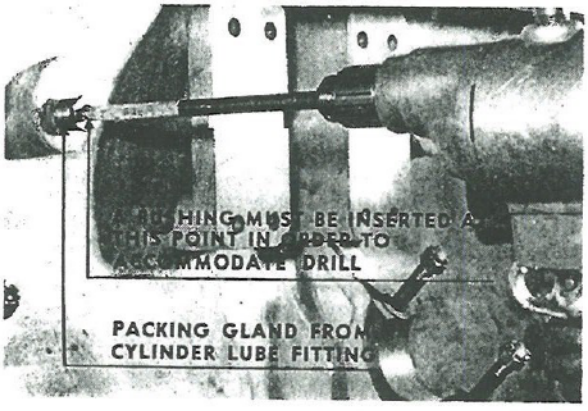


Fig. 110. Drilling Liner for Oiler Connection

pipe tap to thread the drilled hole so that the pipe nipple will screw into the liner wall. Repeat this operation on the other side of the cylinder. Be sure the nipple does not extend beyond the inner surface of the liner.

e. Connect the oil tubing to the nipple, making sure that the compression fitting is secure on the ferrule type washer. Wrap strips of flax packing around the packing gland and tighten the gland nut securely.

f. Wipe off the grease, glycerine or soap from its surface, and knock out the wooden plug. Fill the engine jacket with water to test

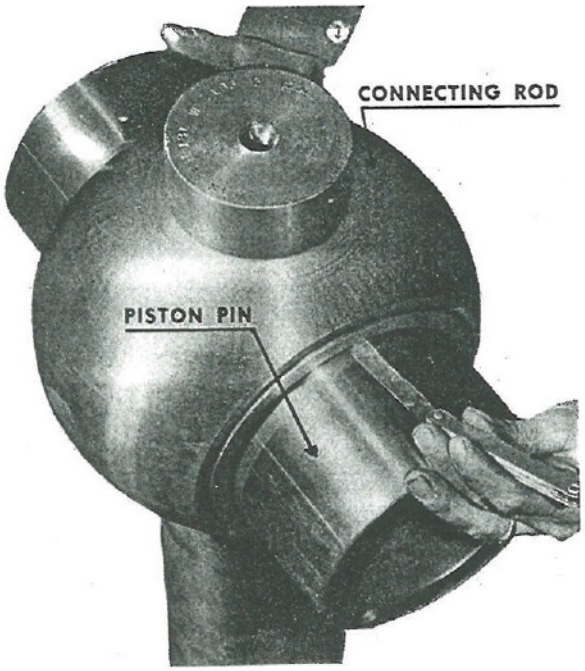


Fig. 111. Measuring Piston Pin Clearance

the new liner for leaks. One man should watch at the top of the engine to warn when the water must be turned off. The water should be turned off before it comes out of the holes at the top of the block. Inspect the liner for leaks with a flashlight, checking particularly where the liner is sealed by the rubber sealing rings. Be sure there are no leaks from the packing around the oiler connections. If no leaks are found, the cylinder liner is ready for use.

130. FITTING PISTON PINS IN PISTON. If a new piston is used, the piston pin for it has already been fitted at the factory. No additional fitting is necessary. The new piston and pin should be thoroughly cleaned and oiled before it is assembled.

131. REMOVING A PISTON PIN BUSHING. Drive the old bushings out. If possible, cool the new bushing in a refrigerator for two or three hours to contract it. Place the new bushing in the eye of the piston and drive in, using a piece of wood to protect the metal of the bushing while hammering. Check to be sure the piston will fit freely in the new bushing, using a feeler gauge as shown in Fig. 111, and finding the proper clearance in Sect. VIII.

Fig. 112. Assembling Piston and Connecting Rod

132. TO REASSEMBLE CONNECTING ROD TO PISTON. Place the piston upside down on a piece of wood. Insert the well-oiled piston pin in the piston a little way, leaving room for the eye of the connecting rod. Before lowering the

connecting rod into the piston, make certain that the side of both the piston and the connecting rod with the cylinder number stamped twice faces the exhaust manifold side of the engine. Lower the eye of the connecting rod into the piston. Tap the pin through the piston so that it is evenly divided, as illustrated in Fig. 112. Fit in the piston plugs, keeping in mind that the plugs are numbered with a corresponding number stamped on the side of the piston they match. Use a block of wood or hammer handle to tap them in snugly, as shown in Fig. 113. Use a 12-inch steel scale, or a straight piece of metal about that length, and work it off and on the plug. If the top of the plug is not flush with the walls of the piston light will be seen underneath the scale or piece of metal. More tapping is necessary.

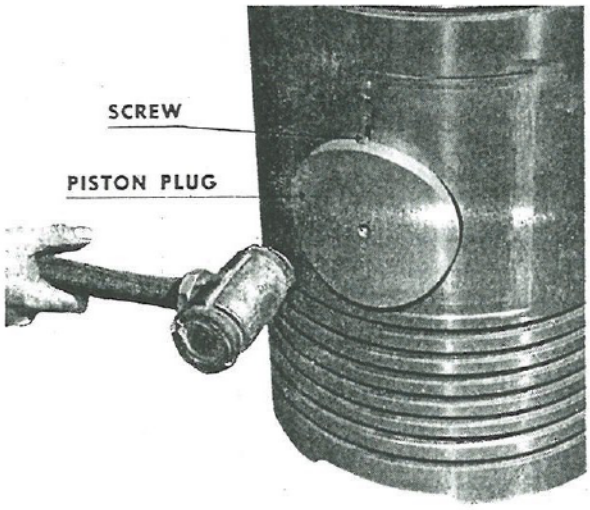


Fig. 113. Installing Piston Plugs

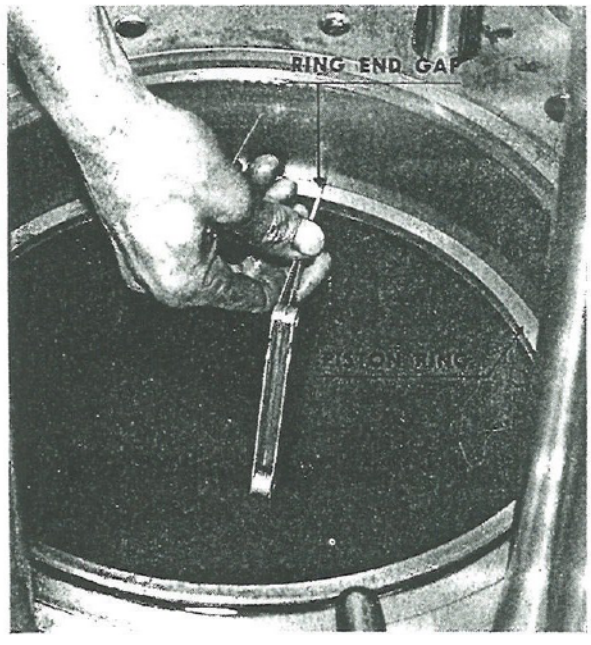


Fig. 114. Measuring Piston Ring Gap Clearances

Fig. 115. Installing Piston Rings

133. INSTALLING NEW PISTON RINGS. Thoroughly clean all grooves and drain holes in the pistons. Insert each ring in the liner and check the gap clearances with a feeler gauge, as shown in Fig. 114. If the gaps in the rings check with clearance specifications in Sect. VIII, check the three compression rings by placing one in the first groove, as shown in Fig. 103, and rotate around the piston. If the ring sticks or binds or does not seat properly in any place, dress down the spot or spots with a fine mill file until the ring rotates freely and seats cleanly. When all rings are fitted, place them on the piston in the grooves to which they were fitted, as shown in Fig. 115, and in the following order: upper oil scraper ring, the third sealing ring, the second sealing ring,

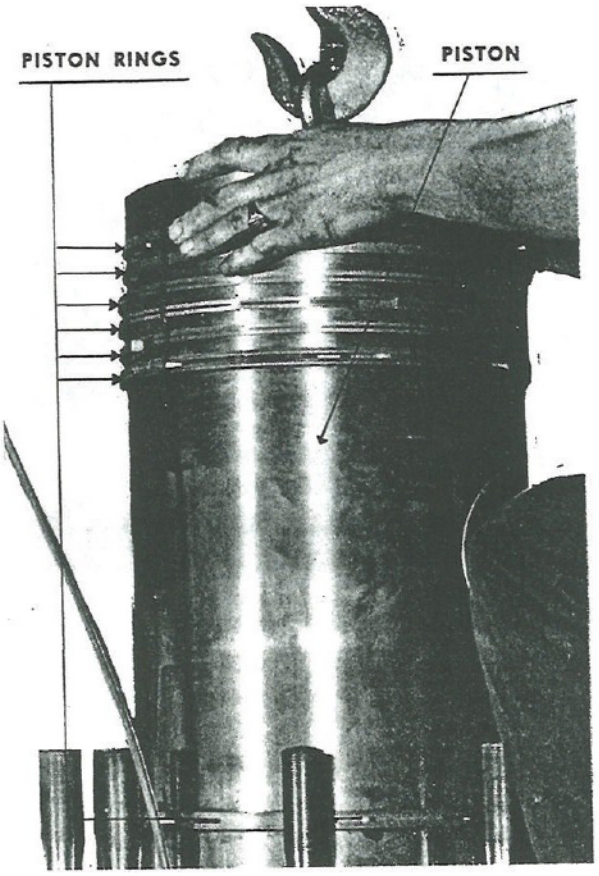


Fig. 116. Piston Showing Ring Gaps in Staggered Position

the first sealing ring, the third compression ring, the second compression ring, and the first compression ring. Put the lower oil scraper ring over the bottom end of the piston.

134. INSTALLING PISTON AND CONNECTING ROD IN ENGINE. ***a.*** Thoroughly clean the cylinder liner, and oil completely with about a half-gallon of clean lubricating oil. Place the piston ring compressor on the top of the cylinder liner with the tapered edge up so that, as the piston is lowered, the rings will be compressed. Lower the piston and connecting rod assembly into the liner, guiding the connecting rod so that it does not rock against the liner walls. When the piston is ready to be lowered into the liner, as shown in Fig. 116, set the rings. The rings should never be set so that the gaps, or slits, at the ends line up. Arrange the rings so that the gaps are staggered. None of them should line up vertically. This will prevent compression loss.

b. With the rings set, slowly lower the piston into the liner, making sure that the rings do not hang up on the ring compressor. Also be certain that the side of the piston which bears the cylinder numeral stamped double, faces the exhaust manifold side of the engine. When the piston still has a foot to go, stop and pour lubricating oil on the connecting rod journal and on the upper half of the connecting rod bearing. Place the bearing box containing the bearing shell on top of the journal and replace the compression shims on top of the bearing box. Be sure that the bearing box is installed according to its markings. Finish lowering the piston until the foot of the connecting rod rests on top of the bearing box. Relieve any strain the chain block still may have on the piston, and remove the ring compressor. Check the clearance between the piston and the liner with a feeler gauge and determine by the table of clearances in Sect. VIII if the clearance is correct.

135. TO CHECK COMPRESSION. ***a.*** The compression of a cylinder is either increased or decreased by the addition or removal of the compression shims between the connecting rod foot and bearing box. The distance from the top of the piston to the top of the engine block should measure .830 of an inch. If the piston is low, add shims until this measurement is reached, taking out shims if the piston is higher.

CAUTION: Never add compression shims just to pep up an engine that needs overhauling. If the engine lacks compression because it needs overhauling, the piston rings have worn metal away from the sides of the liner. This wear starts at the point in the liner touched by the top compression ring in its travels. Thus, a ledge has been formed at the top of the liner, and if a shim is added to increase compression, the top ring will hit this ledge, doing great damage to the engine.

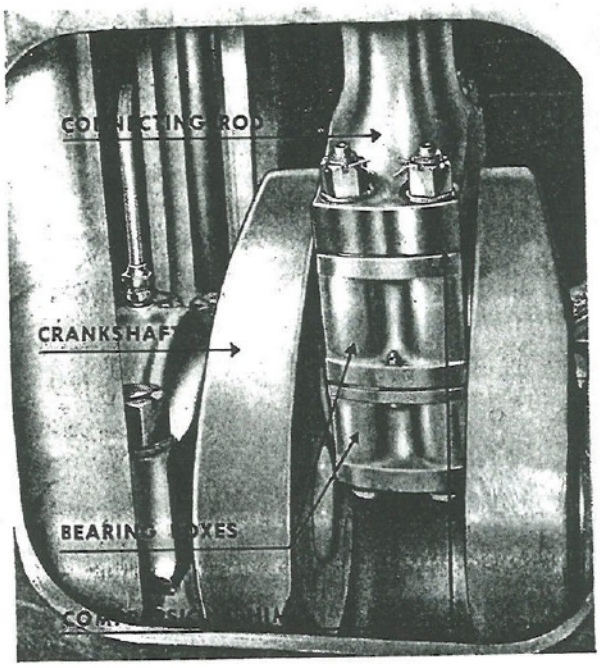


Fig. 117. Connecting Rod Bearing Assembled on Crankshaft Journal

b. With the shims adjusted for proper compression, place the lower half of the bearing on the crank pin journal and insert the four bolts through the bearing box and foot of the connecting rod. Be careful not to put the bolts through the holes carrying corresponding numerals. DO NOT drive the bolts through the bearing box. If they do not slide into place easily, either the foot of the connecting rod or the compression shims are incorrectly aligned. Tap the shims or connecting rod foot with a wooden hammer handle until they are aligned and the bolts will go through easily.

c. Replace the washers and the nuts, tightening the nuts until a torque, or turning effort, of 450 pounds is developed. Lock the nuts with new cotter pins. When the job is completed it should look like Fig. 117. Check the sump to see that no possible rags or tools have been left in it before replacing the side covers. In replacing the covers use only two bolts in the top and two bolts in the bottom. After the engine has been run for ten minutes, the doors will have to be removed for a check. Replace the cylinder head, as directed in Sect. X, and fill the engine jacket water system until the surge tank is about half full.

d. Bar the engine over three or four times to be sure that everything is free. If there are no water leaks, make the full routine inspections as directed in Sect. VII, before starting the engine. Run the engine at low speed for ten minutes, and then shut it down. Close the starting air valve and remove the side covers. Feel the connecting rods for excessive heat. Use a flashlight to check the liner where it is sealed, and look for traces of water. If the connecting rod bearing and piston pin bushing are not too hot to hold and there are no leaks, replace the side covers, using all bolts to make them secure.

136. OPERATING AFTER OVERHAUL. When new rings and liner have been installed, the engine must not be operated at full speed, or full load, until after about ten hours of operation. If the engine is operated at full speed immediately, both the liners and pistons may "freeze" from excessive heat, and this will necessitate another overhaul.

SECTION XII
CONNECTING ROD BEARINGS

137. CONNECTING ROD BEARING. The connecting rod bearing is often referred to as the crankpin bearing, but it is common practice to speak of it as a connecting rod bearing. This term is used in this manual. In Fig. 118 the connecting rod is shown with all its parts. The connecting rod connects the piston to the crankshaft. The connecting rod bearing is

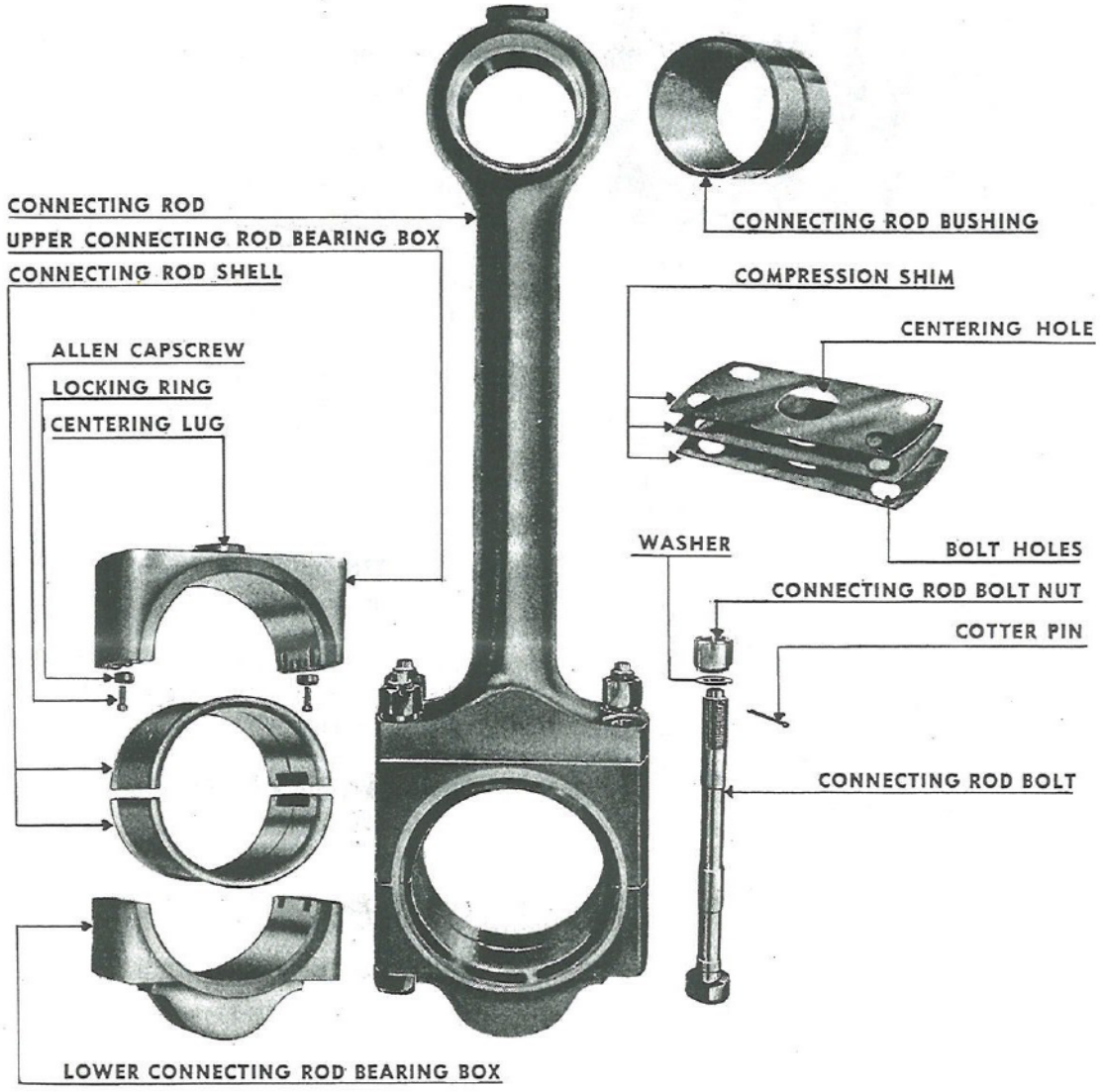


Fig. 118. Connecting Rod and Bearing Disassembled

made of soft bearing metal. The connecting rod transmits to the crankshaft all the power developed by the piston. Practically all Enterprise engines covered by this manual use precision type connecting rod bearings. The bearings fit the journals exactly without the use of shims. When the bearing has worn down past its useful life no adjustment is possible. A new bearing must be installed.

138. BEARING SHELLS AND BEARING CAPS. Bearing shells are the parts that absorb the wear and have to be replaced. These shells fit into upper and lower caps of steel which are often referred to together as the "bearing box." A threaded hole is drilled on the under edge of the upper bearing cap. A capscrew fits into these holes. The capscrews secure small round pieces of metal something like washers. They are called locking rings. These locking rings contact both the bearing cap and bearing shell, and in this manner hold the upper bearing shell in place.

139. TO REMOVE CONNECTING ROD BEARING. *a.* When disassembling the engine always be sure that the globe valve on the front of the engine controlling the supply of compressed air to the air starting system is shut off. Also open the safety relief valves. Bar the engine over until the desired piston is at top dead center. This position will prevail when the flywheel pointer is directly opposite the cylinder number stamped in the flywheel. Remove the side cover doors on both sides of the engine at the proper cylinder.

b. Find the hole located in the bottom of the cylinder liner on the exhaust manifold side of the engine. Place a piston strap on the wall of the cylinder and insert a capscrew through the hole of the piston strap into the hole of the liner wall. Be positive that the top portion of the piston strap is directly under the piston since this will keep the entire piston and connecting rod assembly from falling down.

c. As shown in Fig. 118, four nuts and bolts secure the bearings. Remove the cotter pins and the nuts and bolts. Take off the lower half of the bearing box, or the lower cap. If it sticks to the crankshaft, pry it off with a screwdriver while holding the part so that the shell will not drop into the sump when released.

140. TO REMOVE THE UPPER HALF OF THE BEARING BOX. The upper half, or upper cap, of the bearing box must be held while the engine is barred over until the crank turns about 70 degrees. This gives sufficient clearance. Take out the upper half, using care to remove the compression shims located between the upper cap and the foot of the connecting rod. Keep the compression shims together so they can be replaced in the same order.

141. EXAMINATION OF BEARINGS. Use new bearing shells for inspection purposes, comparing them with the bearing shells taken out. Shells that show they have been burned, badly worn, scored or cracked should be replaced. If only one-half is in bad condition, replace both halves with new bearing shells. Check the bearing shell thicknesses with a micrometer and if they measure less than the minimum stated in Sect. VIII, replace them.

142. TO REMOVE BEARING SHELLS. The lower bearing shell can be slid out of the bottom cap, or lower half of the bearing box. If difficulty is experienced, pry out with a screwdriver. Be careful not to injure the lower cap. Unscrew the two capscrews in the upper half of the bearing box with a capscrew wrench. Remove the locking rings held in place by these screws. Take out the upper bearing shell.

143. INSTALLING NEW BEARING SHELLS. *a.* Insert a new bearing shell in the upper half of the bearing box, replace the locking rings, and secure with the capscrews. Fit the lower bearing shell against the upper shell and be sure that there are no burrs to keep them apart. Feel the crankshaft journal for burrs or metal particles, removing any with emery cloth. If all is found in order, install the lower bearing shell in the lower half of the bearing box. Before starting this task, be sure that the oil

Fig. 119. Oil Grooves in Bearing Shells

grooves in the two halves will not meet, but will be staggered, as shown in Fig. 119. This will insure an even distribution of lubricating oil and prevent the formation of an oil ring which will wear a groove into the journal. Clean both shells so that there are no sharp edges on the grooves.

b. Install the lower bearing shell into the lower half of the bearing box. This is accomplished, as shown in Fig. 120, by placing an end of the shell on the end of the bearing box half, and then pushing the shell forward with a rolling motion. Be sure that on both the upper and lower shells the shoulders are on the outside shoulders with the numerals that appeared on the old shells.

144. TO REASSEMBLE THE BEARING. *a.* Pour clean lubricating oil over the crankshaft journal and the upper half of the bearing shell. Place the upper bearing cap in the engine so that the side with the double numerals faces the exhaust manifold side of the engine. Besides the four bolt holes on their edges, compression shims have a larger hole in the center. Place the compression shims on top of the upper bearing box so that this hole fits over a round lug on the top of the box, and line up the shims with the bolt holes corresponding. Bar the engine in the direction that brings the bearing box under the foot of the connecting rod. Tap the foot of the connecting rod and shims until the bolt holes line up, trying a bolt through the hole to check. Place the lower half of the bearing box on the crankshaft journal, making sure that the double identifying marks on this part face the exhaust manifold side of the engine. Push the bolts up through the bearing box and fasten with the nuts tightened down to 450 pounds torque pressure. Lock the nuts with new cotter pins.

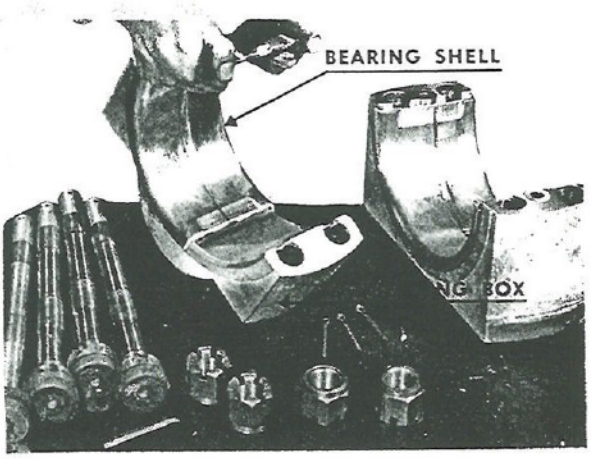


Fig. 120. Installing Bearing Shells in Caps

b. Remove any loose rags, tools and other articles that may be in the engine, and then close the side covers. Use only two bolts in the top and bottom. Make the usual pre-starting inspections. Run the engine for ten minutes. then stop it. Remove the side covers and feel the bearing for excessive heat, comparing with the other bearings. If there is no excessive heat, replace the side covers and fasten with all bolts. The engine is now ready to resume full operation.

SECTION XIII

CRANK SHAFT AND MAIN BEARINGS

145. LOCATION OF MAIN BEARINGS. The main bearings securing the crankshaft to the crankshaft cradle in the engine base hold the crankshaft in place while it absorbs power developed by the cylinders. The engine crankshaft is shown in Fig. 121. The connecting rods are not attached in this illustration, but they fit to the journals that are shown bare. It can be seen that the connecting rod journals are located so that a main bearing is on each side of them. The main bearings are numbered in order from the front of the engine according to the regular engine marking system, and they also are identified by names. The main bearing that fits the extreme front end of the shaft just ahead of the first crank is called the front main bearing. The bearing behind the last crank and in front of the flywheel is called the rear main bearing. Between these two bearings are five main bearings called intermediate main bearings. Notice that there are three widths of main bearings. The rear main bearing is the widest. It absorbs the stresses developed in the entire crankshaft and also the extra stresses caused by the rotation and weight of the flywheel. The front main bearing ranks next in width. It secures the front end of the crankshaft. The five intermediate bearings each absorb an equal amount of crankshaft stress. They are of the same width.

146. REMOVING THE BEARING. *a.* Shut off the globe valve admitting air to the air starting system. Remove the two side covers of the engine that permit access to the desired bear-

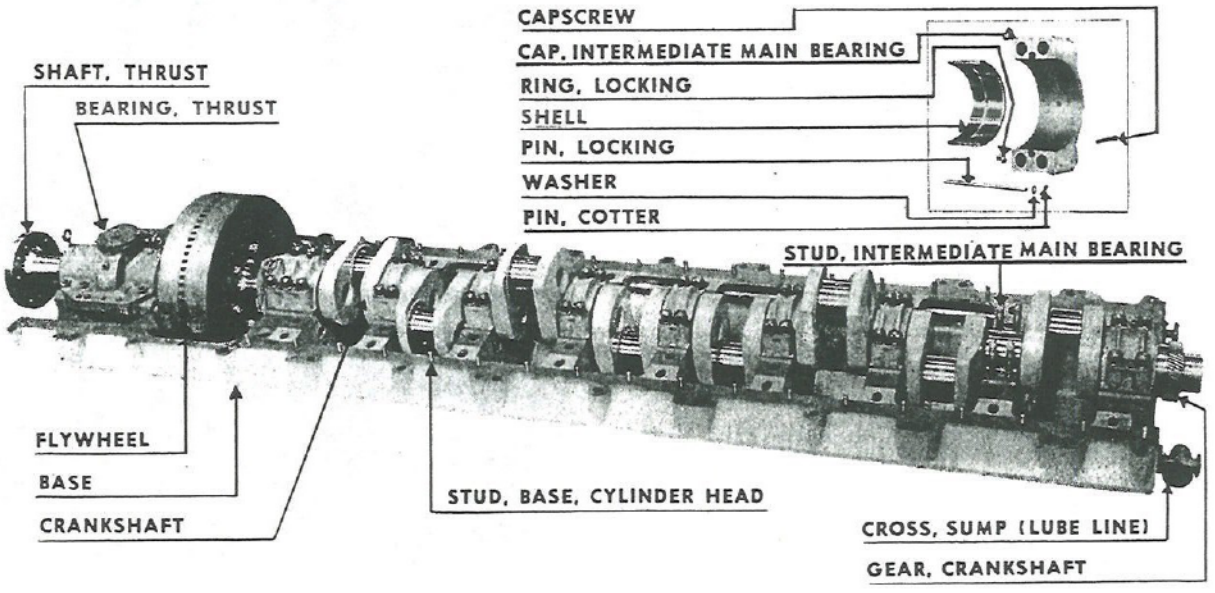


Fig. 121. Crankshaft and Parts

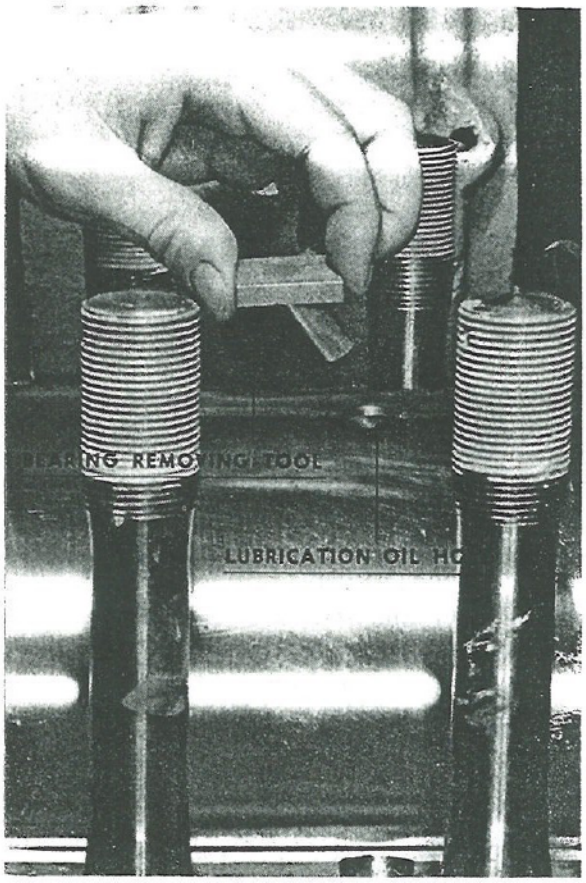


Fig. 122. Main Bearing Removal Tool

ing. Disconnect the copper tubing that supplies lubricating oil to the bearing through a connection in the upper bearing cap and also remove the parker clamp that holds this tubing in place. Place the tubing aside carefully so that no dirt can get into it. Remove the cotter pins, nuts, and washers from the four stud bolts holding the bearing box together. It may be necessary to bar the engine over to provide sufficient room for the wrench.

b. Lift off the main bearing cap, exercising extreme care to avoid damaging the part. Since this bearing is heavy and must be lifted out almost entirely with the muscles of the forearms, it is recommended that a special tool be assembled to assist in the operation. This special tool is made as follows: Unscrew the lubricating oil connection in the cap. Use a short pipe nipple of the same diameter as this connection and fit it into a pipe tee. Screw the nipple well into the threads of the oil connection fitting and, grasping the tee as a handle, lift the bearing cap over the studs and out of the engine.

c. The lower bearing half is removed by using a special bearing tool which is included in the tools supplied with the engine. Never remove all the main bearings, or two adjacent main bearings at the same time. To do this leaves the crankshaft without support and makes bearing replacement extremely difficult. The special bearing tool has a stem end. Insert this stem end into the lubricating oil hole drilled in the main bearing journal of the crankshaft, as illustrated in Fig. 122. Bar the engine over slowly until the bearing tool contacts the leading edge of the bearing shell, as shown in Fig. 123. Continue to bar the engine over slowly until the bearing shell is free. Then remove both the shell and the bearing tool. Always bar slowly to avoid damaging the shell with the bearing tool. Remove the two capscrews from the edges of the upper main bearing cap, and take out the locking rings, and remove the upper shell.

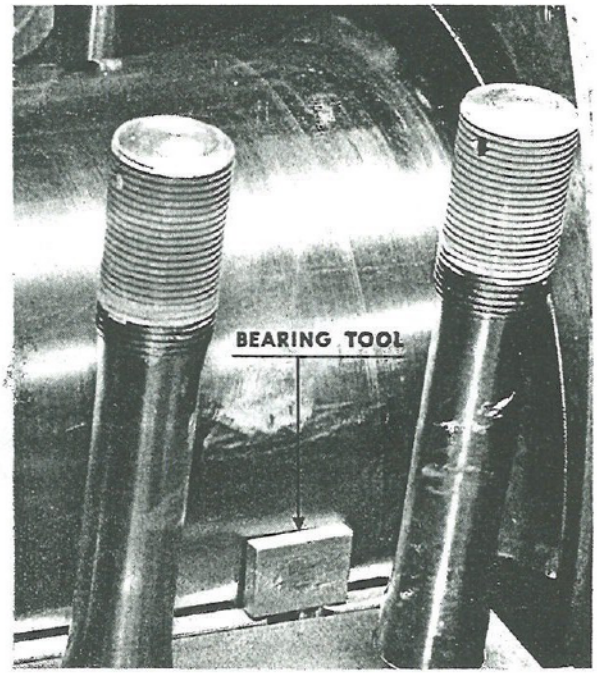


Fig. 123. Removing Lower Main Bearing Shell

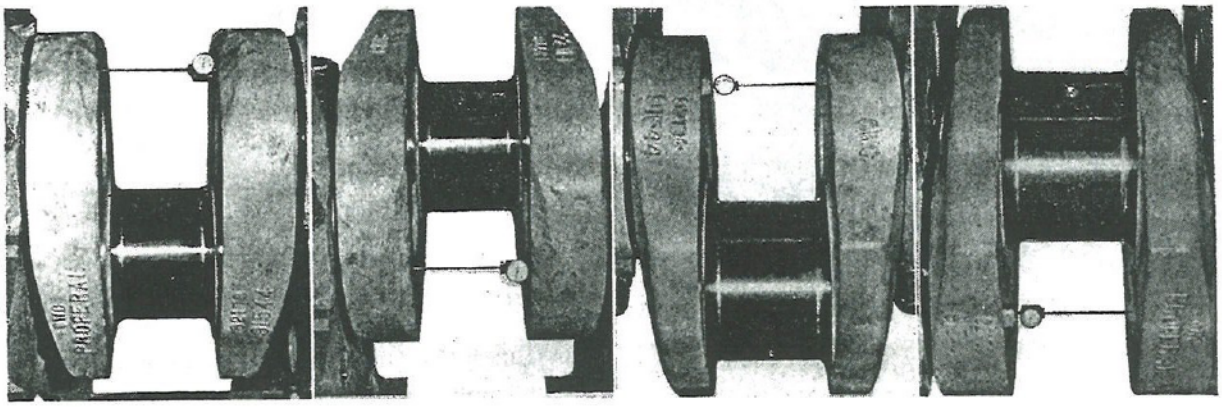


Fig. 124. Measuring Crankshaft Deflection

147. DETERMINING MAIN BEARING WEAR. It is not advisable to change only one main bearing unless burned out due to the failure of the lubrication system serving this one bearing, or other causes. If one main bearing is found worn, inspect the rest of them so that necessary replacements can be made at one time. In determining bearing wear, the shaft should be measured also to determine under size. Maximum wear on bearing shell is .010 of an inch. Shims are not used to fit main bearings in any Enterprise engines. Therefore, if a main bearing is worn, it must be replaced, not adjusted. Measure the thickness of the old bearing with a micrometer, and compare it with the thickness of a new bearing. If this measurement reveals that either of the two bearing shells are worn .010 of an inch, or if either bearing shell is badly burned, replace them.

148. UNEVEN WEAR OF CRANKSHAFT. If the main bearings seem to show an uneven wear, it is an indication that the crankshaft is out of alignment. Crankshaft deflection is tested by removing a connecting rod bearing, and proceeding in the following manner: On the inside faces of the cranks on each side of the bearing center punch small holes exactly opposite each other. Place the leg of a dial indicator in each hole in such a manner that the instrument will remain secure while the engine is barred over. Bar over the engine a quarter turn at a time and make four different readings, as shown in Fig. 124. The readings should not vary more than .003 of an inch. If a larger difference in reading is found, the engine probably is out of alignment. It must be realigned. This is an operation that should be undertaken only in a shipyard. The only thing the operator can do on shipboard is to check the shimming under the thrust base housing, and to check the clearance between the thrust shaft flange and the flywheel to be sure that the thrust bearing is in line. Write down the results of the deflection test in the engine log, and report the findings at once. To neglect this condition will ruin the engine. This test should be made every six months.

149. REAR MAIN BEARING THRUST. None of the rear main bearings absorb any fore and aft thrust. All thrust is absorbed by the thrust bearings between the flywheel and the propeller shaft. It is important the thrust bearings always function properly.

150. REASSEMBLING MAIN BEARINGS. *a.* When each main bearing is ready for reassembly, bar the engine over one complete revolution, and feel the main journal. Be sure there are no burrs, and that the lubrication oil hole is clear. If the journal is in good shape, pour clean lubricating oil over it and on the lower half of the main bearing shell. Place the lower bearing shell on top of the journal and center it with finger pressure. Determine which

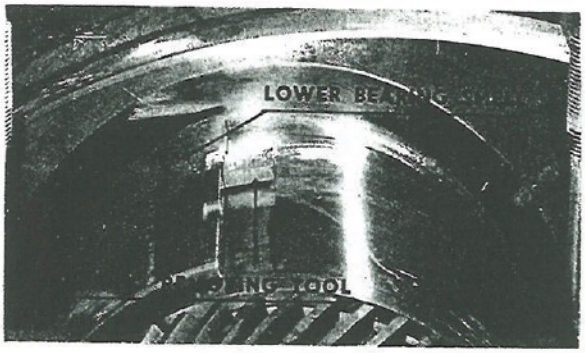


Fig. 125. Replacing Lower Main Bearing Shell

side of the lower bearing cap the shell will have to enter to be installed so that the proper markings will be on their respective sides and the oil grooves staggered. Slide the bearing around the journal in this direction and push the lower bearing cap in as far as it will go with manual pressure. Bar the engine over very slowly in the same direction the bearing is being inserted in the cap until the lubricating oil hole can be seen. Place the stem of the bearing tool in this hole and continue to bar the engine over until the bearing tool contacts the bearing shell, as shown in Fig. 125.

b. Do not force the bearing into place. To do so may crack or bend it and make it unfit for use. Bar the engine over again very slowly, watching the shell carefully as it enters the lower bearing cap. If the shell appears to catch, or hang up, ease off the pressure on the bearing tool by barring the engine in the opposite direction. This usually relieves the shell of undesirable stress. Bar the engine back again in the same direction until the bearing tool contacts the shell again, and continue to bar until the shell is all the way in.

c. Examine the placement of the shell, making sure that it is centered in the lower bearing cap. This will be shown if both ends of the shell extend an equal distance on each side of the cap. The ends, or leading edges, of the bearing shell should also be placed so that they stick up about ¼ inch above the base. When the position of the bearing shell is satisfactory, remove the bearing tool.

d. Pour more clean lubricating oil on the journal and on the upper main bearing shells. Fit the upper bearing over the studs, again making sure that the numbers are on the proper sides. Tap on the cap on opposite sides if necessary until the two halves are centered and the dowels of the upper half enter the dowel holes in the lower shell. Be sure the bearing is down snugly on all surfaces. When the bearing halves are fitted snugly together, replace the washers and tighten down the nuts to 450 pounds torque pressure. Put in new cotter pins and spread them to lock the nuts. Remove the pipe nipple and tee used to lift the upper bearing cap, and replace the tubing connector. Reconnect the lubricating oil tubing to the bearing and to the lubrication oil header line. Draw the connections tight. Replace the parker clamps that fasten the lubricating oil tubing.

e. Remove any rags, tools or other materials that may have been in the engine base. Replace the side covers, using only two bolts at top and bottom. Start the engine and run it for ten minutes and then shut it down. Remove the side covers and feel all the replaced main bearings for excessive heat. If the temperatures are normal, replace the side covers, using all the bolts. The engine is ready for duty.

SECTION XIV
THRUST BEARING

151. TYPES OF THRUST BEARINGS. Enterprise engines are equipped with either one of two types of thrust bearings. One is the Kingsbury thrust bearing and the other is the thrust bearing that uses a Timken roller bearing. In the type using the Kingsbury bearing, the heat exchanger principle is employed to cool the lubrication oil with sea water. The function of the thrust bearing was explained in Sect. IV.

152. KINGSBURY THRUST BEARING. The Kingsbury thrust bearing, illustrated in Fig. 126, is composed of a short piece of shafting

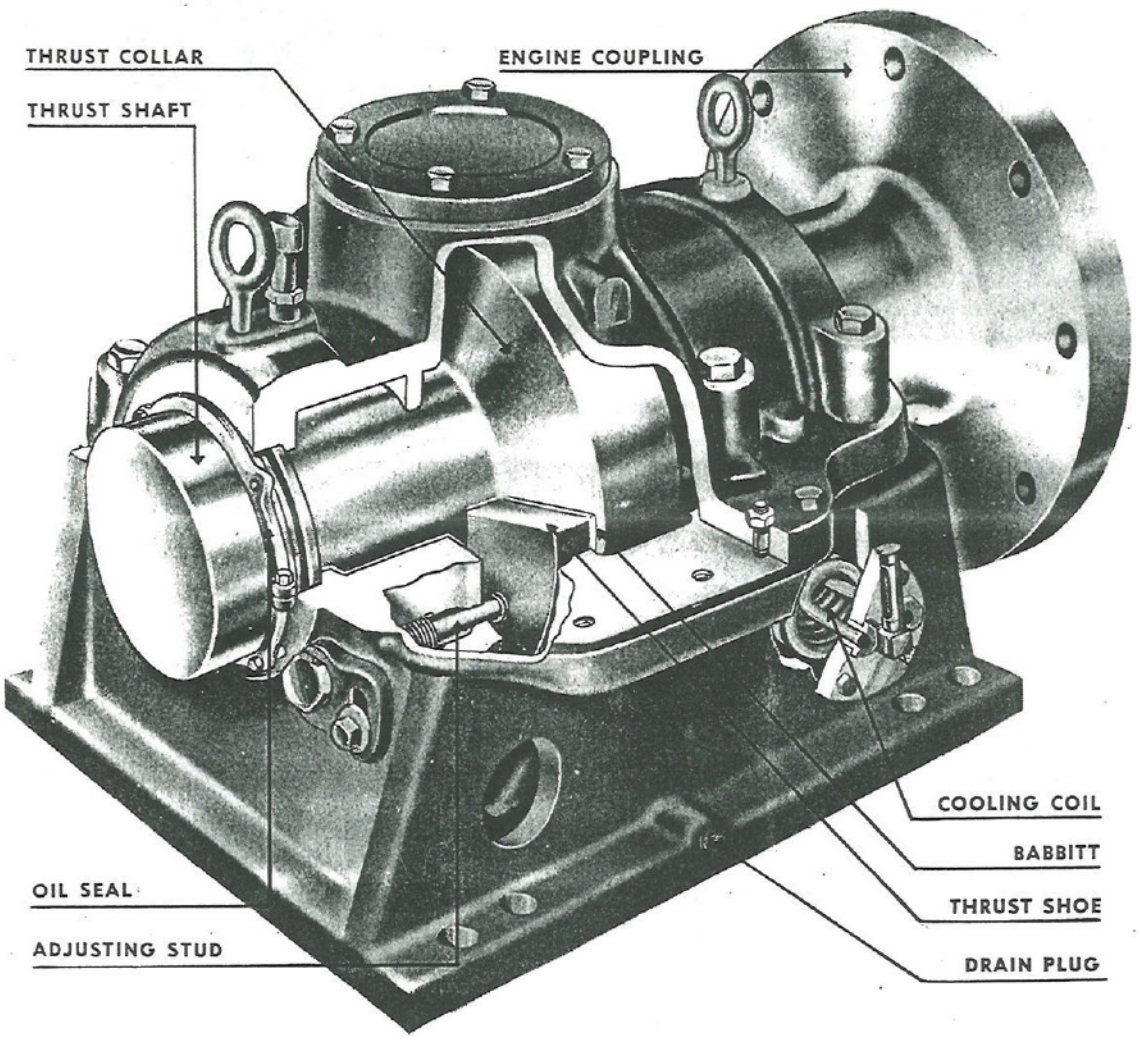


Fig. 126. Kingsbury Thrust Bearing Cut Away

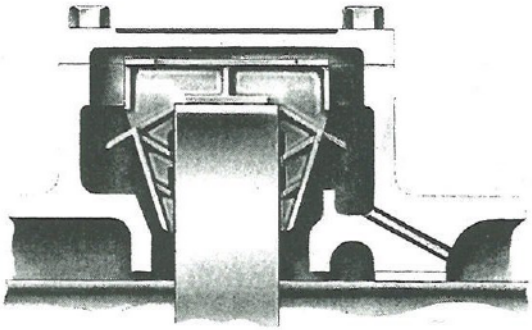


Fig. 127. Lubrication of Thrust Bearing

called a thrust shaft. A flange, or collar, called a thrust collar, is part of this shaft. Both ahead and behind this collar is fitted a set of two thrust shoes. The forward axial thrust is stopped by the collar meeting the forward thrust shoes. The aft thrust is stopped by the rear thrust shoes contacting the collar. The thrust bearing is contained in a compact housing which has a lubricating oil reservoir at the bottom and a sight glass for checking the oil level. The oil is picked up by the thrust collar as it revolves through the reservoir, and it is spread on the faces of the collar and shoes. This film of oil cushions the force of the axial thrust. The main journal is located ahead of the thrust collar. It is oiled by the scraper and oil passage as illustrated in Fig. 127.

153. CARE OF BEARING. The Kingsbury thrust bearing, unless operated at temperatures above the safe level, requires little attention except to maintain the oil supply at the proper level. After 500 hours of operation drain off the old oil, wash the oil reservoir thoroughly, and replace with clean oil meeting the specifications stamped on the plate of the bearing.

154. ADJUSTMENT AND MAINTENANCE. Remove the housing cover and inspect the faces of the thrust collar for rough spots, or burrs. If any are found remove them with emery cloth. Unscrew the four stud locks and release

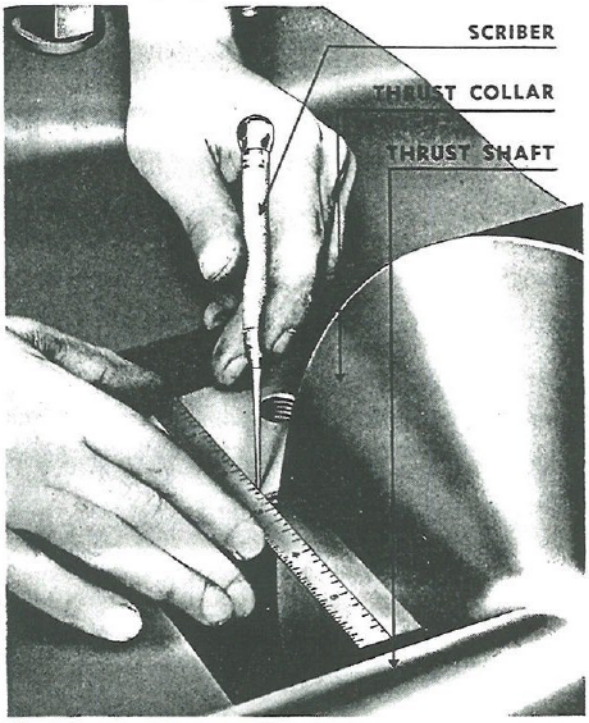


Fig. 128. Measuring Thrust Bearing Travel

the four thrust adjusting studs shown in Fig. 126. Since most engines are installed so they tilt aft, the thrust bearing shaft will probably slide back until the bearings inside the engine come against the cranks. Lay a straight edge across the face of the thrust collar and scribe a line across the edge of the thrust housing, as shown in Fig. 128. Jack or bar the crankshaft forward and repeat this process. The distance between these two lines is the amount of the fore and aft travel of the crankshaft. Screw in the two rear adjusting studs so that the two rear shoes move ahead one-fourth of this distance. Be sure that both rear thrust shoes are tight against the thrust collar. Select a shim exactly .014 of an inch thick and large enough to cover the face of one thrust shoe. Place this shim between the forward face of the thrust collar and one of the thrust shoe faces. Tighten up on the adjusting stud until the shim can just be removed by hand. Insert the shim on the other side and repeat the operation. There is now the proper clearance. All four stud locks may now be attached to the four adjusting studs.

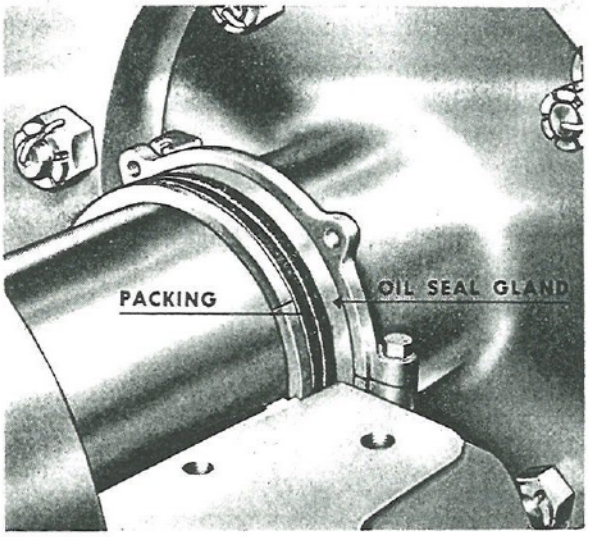


Fig. 129. Oil Seal on Thrust Bearing

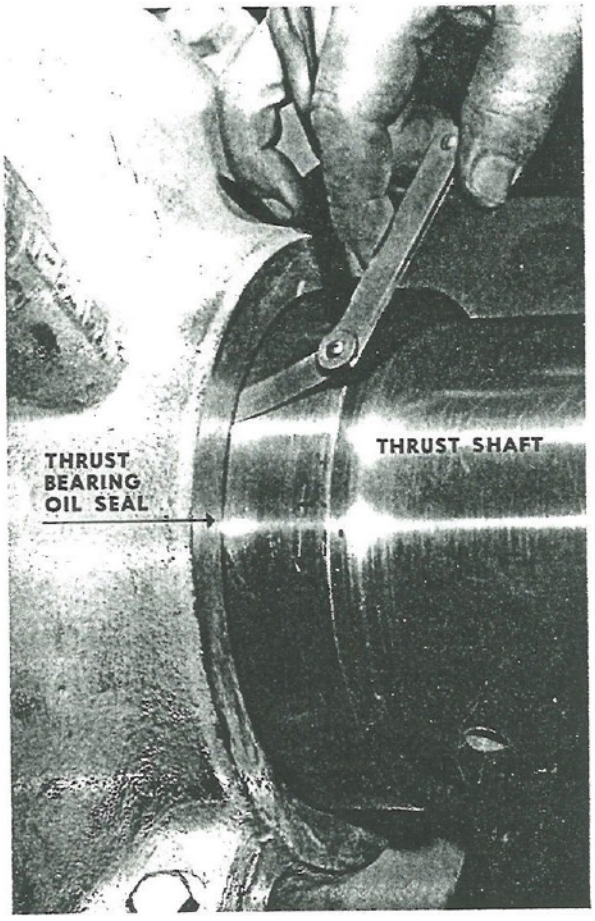


Fig. 130. Measuring Clearances Between Thrust Bearing Shaft and Housing

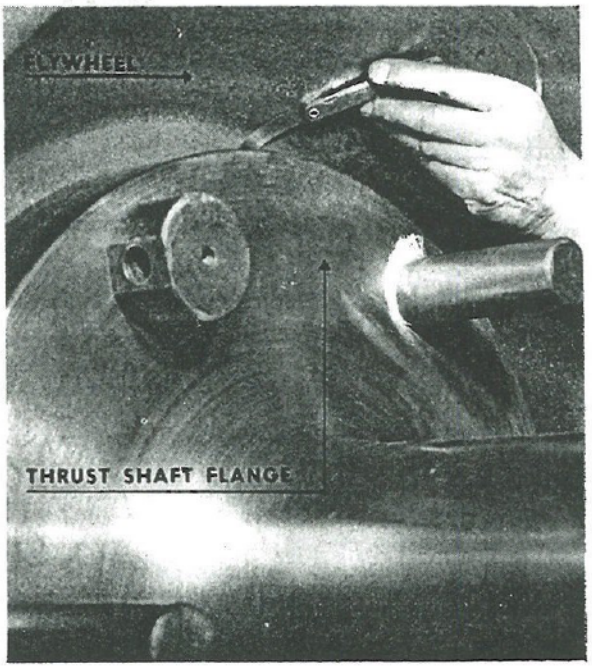


Fig. 131. Measuring Thrust Bearing Alignment

155. LUBRICATING OIL COOLER. While working on the thrust collar, remove the flange or plate connecting the sea water pipes to the base of the thrust bearing. Clean out the water tubing thoroughly with a stiff brush.

156. OIL SEALS. After completing all adjustments, examine the packing in the oil seals. If the packing is worn or hard, replace with new packing inserted as illustrated in Fig. 129. Do not tighten the seals more than necessary to prevent oil from leaking out.

157. ALIGNMENT. ***a.*** When the thrust collar clearance is adjusted there is a possibility that the crankshaft may be moved too far either forward or back. Remove the side doors of the engine and check the clearance between the ends of the connecting rod bearing and cranks with a feeler gauge. If the end clearances are not correct, the thrust bearing must be readjusted.

b. If the thrust bearing is removed from its base before securing the bolts holding down the housing to the base, connect the flanges to

the propeller shaft and to the flywheel, tightening securely. Check the alignment first, with feeler gauges of the proper width. Insert a feeler gauge between the thrust shaft and the housing, as shown in Fig. 130. The same clearance should be found all around the shaft. Make the same test between the flange and the flywheel, as shown in Fig. 131. If in either place there is a difference in clearances, the shims will have to be added or removed from under the bearing until this defect is corrected. As a final check, measure the end clearances of the connecting rod bearings in the engine.

SECTION XV
FUEL INJECTION PUMPS, NOZZLES AND GOVERNORS

158. PRECISION PARTS. The injection fuel pumps and fuel nozzles are made with great precision and require fine craftsmanship and fitting to work properly. In ordinary engine operations, a fuel injection pump should last the life of the engine. If a fuel injection pump stops functioning, it is advisable to replace with a spare and send the old one to higher echelon for repairs. For the same reasons, fuel nozzles not functioning properly should be replaced with spares, and the old ones sent to higher echelon for repair. However, it is recognized that under certain conditions repair operations must be undertaken which are not normally attempted by any but the most skilled workmen.

159. HANDLING PRECISION PARTS. Before attempting to take a fuel injection pump or fuel nozzle apart, certain preliminary precautions must be taken. Cover the workbench with clean, grease-proof paper. Be sure that all tools are spotlessly clean, and keep hands clean and free of grit at all times. Fill a clean pan, preferably a white enameled hospital pan about 10 x 15 inches and 2 inches deep, two-thirds full of filtered kerosene. Wash the parts. If the parts appear extremely dirty as they are taken out, use a second pan of filtered kerosene for a second wash. A clean squirt can filled with kerosene will also be useful in cleaning out the corners of small parts and various small openings. Do not leave the parts exposed to the air for more than a very few minutes as the smallest amount of oxidization, scum, or rust will ruin them. In wiping the parts use only the softest cloths. Tiny scratches will cause trouble.

160. TESTING FUEL INJECTION PUMP. Before condemning the fuel pump for faulty operation, test it. Make sure that the fuel oil is reaching the pump. Loosen the vent screw located on the front of the pump just above the connection to the fuel supply line. If air bubbles are seen, allow the fuel to flow until the bubbles disappear. Replace vent screw. Then remove the bonnet on the cylinder head and open the fuel bleeder valve on the fuel nozzle by turning two revolutions in a counter-clockwise direction, as shown in Fig. 132.

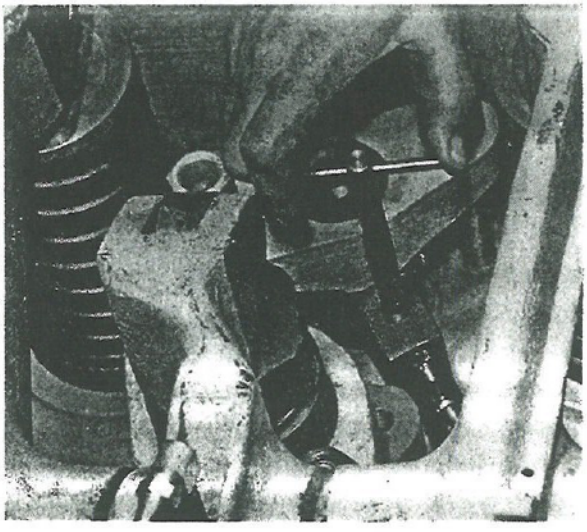


Fig. 132. Bleeding Fuel Nozzle

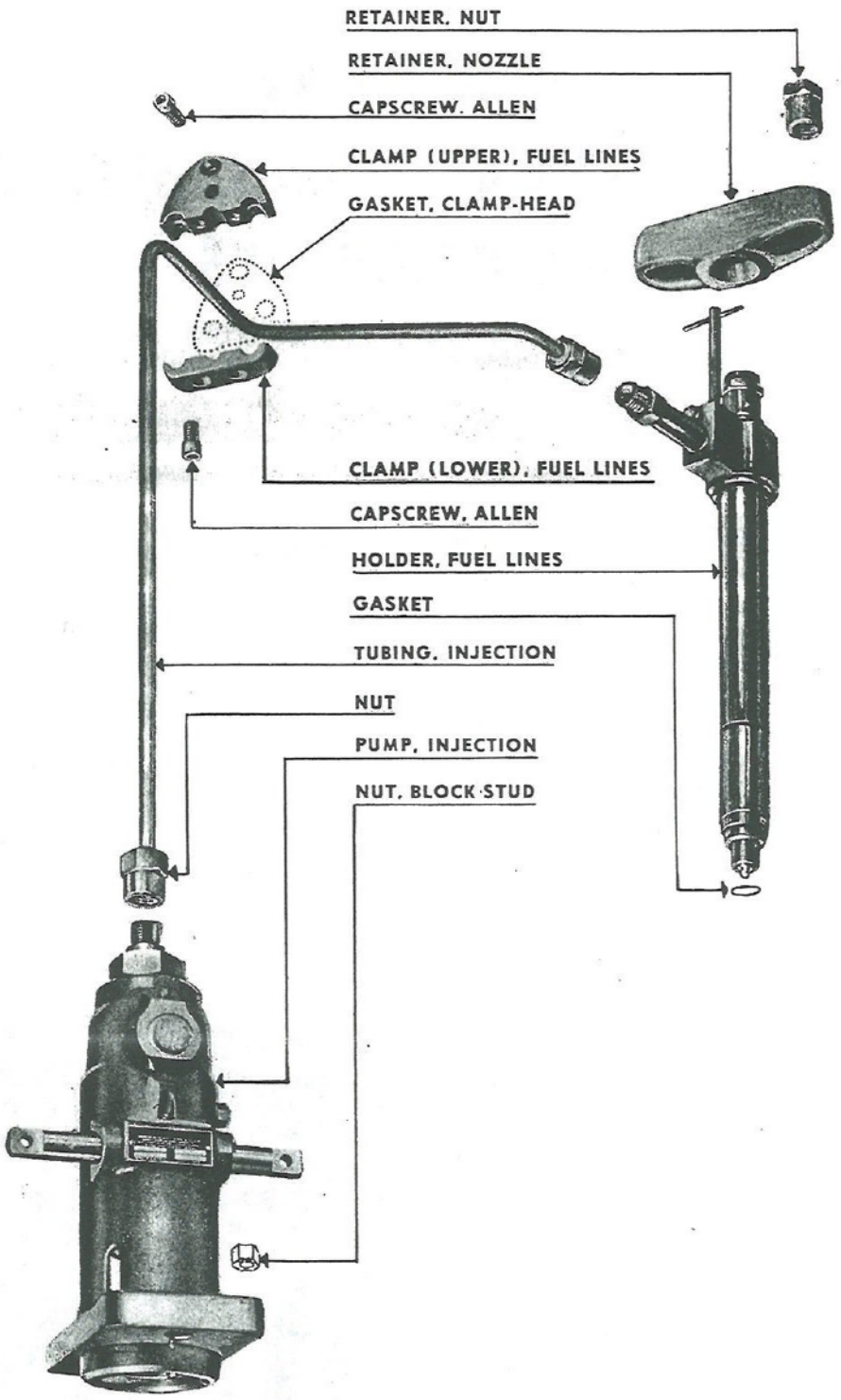


Fig. 133. Fuel Injection Pump and Nozzle with Connecting Tubing

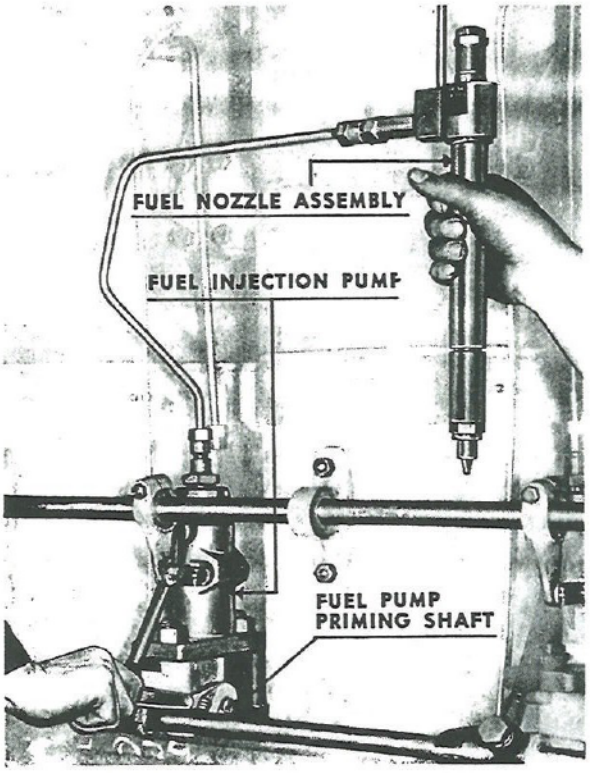


Fig. 134. Manual Operation of Fuel Pump

Go back to the fuel pump and set the control rod at approximately 20mm. In Fig. 133 the fuel injection pump and the fuel nozzle are shown together. Operate the priming shaft at the base of the pump a few times by working up and down with a crescent wrench, as illustrated in Fig. 134, barring the engine over to remove the fuel tappet from the cam lobe if the tappet is in that position. After priming the pump a few times to bleed air from the line, tighten up the bleeder valve in the nozzle and try the pump in operation again. If it still fails to function properly, replace with a spare. Where no spare is available, the following procedure may be used.

161. DISASSEMBLY OF FUEL INJECTION PUMP. ***a.*** Remove the tubing connected to the fuel pump and take off the bolts holding it on the tappet base. Also disconnect the arm of the fuel control shaft from the control rod of the pump. Place the pump in an inverted position in a vise. Remove control rod.

b. In Fig. 135 the parts of the pump are shown disassembled. Press down on the plunger guide and insert a 5/32-inch pin about two inches long in the hole of the flange spigot. Remove the spring ring with a screwdriver and pliers. Press the plunger guide down again and remove the temporary pin. Remove the parts from the lower portion of the pump body in the following order: plunger guide, lower spring plate, plunger spring, pump plunger, regulating sleeve, spring ring, and upper spring plate. Immediately place all these parts in a pan of kerosene.

c. From the upper part of the pump unscrew the delivery valve holder and take out the delivery valve and delivery valve spring. Back off the locking screw about three turns and carefully press out the pump barrel, the delivery valve seat, and the special gasket.

d. Wash the parts in kerosene and examine them. If plunger or pump barrel is found to be damaged, they must both be replaced since these parts are fitted together as a unit and are not interchangeable. This also applies to the delivery valve seat. As now seen, there is not much that can be done on shipboard to repair a fuel injection pump except clean it. When satisfied that every part is clean, prepare to reassemble the pump.

e. Place the clamp body in the vise in an upright position. Place pump barrel in the body in a way that the largest diameter of the positioning groove lines up with the locking screw. The locking screw should fit into groove of the barrel without binding or distorting the barrel. Test it by moving barrel up and down in the pump body.

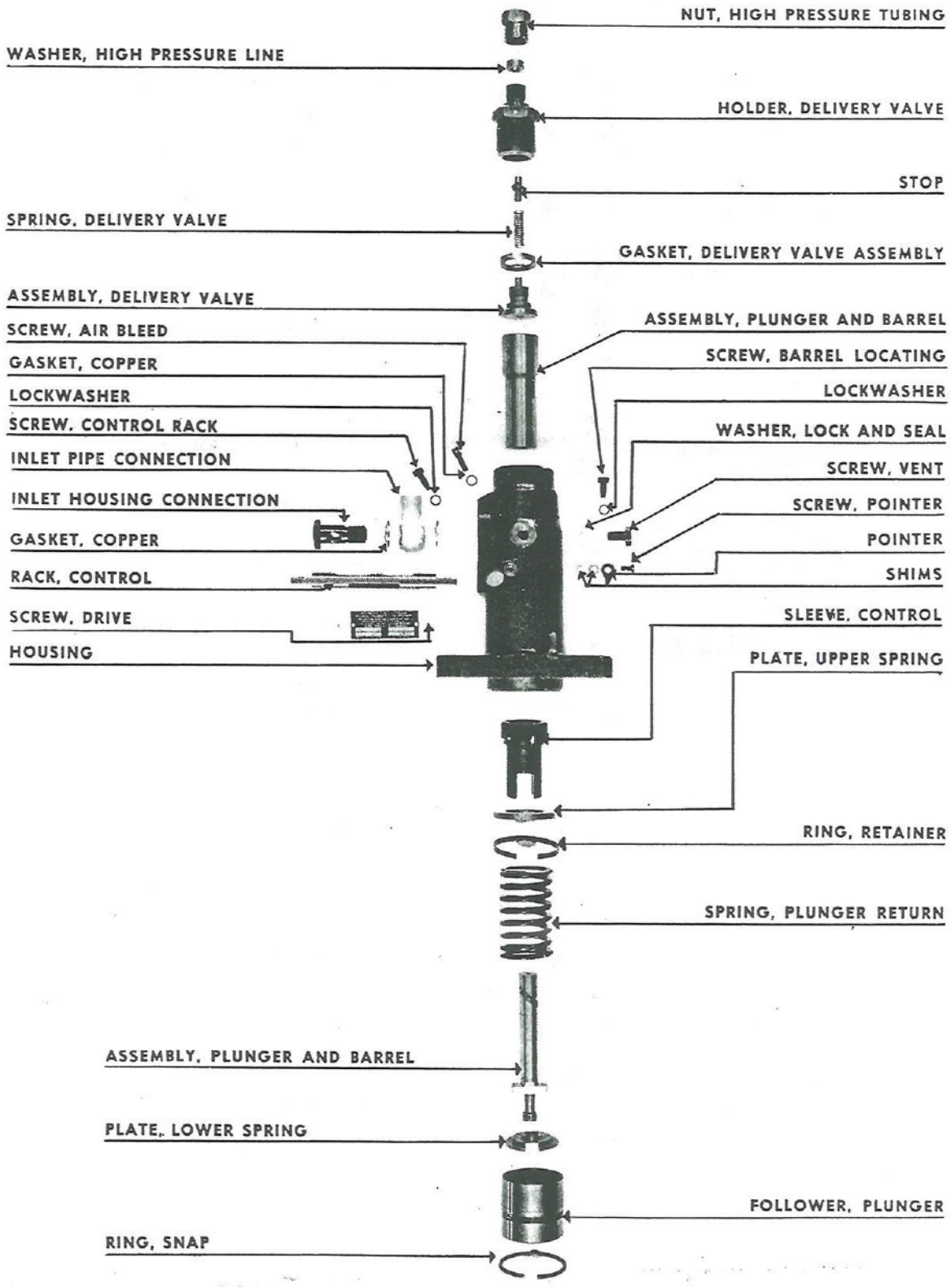


Fig. 135. Fuel Injection Pump Parts

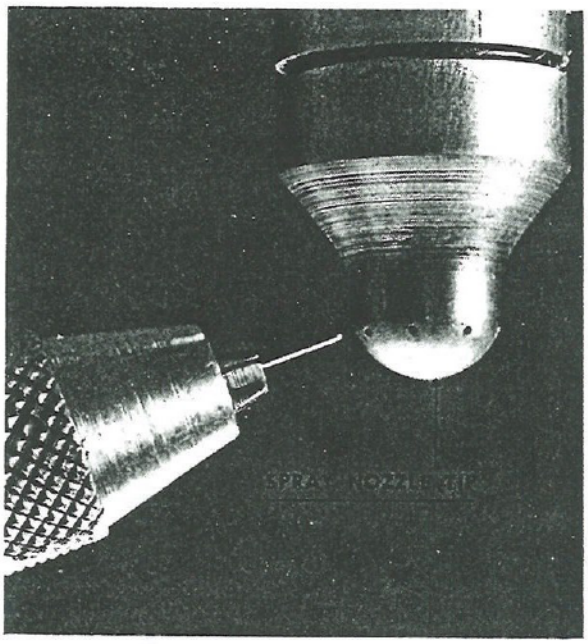


Fig. 136. Cleaning Holes in Fuel Nozzle Spray Tip

f. Replace the delivery valve seat and the special gasket, making sure that the lapped face of the delivery valve seat is perfectly seated with the top face of the barrel. Insert the delivery valve, the spring, and the screw delivery valve holder into the body, and tighten sufficiently on the gasket to prevent leaks.

g. Take the pump body out of the vise and put it back in an inverted position. Replace control rod so that the punch mark which is in the center between the teeth is approximately in the center of the pump body. Replace the regulating sleeve so that the punch marked tooth of the sleeve meshes with the punch mark on the control rod.

h. With these two parts fitted, replace the remaining parts in the following order: upper spring plate, spring ring, plunger spring, pump plunger, and lower spring plate. Be sure the plunger is inserted so that the mark on the lug of the plunger is in line with the marks on the regulating sleeve and control rod. Replace the plunger guide on top of the lower spring plate and press in, using a temporary pin to hold it in place. Press in the spring ring and remove the temporary pin.

i. Work the control rod back and forth to be sure it is functioning. Remove the pump from the vise. Place a hammer handle in the vise, and test the plunger action by pressing the plunger guide down against the end of the hammer handle a few times. The guide should return through the force of the spring, and the plunger should move freely.

162. REMOVING A FUEL NOZZLE. Disconnect the fuel inlet and drain from the nozzle. Remove the nozzle retainer in the cylinder head with a special wrench. Gently pry out nozzle head. After its removal clean off the carbon from the nozzle seat in head and also from the gasket. Inspect the gasket for cleanliness and condition, replacing it if necessary.

163. TESTING NOZZLE. Always test the nozzle first before disassembling it. Connect the nozzle to any fuel pump and operate the pump by the priming shaft in the base. The fuel should come out of each hole in the nozzle in fine sprays of uniform pattern. If the fuel does not come out, or if it comes out in a solid stream or in dribbles, the holes in the spray tip may be clogged. Insert a fine piece of piano wire, or a special tool into the holes, as illustrated in Fig. 136. If after this operation the nozzle still will not spray fuel properly, it may be assumed that gummy particles, or dirt, or rust are interfering with the nozzle mechanism. The nozzle should be replaced with a spare and the old one returned to the factory for repairs, if that is possible. However, if under service conditions a spare is not available, the nozzle can be taken apart.

164. DISASSEMBLING A FUEL NOZZLE. *a.* First prepare the work bench, and provide the kerosene baths as already explained. Then study Fig. 137 carefully, and become familiar with the parts. Place the nozzle holder body in a vise, as illustrated in Fig. 138. Remove the assembly cap nut and the spray tip, valve body, and stop plate. Place the parts in the kerosene bath and wash well. Clean out the interior of the nozzle with a small strip of wood soaked in kerosene. Take the unit out of vise,

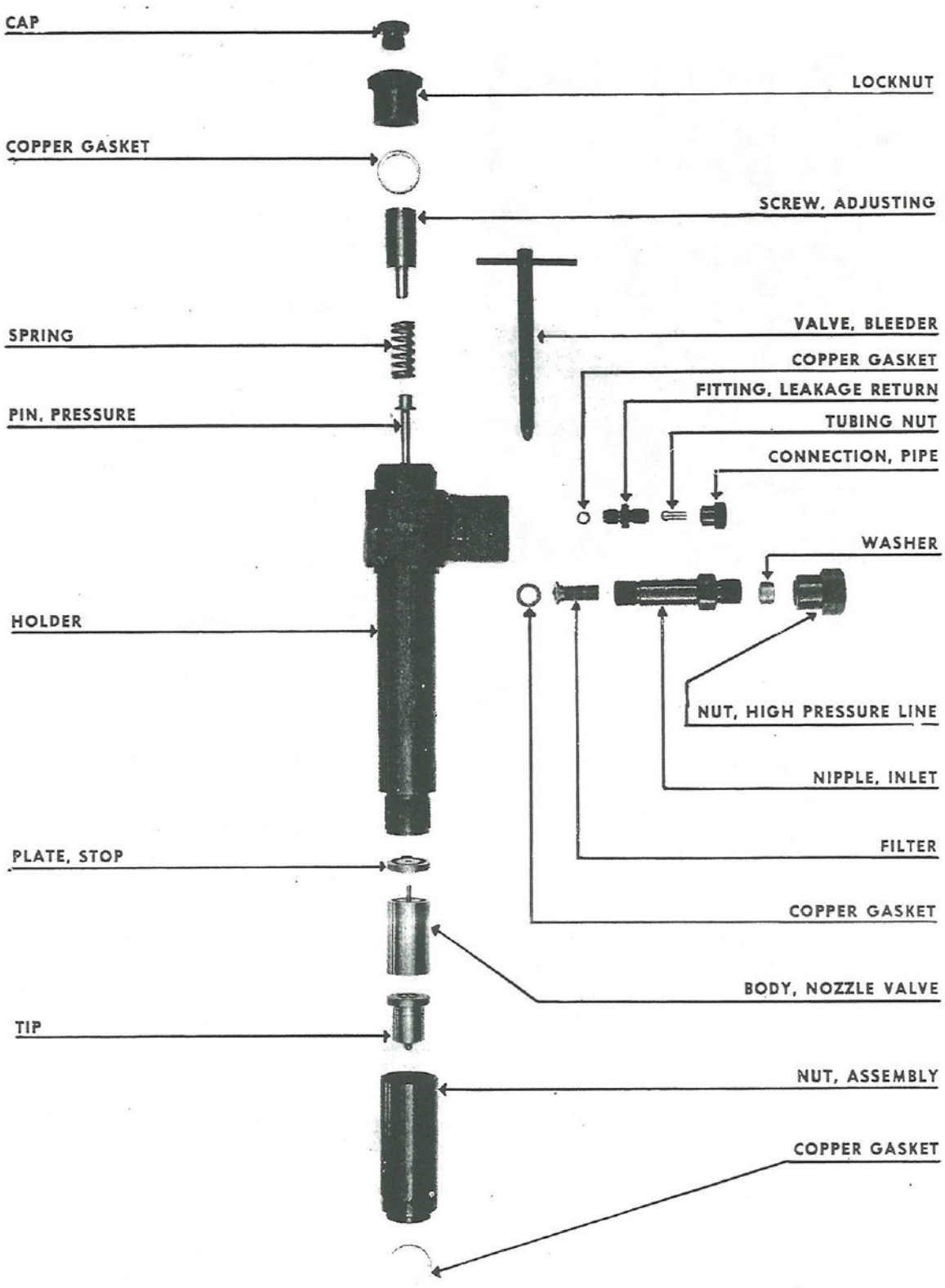


Fig. 137. Fuel Nozzle Parts

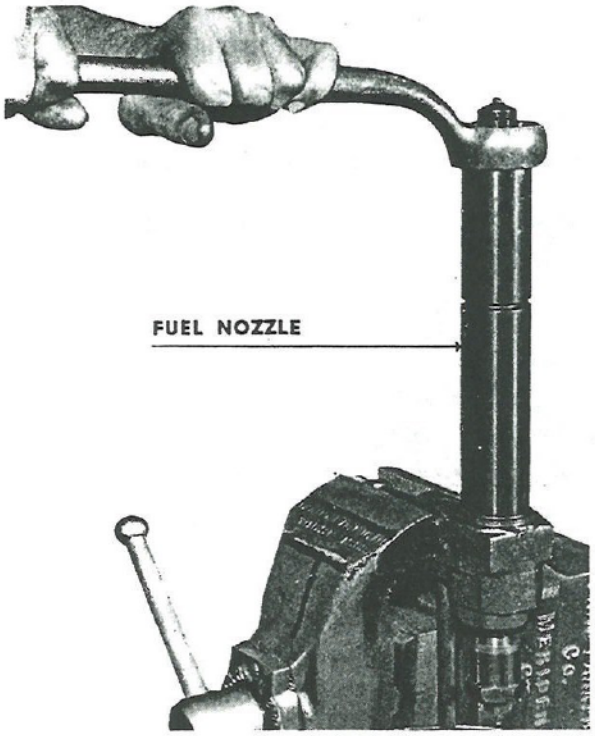


Fig. 138. Disassembling Fuel Nozzle

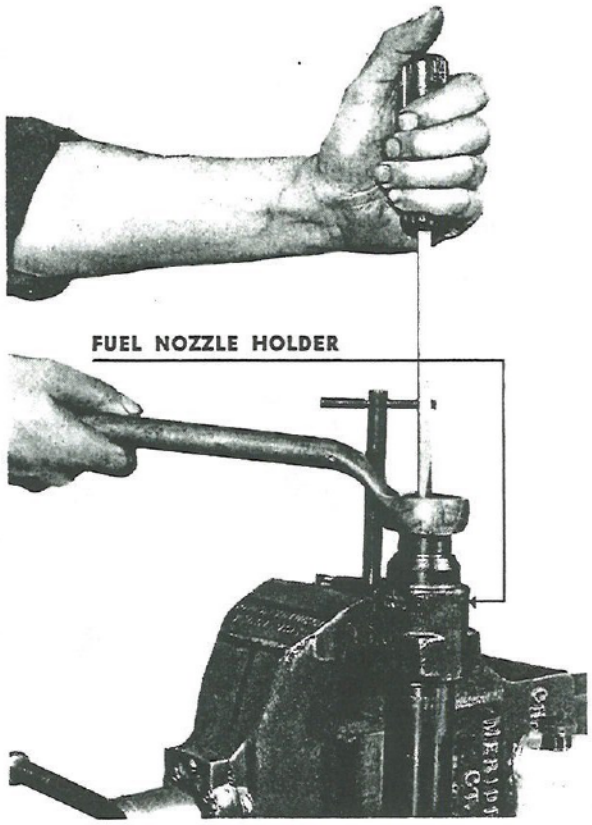


Fig. 139. Disassembling Fuel Nozzle

and replace in vise with the other end up. Loosen the locknut and unscrew the screw, as illustrated in Fig. 139. Take out the pressure adjusting screw, the spring, and pressure pin, and put these parts in the kerosene bath.

b. Remove the bleeder valve and fitting, and also the fuel inlet fittings, and examine the edge filter. Clean the filter and the inside of the inlet connections with kerosene. When all parts are cleaned, test them.

c. The nozzle valve should fit into its holder with ease and move around without "knocking." If either part is found damaged, both must be replaced. They are precision-fitted to each other. Replace the edge-type filter into the fuel inlet, forcing it in by hand with the aid of a 3/16-inch pin. The filter should just fit into its housing. If it is too loose, it should be replaced with a new element.

165. REASSEMBLING FUEL NOZZLE. Reassemble the fuel nozzle in the same order it was taken apart, being careful that all part faces are clean. Tighten all connections gently but firmly.

166. ADJUSTING NOZZLE PRESSURE. If it has been necessary to disassemble the nozzle, it will be necessary to test it again and to adjust the spring tension so that it will open at a pressure between 2200 and 2300 pounds. If a test pump with a gauge is not on board, improvise a test line with a pressure gauge cut into it between the fuel injection pump used and the nozzle. While someone operates the pump by the priming device, the gauge must be watched to find the pressure at which the nozzle just delivers fuel. The spring pressure is adjusted by loosening the locknut and turning the pressure screw. Each quarter turn changes the opening pressure approximately 150 pounds. This work will continue until the nozzle starts to function at the correct pressure.

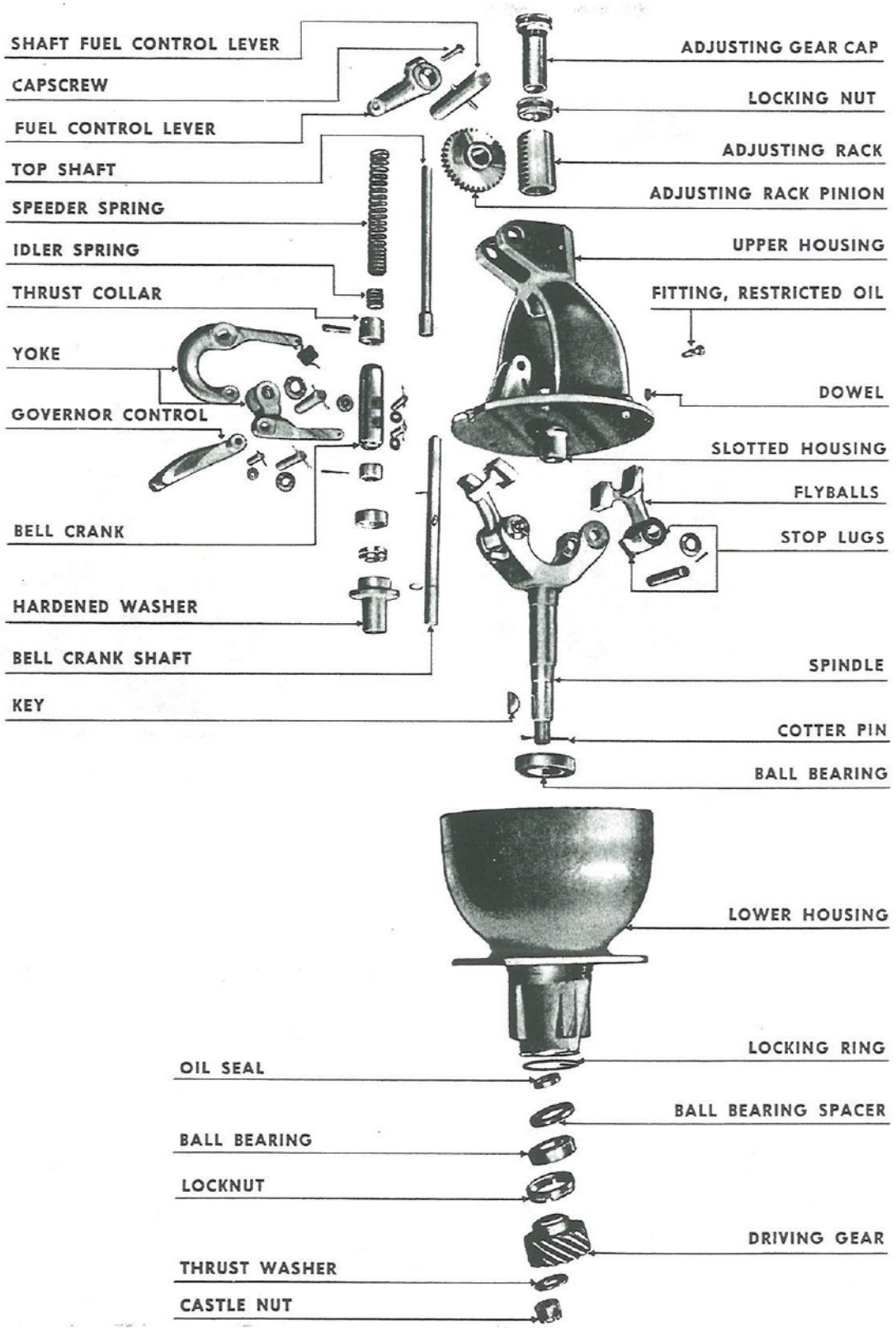


Fig. 140. Fuel Governor Parts (Mechanical)

167. THE MECHANICAL GOVERNOR. *a.* If the governor fails on the engines equipped with the mechanical governor, the engine can be operated manually until either repairs can be made or a new governor installed.

b. To disassemble the governor, disconnect the linkage for the fuel throttle and the fuel control shaft, as shown in Fig. 140, and remove the four capscrews holding it to the engine.

c. Starting from the top of the governor, remove the cotter pins which hold in place the shaft on which the adjusting rack pinion rotates. Remove the shaft and pinion gear. The adjusting cap and adjusting rack can now be removed in one piece. Next remove the speeder spring and, underneath it, the short idling spring. Remove the yokes from the bell crank, and take out the screw holding the lower end of the top shaft to the coupling. The entire unit can be lifted off.

d. Remove the capscrews holding the top and bottom governor housing together, and lift off the top of the housing. At the bottom of the housing, remove the nut and washer holding the gear in place. Follow this by the removal of the locking ring, the ball bearing spacer, and the ball bearing. The spindle holding the flyball arms and flyballs can now be removed, as can be the inner shaft. This is held in place by a coupling on the top of the spindle and a slotted shaft housing in the bottom of the top half of the governor housing. A pin in the bell crank shaft fits into this slot to prevent it from rotating.

e. Remove the locking ring at the lower end of the inner shaft and slide off the thrust sleeve, the ball bearing and the hardened washer. Another ball bearing is located in the inside of the bottom of the lower governor housing. Remove this bearing.

168. INSPECTION. *a.* Inspect all bearing shells. If they show wear or damage, replace them. Inspect all bushings. If any are loose, drive them out and replace them, making sure they fit properly without binding and without excessive looseness.

Inspect the flyballs, bearing in mind that they close upward and in toward the bell crankshaft, and also that each one is built with two lugs on opposite sides. The inside lugs force the hardened washer up and down the shaft to control the engine speed while the outside lugs prevent the flyballs from moving out too far.

b. If either the flyballs or these stop lugs show damage, replace with new flyball arms if possible. If this is not possible, repair them. With the flyballs assembled, push them up toward the bell crank shaft. Use pieces of metal or shims exactly ⅛ of an inch thick to separate the flyballs. The inner stop lugs should remain in contact square on the hardened washer. If this condition is not found, it means that metal has been chipped off at least one of these lugs. Now allow the flyballs to fall outward. If they can open a gap between them wider than 1¼" at their closest corners, the stop lugs on the backs of the flyball arms either are chipped or worn.

c. It will be necessary to spot with a welding torch more metal on lugs that are chipped or worn. Then this added metal must be filed down so that with the flyballs exactly ⅛" apart, both inner lugs will be on the hardened washer, and the back stop lugs will permit only an extreme opening distance of 1¼".

d. In reassembling the governor, reverse the order used in taking it apart.

169. THE HYDRAULIC GOVERNOR. *a.* Due to the hydraulic action of the Woodward governor, an adequate supply of oil is essential. A glass gauge is provided to check the oil level. This should be done every twenty-four hours. Use SAE 30 oil for ordinary temperature conditions. If the governor is operating under extremely hot conditions, use SAE 50 oil, and SAE 10 in extremely cold conditions. If the governor fails to function properly, the oil should first be checked, as dirty oil will re-

sult in trouble. In any event, the oil should be changed every six months. Remove the linkage to the terminal shaft, remove the capscrews securing the governor to the engine, and by gently prying upward, the governor is removed from the engine. Take out the capscrews holding the top cover in place and turn governor upside down to drain. When drained completely, refill with new oil. All containers used for the oil should be first rinsed with light fuel oil. If the oil supply is maintained properly, the governor should operate without trouble. Any trouble that might be encountered will probably indicate that a readjustment is necessary.

b. High overspeeds and underspeeds after load changes, and slow return to normal speed are caused by incorrect compensation adjustments. If these troubles are encountered run the engine until it is thoroughly warmed up. Before making any adjustments be sure the engine is operating under limited load conditions and not bucking strong tides, currents, winds, or other conditions which increase the load.

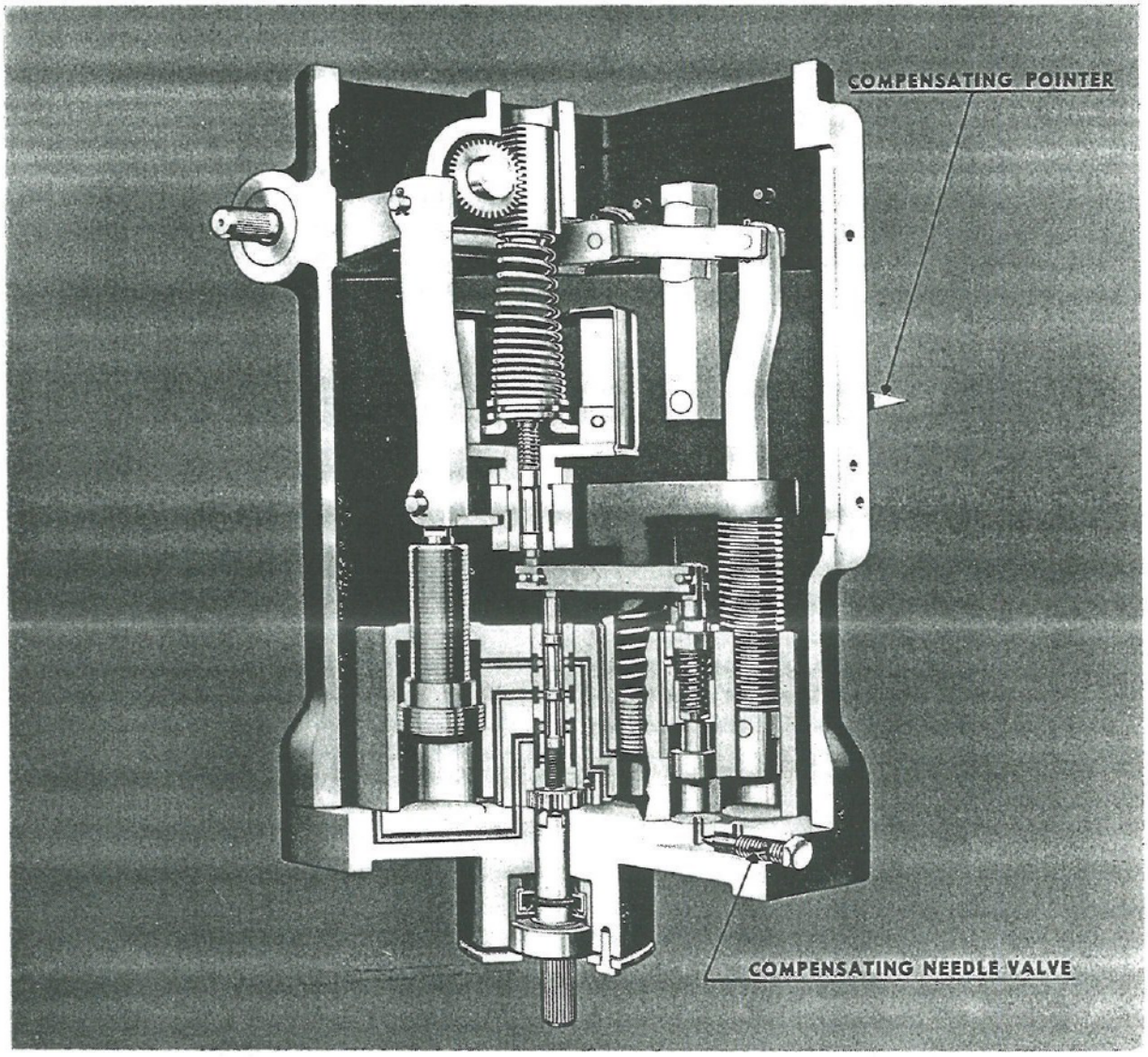


Fig. 141. Adjustment of Hydraulic Governor

c. In Fig. 141 the compensation adjusting pointer is shown on the side of the governor. Loosen the nut holding the pointer and set the pointer at the extreme downward position. The illustration also shows the location of the compensating needle valve. On the outside of the bottom front of the governor housing, remove the screw plug and the compensating screws will be accessible. Turn this screw two or three turns with a screwdriver and allow the engine to hunt, or surge on varying speeds for about 30 seconds to bleed trapped oil from the governor passages. Gradually close the needle valve until the hunting just stops, taking care not to turn the screw beyond this point. Carefully turn the screw in as far as it will go, noting the exact part of a full turn required to close the needle valve. Open the valve to the point where it was found hunting stopped. If the needle valve is now less than ½ turn open, and more than ⅛ turn open, the adjustment is satisfactory. If it is found that hunting is not stopped when the needle valve is ⅛ of a turn open, raise the compensation pointer two divisions of the scale and follow through again with the procedure already outlined for closing the needle valve. If necessary repeat the process, raising the compensation pointer two divisions at a time until the proper adjustment of the needle valve is obtained. The desirable needle valve opening is from ⅛ to ¼ of a turn open. This adjustment is closely limited. Closing the needle valve too much results in the governor being slow to return to normal speed after a load change. If the compensation adjusting pointer is too far advanced, excessive speeds will be encountered when the engine loads change.

d. In view of the intricate construction of the hydraulic governor, no further repairs should be attempted. Further work should be done by a specialist. For this reason it is advisable to have a spare on board ship for replacement. In event the hydraulic governor fails suddenly, damage will be prevented by the overspeed governor.

170. THE OVERSPEED GOVERNOR. ***a.*** A cross-section of the overspeed governor is shown in Fig. 142. This governor is set at the factory to operate only if the engine builds up a speed in excess of the maximum speed rating of the engine. In the event the overspeed governor does not operate if the engine attains a higher speed than the engine rating, unscrew the adjusting screw to decrease the spring tension. Likewise, the operation of the governor at too low speeds can be remedied by tightening the spring tension with the adjusting screw. Due to the fact that this governor infrequently operates, repairs to it will not be necessary during the life of the engine.

b. The balancing valve, which is a part of the overspeed governor system is adjusted at the factory and due to its infrequent operation will not require repairs.

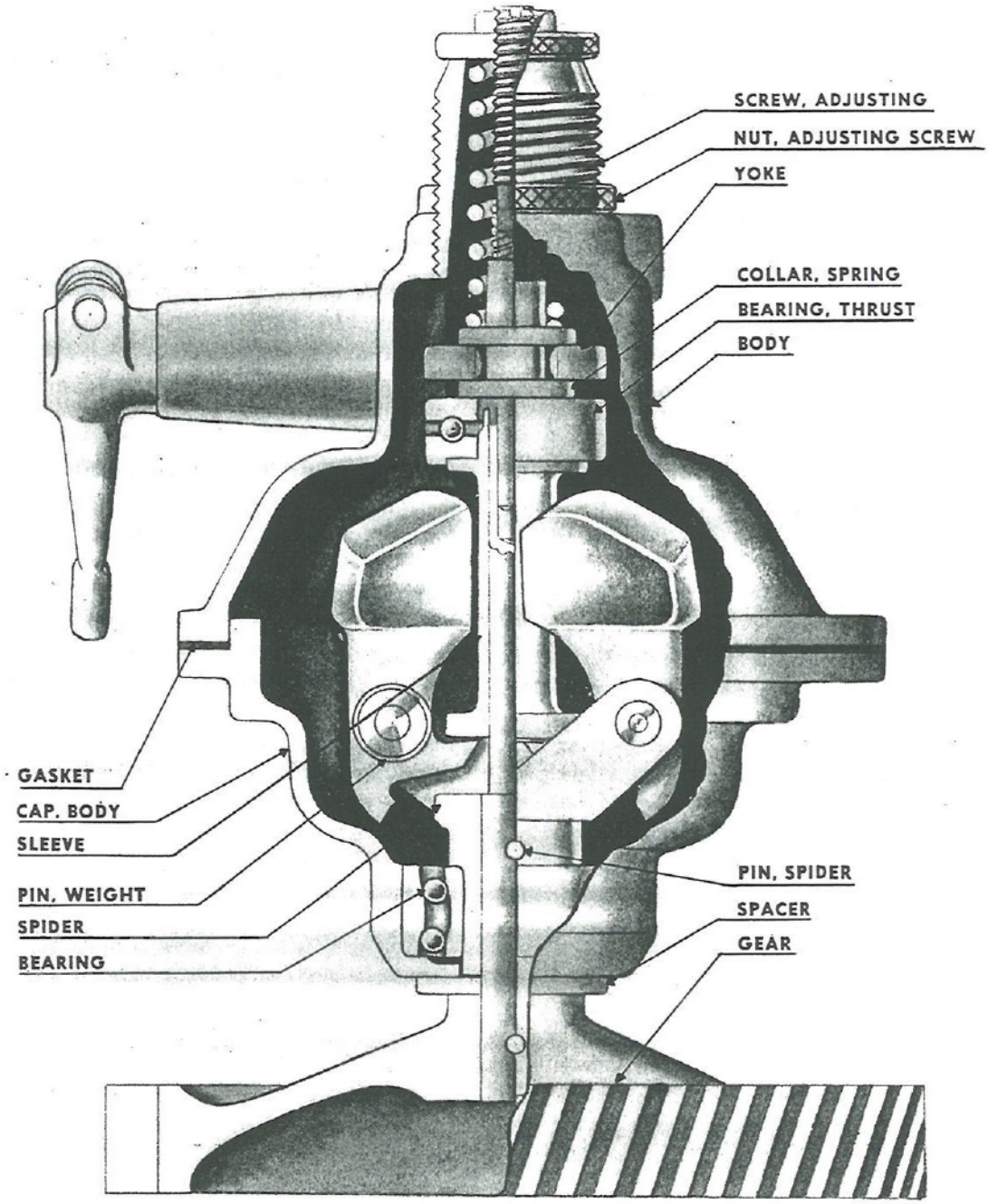


Fig. 142. Overspeed Governor Cut Away

SECTION XVI
CONTROLS AND REVERSING MECHANISM

171. CONTROL HANDLE. *a.* The control handle sets the direction of the engine rotation, and activates the air starting system. In the event the control handle fails to perform its proper functions, the following procedure should be undertaken.

b. Remove the two nuts holding the control box cover in place to expose the mechanism, shown in Fig. 143. The direction indicator is on the top of the direction indicator shaft. This shaft is in two parts connected with a tapered shear pin which is fitted into holes drilled in the socket at the top of the upper part of the shaft and in the upper part of the lower shaft. If the control indicator moves around without stopping, this shear pin is broken. Remove the shaft by pulling up both pieces of the shaft. Insert a new tapered pin. The two pieces of the shaft must be lined up so that the tapered pin will go into place by hand pressure. If it will not go in under hand pressure, the pin is being inserted from the wrong side. Turn it around.

c. The shaft is seated and held in position by off center lugs and grooves, and the shaft will only seat in one position. Rotate the shaft until it drops into position. Shear pins are broken most frequently by operation of the hand capstan in one position while the control handle is set for the opposite rotation.

d. If the control handle does not cause the air starting system to operate, inspect the pilot valve located on the wall of the control

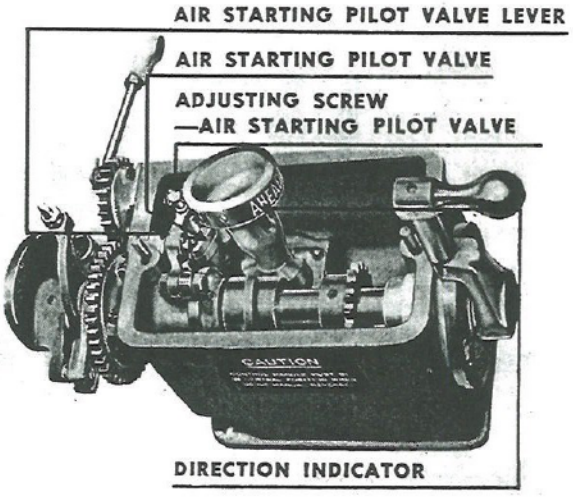


Fig. 143. Interior of Engine Control Box

box, as indicated in Fig. 143. The valve and valve spring are easily removed by taking out the two capscrews which hold on the top face plate. Clean out any dirt which may be between the valve and its seat, and look for signs of wear. If the valve or its seat is not true, seat the valve by using a fine grinding compound. Replace the valve stem and spring, the top plate, and reinstall the unit on the side of the control box wall. To operate the valve stem, push down a lever on the control handle. There is an adjusting nut at the end of this lever. After the valve is replaced, push the control handle over to the starting position. If the valve stem is not pushed all the way down, screw down on the adjusting nut until it is.

e. The gears shown outside the control box are timed at the factory. If these gears

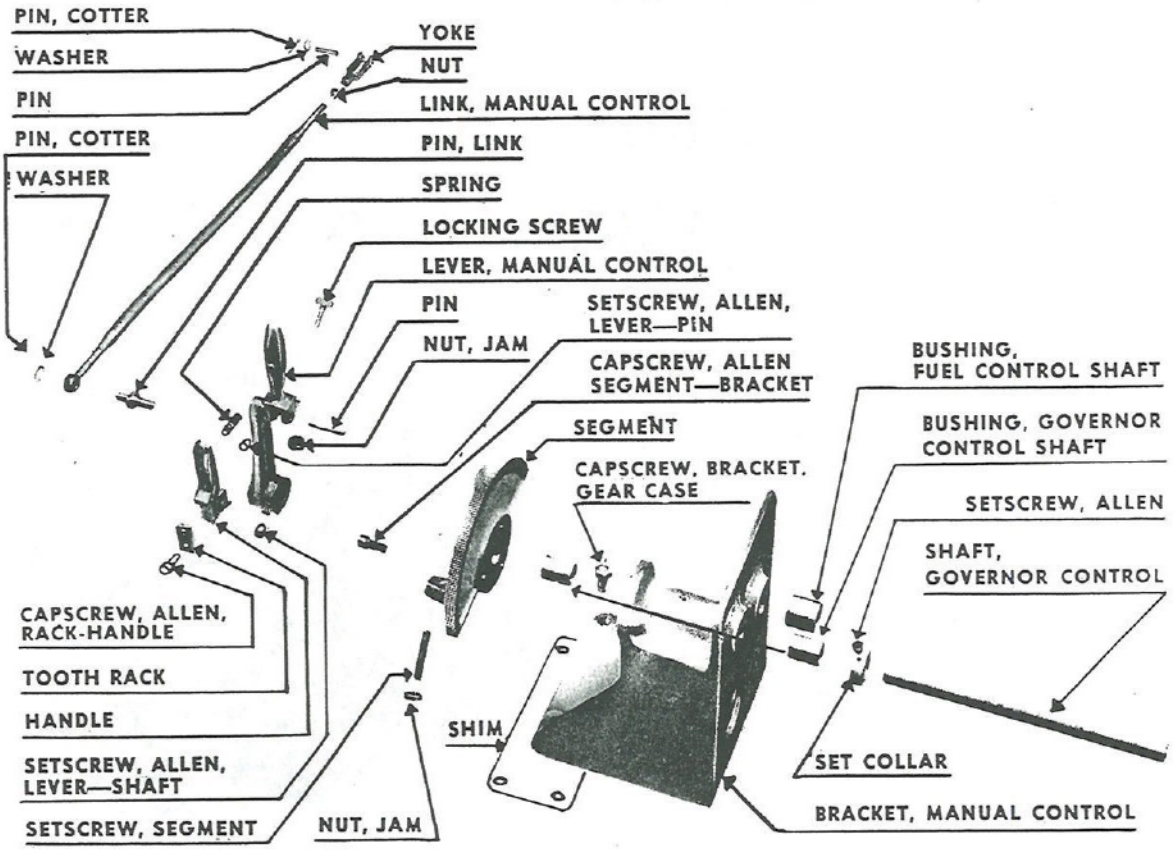


Fig. 144. Parts of Throttle Assembly

are removed, reassemble so that the center punched lines on their teeth are lined up.

172. THE THROTTLE. a. The throttle controls the governor and determines the speed at which the governor will maintain the engine. The throttle is shown disassembled in Fig. 144. The unit is supported by the bracket. This is bolted onto the engine frame through a short shaft, as shown in the lower right of the illustration. There is another hole with a bushing on the rack. This supports the front end of the fuel control shaft which extends the length of the engine. The link shown at the upper left connects directly with the governor located above and to the right of the throttle. With the exception of replacing a bushing, or the spring in the control handle, no work should be necessary on this unit if it is not abused and if it is properly taken care of.

b. Fig. 145 shows, disassembled, the link from the governor and the parts on the front end of the fuel control shaft. The end of the fuel control shaft is shown at the extreme left top. Two injection pump levers are shown. These are tightened on the fuel control shaft by the capscrews. The fuel control shaft is supported by bushings in brackets along the engine. The link from the governor is attached to a lever on the shaft, and is securely anchored with a capscrew. This unit should operate without trouble if properly handled. When the bushings start to become worn, examine the fuel control shaft and replace the bushings at the next opportunity.

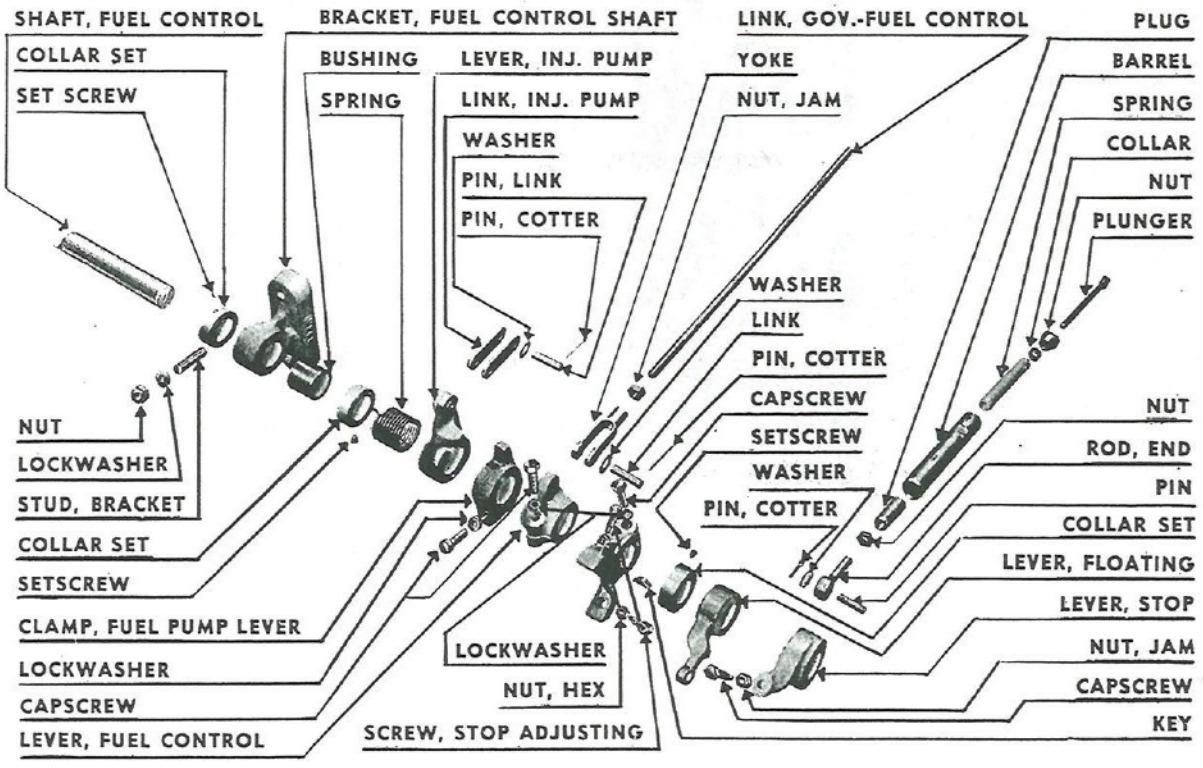


Fig. 145. Parts of Fuel Control Assembly

173. REVERSING MECHANISM. a. If the reversing mechanism should fail, maneuver the engine manually by using a bar in the hand-reversing capstan located underneath the reversing mechanism housing, as illustrated in Fig. 146.

b. Occasionally, it may be necessary to adjust the bumpers controlling the arc of the position of the cams in respect to the tappet rollers. Fig. 147 shows how this adjustment is accomplished outside of the mechanism housing.

c. In making the adjustment, remove the camshaft cover exposing the cams for No. 1 cylinder. With a spanner provided for this purpose, tighten the front bumper until resistance is felt. Manually operate the reverse mechanism with the capstan until the camshaft is in the extreme position aft, or as far back as it will go. Measure with a feeler gauge the distance between the rear face of an intake valve cam on the camshaft and the forward face of the bearing directly behind the

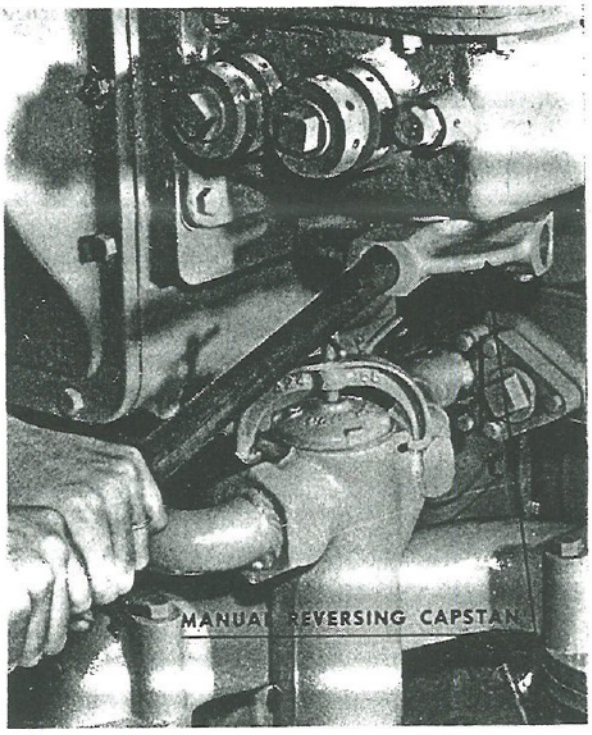


Fig. 146. Manually Reversing Engine with Capstan

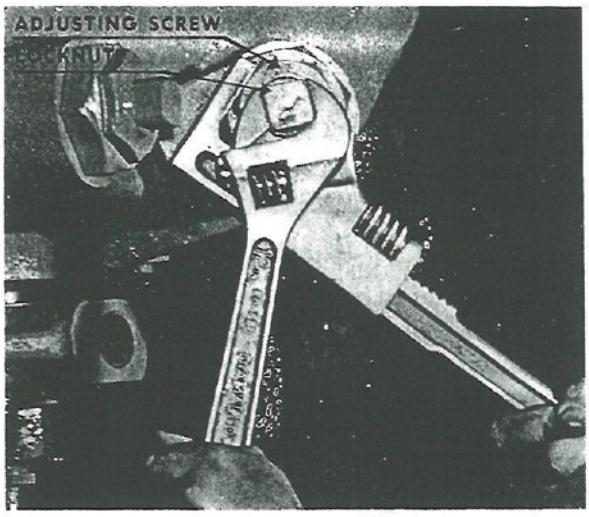


Fig. 147. Adjusting Bumpers on Reversing Mechanism

cam. Turn again on the capstan in the same direction until the eccentric strap can be felt to strike the bumper by the resistance. The camshaft will have moved forward slightly. Measure the clearance again between the same cam and bearing without putting a strain on the eccentric shaft. The clearance should be .030 to .040 of an inch more than the previous measurement. If this clearance is not obtained, screw the bumper in or out until this clearance is obtained.

d. Tighten the rear bumper until resistance is felt, and then use the capstan to move the camshaft to its extreme forward position. Measure the clearance between the forward face of the fuel cam and rear face of the adjacent bearing. Then operate the capstan until the camshaft strikes the bumpers, and measure the clearance. It should be the same as already stated. The forward bumper controls the clearance when the camshaft is forward, and the rear bumper controls the clearance when the camshaft is aft. When the eccentric is on dead center, there should be a minimum clearance of .005 of an inch between any one bearing face and the adjacent cam face in either direction.

174. DISASSEMBLING REVERSING MECHANISM. *a.* If the reversing mechanism fails, operate the engine with the hand capstan until repairs can be made. To disassemble the reversing gear mechanism it is first necessary to remove the front camshaft cover on the engine. The reversing strap is connected to the camshaft with a pin fitted with a cotter pin. Remove the cotter pin and take out the pin. Shut off the air supply at the air storage tanks. Disconnect the tubing to the balancing valve if the hydraulic governor is installed on the engine. Next remove all but two of the capscrews that hold the entire control box and reversing mechanism gear assembly to the side of the engine. Put a rope sling around the unit, and put on a strain before removing the balance of the capscrews. Remove these capscrews and pull the unit out away from the engine.

b. With a socket wrench remove the two capscrews inside holding the control box to the reversing mechanism housing. Likewise remove the two capscrews on the outside of the control box. The control box can then be taken off.

175. THE AIR MOTOR. *a.* To take apart the air motor unit on the reversing mechanism, remove the capscrews holding its housing. Disconnect the connections to the motor. The air motor valve is located in the handle, as shown in Fig. 148. Remove this handle by taking out the four capscrews in the flanged connection. Unscrew the hexagon or six-sided nut at the other end, and the valve will come out. Clean out any dirt between this valve and its seat, and replace the spring if it is broken or badly worn.

b. The air motor is disassembled by removing the capscrews on the face plates. The rotor is fitted with composition vanes which move in and out of their slots as the rotor rotates in an eccentric housing. Replace any vanes that are broken or damaged.

c. Remove the adapter plate as shown in Fig. 148 and inspect the ball bearing race. If not in good condition, replace. Inspect the gears. If they have been damaged, replace

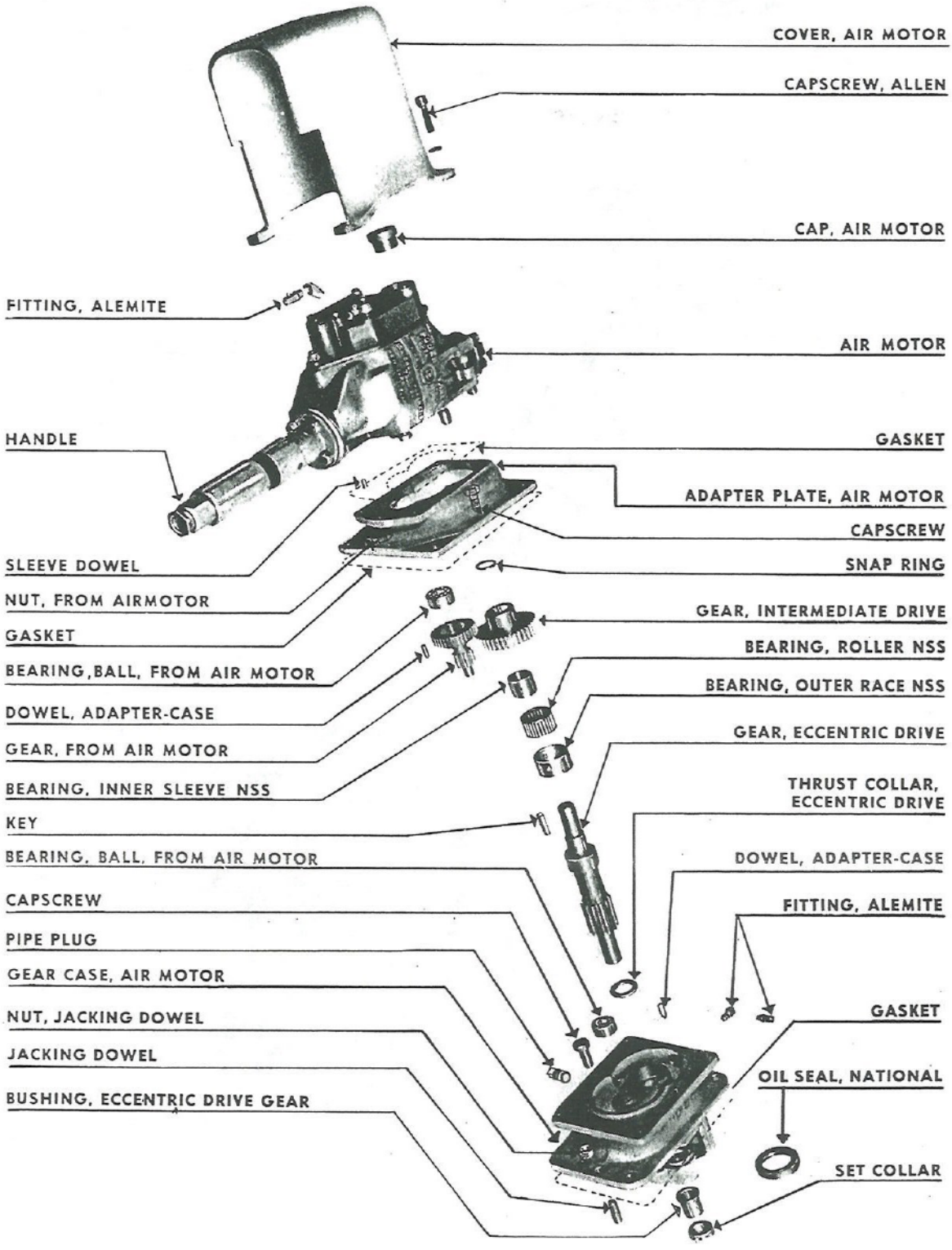


Fig. 148. Parts of Reversing Air Motor

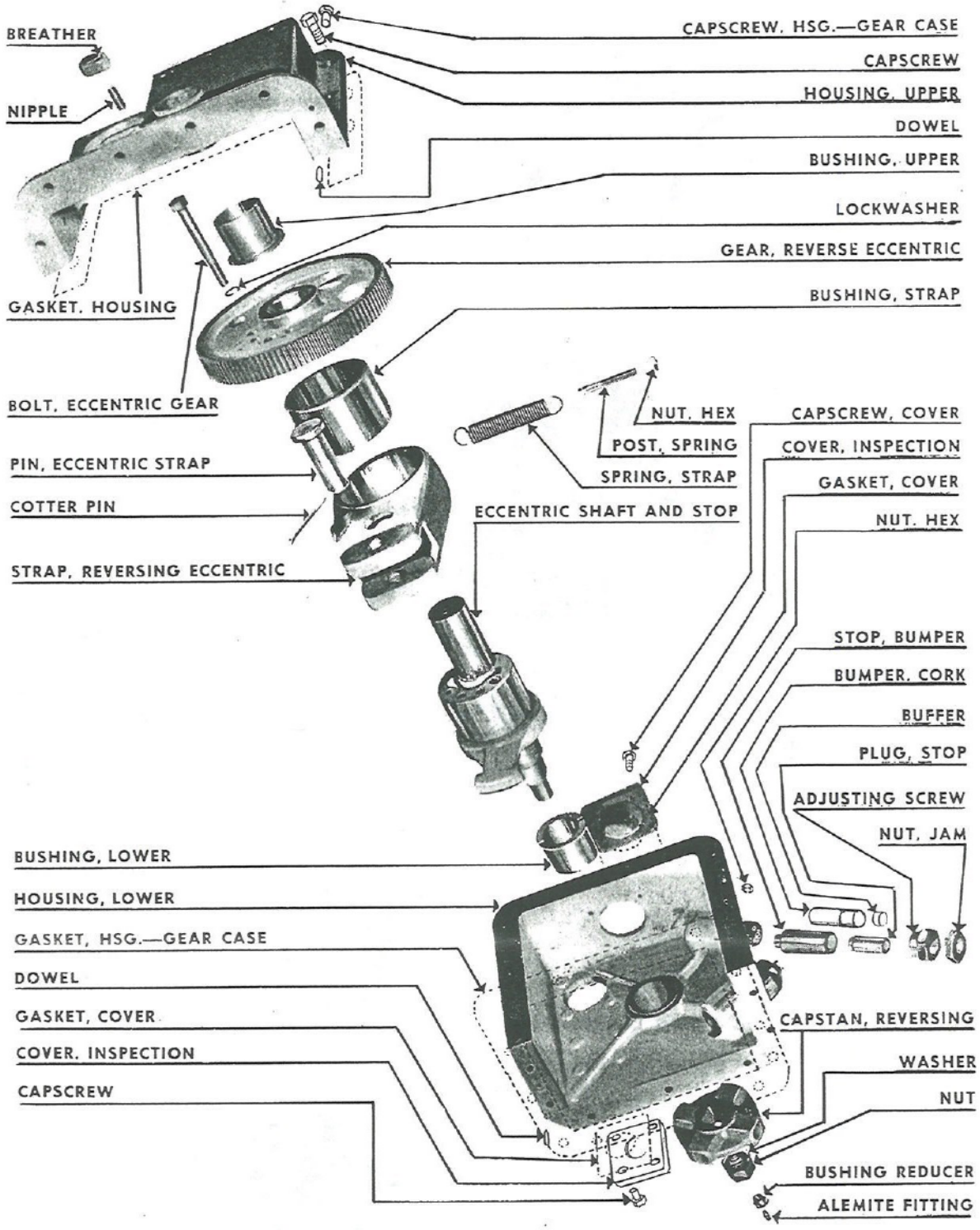


Fig. 149. Parts of Reversing Mechanism

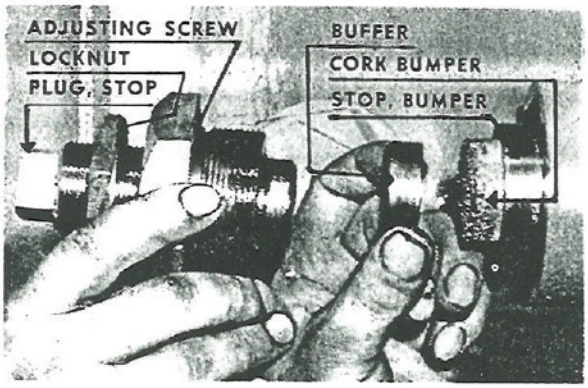


Fig. 150. Installing Cork Bumpers in Reversing Mechanism

them. Reassemble the unit in the opposite order it was disassembled, making sure to replace all gaskets and to tighten the capscrews securely.

176. REVERSING MECHANISM GEAR BOX. ***a.*** Ordinarily, the reversing mechanism gear can be examined by removing the inspection cover shown in Fig. 149. To disassemble the unit, remove the capscrews holding the upper and lower halves of the housing together. Remove the jam nut and washer holding the hand reversing capstan on the bottom of the housing. Inspect all bushings for excessive wear, replacing any that fit loosely.

b. If the eccentric shaft is hitting the bumpers with a loud noise, remove the bumper assemblies. Place these assemblies in the vise, take out the locking plugs, and remove the cork inside the housing. Replace with new cork. The cork will have to be compressed by screwing in the locking plug, as shown in Fig. 150.

c. Examine the coil spring that is connected at one end to the eccentric shaft and a spring post screwed into the housing wall. If this spring is broken, or lifeless, replace.

d. Reassemble all units as they were disassembled, and bolt together the two halves of the housing. Next, reinstall the air motor, making sure that the gear at the end of the drive shaft is properly meshed with the gear on the top of the housing. Bolt the air motor housing back on the unit. Fasten the control box to the reversing gear housing. Hoist the entire unit back into position against the engine and connect the eccentric strap to the camshaft with the linkage pin and cotter pin. Bolt the entire assembly back to the engine. Connect the tubing to the overspeed governor balancing valve if engine is so equipped.

SECTION XVII
CAMSHAFT, CAMS, AND TAPPETS

177. THE CAMSHAFT. The camshaft controls the action of the valves and fuel pumps. Under ordinary operating conditions the only maintenance work usually required on the camshaft is occasionally balancing it for fuel pump timing. However, under certain conditions it may be necessary to repair the camshaft gears.

178. CAMSHAFT GEAR. *a.* The camshaft gear drives the camshaft, and the governor and tachometer gears. It, in turn, is driven by an idler gear that is meshed with the gear on the front end of the crankshaft. In order to maintain the timing ratio of one complete revolution of the camshaft to two complete revolutions of the crankshaft, the gear on the end of the crankshaft is half the size of the camshaft gear. The location of the gears in the front of the engine is shown in Fig. 11. In Fig. 151 the camshaft gear is shown with the idler gear underneath it. The camshaft gear is in two parts, one is the hub and the other the gear ring which is bolted onto the hub as shown in this illustration.

b. The camshaft is timed by adjusting the position of this gear ring. If teeth in the camshaft gear are broken or worn, it is only necessary to replace the gear ring. If the camshaft gear hub is broken, remove bolts holding on gear ring and take off the ring. Take off the cotter pin and nut holding the hub onto the shaft and insert ½ inch studs about six inches along in the four tapped holes around the hub. Use a bar ¾ inch by 1¼ inches,

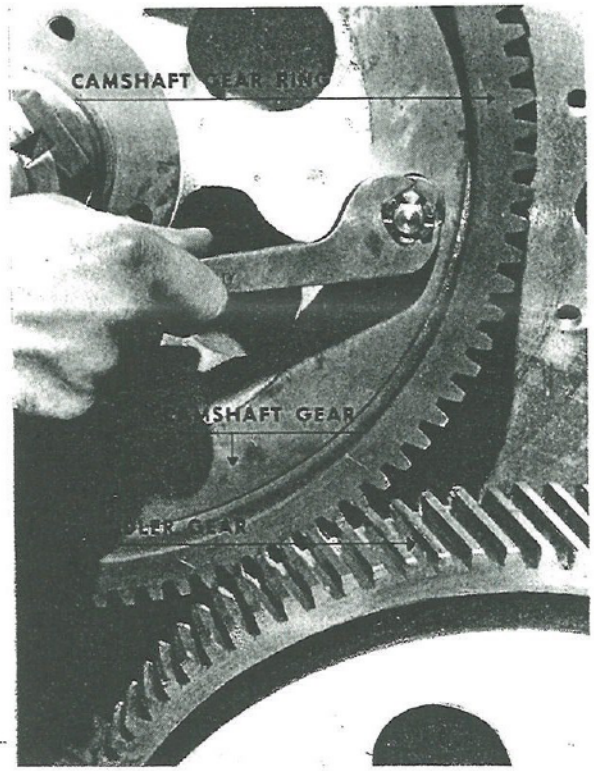


Fig. 151. Camshaft Drive Gear

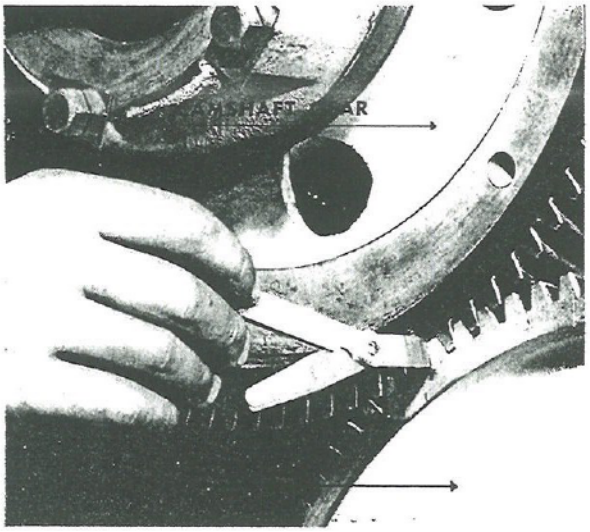


Fig. 152. Measuring Camshaft Gear Back Lash for Timing Adjustment

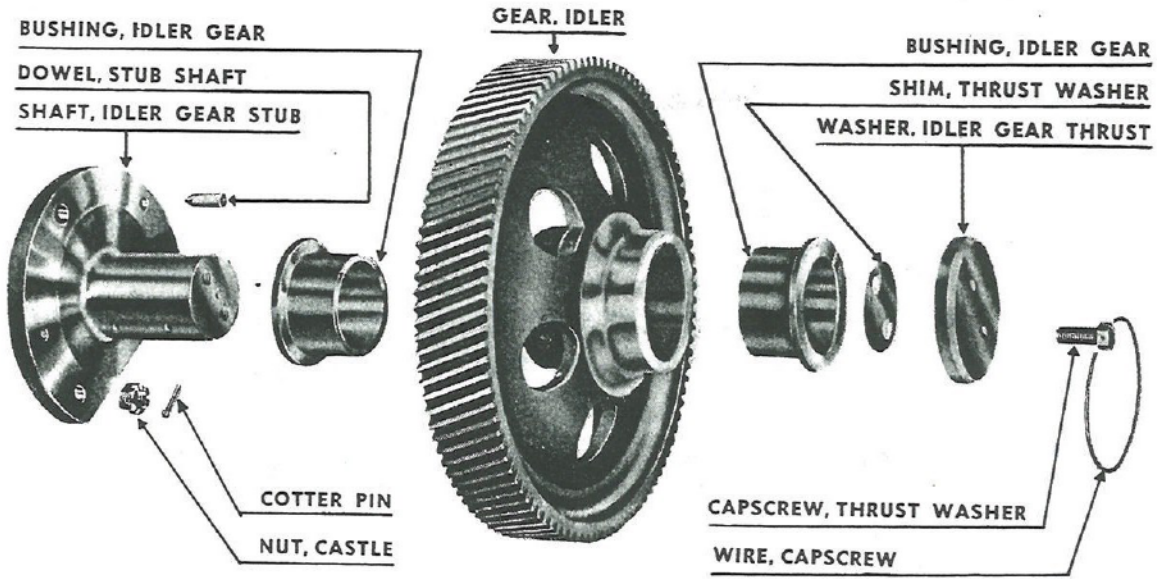


Fig. 153. Idler Gear and Shaft

about ten inches long, containing two holes 9/16 inch in diameter with 8⅛ inch centers. Use this bar over the studs as a puller. In assembling a new gear ring and hub, place the ring in position to line up the four holes in the hub with four holes in ring. Clamp the ring to gear hub, but do not drill, and ream the remaining two holes in the ring gear until the camshaft is timed.

c. Usually the only maintenance required is an examination with a feeler gauge of the backlash between the idler gear and the camshaft gear, as illustrated in Fig. 152. If the backlash exceeds the clearance given in Sect. VIII the camshaft gear ring must be adjusted to take up this backlash unless the condition of the gear ring teeth makes replacement of the ring necessary.

179. ENTRY INTO GEAR CASE. To get into the gear case, remove the connections to the attached accessories which are mounted on flanges, and then remove the accessories. Remove the pin connecting the reversing mechanism strap to the camshaft and take off the reversing mechanism. Unbolt the gear case from the cylinder block to the base.

180. IDLER GEAR. a. The idler gear is shown in Fig. 153. Unlike the camshaft gear, the idler gear does not have a removable gear ring, but is a solid piece. As seen from the illustration, the idler gear shaft is a short stub shaft fastened to the front of the engine frame by dowels. The bottom of the illustration shows how the idler gear meshes with the crankshaft gear. Besides driving the camshaft gear, the idler gear also meshes with the gears operating the water pumps, the lubricating pump, and other accessories.

b. The idler gear cannot be adjusted for backlash. The other gears meshing into it are positioned to provide the proper clearance. The idler gear and crankshaft gear must have the proper backlash, as stated in Sect. VIII, and if the backlash exceeds the maximum clearance it may be due to the fact that the idler gear teeth are badly worn. This necessitates a replacement. If the crankshaft gear teeth are worn, the replacement of this gear must be done in a shipyard.

c. Excessive idler gear backlash may be caused by the wear on the bushings. This condition will result if something stops the flow of lubricating oil to the tubing which drops oil

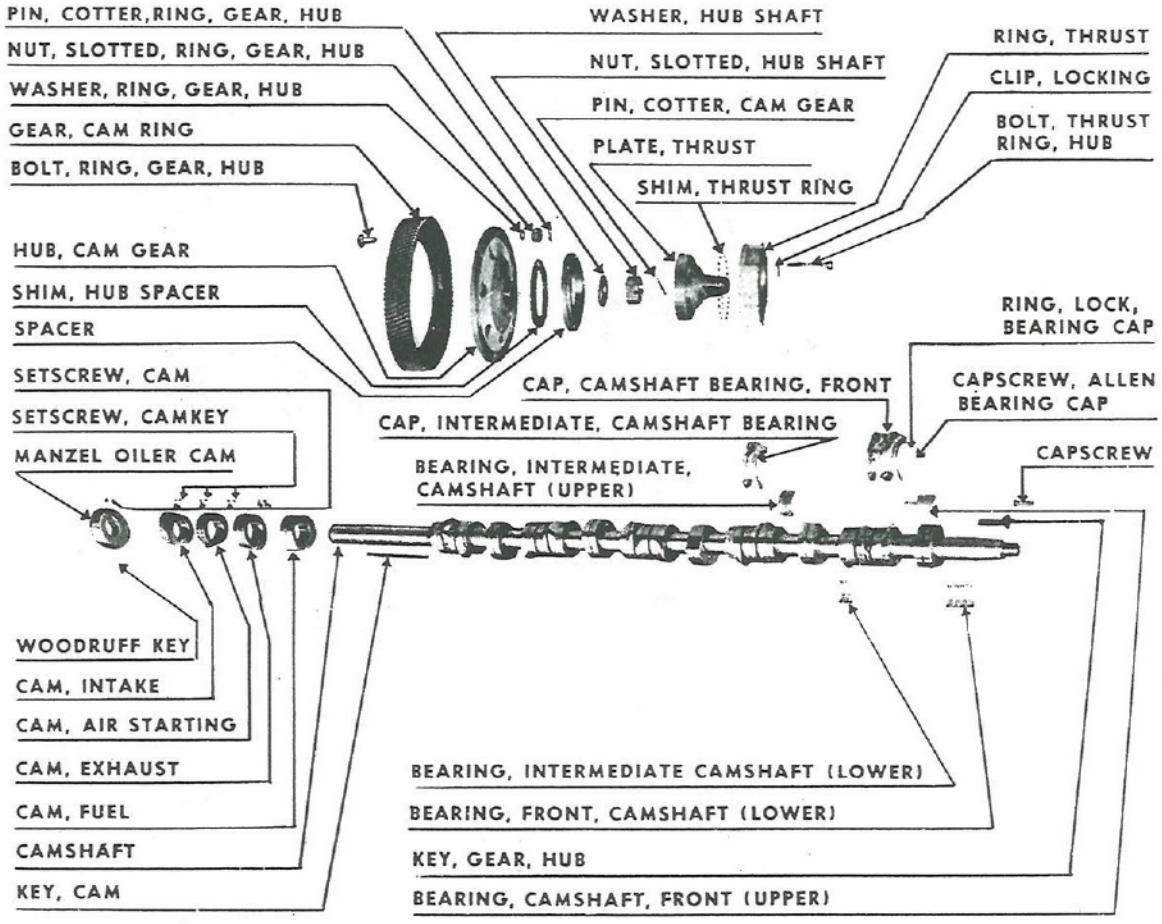


Fig. 154. Camshaft and Cam Parts

into the gear train. Remove the capscrews holding idler gear thrust washer, and remove the washer and shim. Draw the gear off the stub shaft and remove the bushing. Check their condition carefully, and check their clearances with the table in Sect. VIII. If it is necessary to replace the bushing, be sure the hole through the center of the gear is free of dirt and burrs. Fit in the bushing, making sure that the proper clearance is obtained. Notice that there are two bushings, one on each side of the gear hub. Replace the shim and the thrust washer, and tighten the capscrews. Use a feeler gauge to check the clearance between the end of the outside bushing and the idler gear washer. If it is not according to the clearance given in Sect. VIII, remove the washer and add or remove shims until the proper clearance is obtained. Then replace washer and capscrews, and use a new piece of wire through the holes in the capscrew heads to anchor them.

181. THE CAMSHAFT. The parts of the camshaft are shown disassembled in Fig. 154. The cams are made of a special steel, and are securely locked onto the shaft. Every six months an inspection should be made of the camshaft bearing with a feeler gauge, consulting the table of clearances in Sect. VIII. Replace any bearings that exceed the maximum clearances.

182. REMOVING A CAMSHAFT BEARING. Remove all covers over the camshaft and the

copper lubrication tubing from the camshaft bearing caps to be worked on. Remove the two nuts securing the bearing caps, and remove the upper bearing cap. Unscrew the two retaining capscrews and locking rings that hold the bearing shell inside the cap, and remove the shell. Bar the engine over slowly and the lower bearing shell will roll out. If all camshaft bearings are to be removed it is necessary to remove and replace one at a time. Otherwise the camshaft will have no support to hold it up, making replacements difficult.

183. REPLACING CAMSHAFT BEARINGS. ***a.*** Before starting to replace, examine both the upper and lower camshaft bearing shells. Notice that the upper shell has a hole which must line up with the lubricating oil hole in the upper bearing cap. The lower shell does not have this hole. Pour some clean lubricating oil on the camshaft, and place the lower bearing shell on the top of the shaft in proper position in regard to markings. Press the shell down with the fingers and then rotate the bearing shell around the shaft and into the lower bearing cap. Install the upper bearing shell in the bearing cap. Replace the two locking rings, and tighten down the machine screws after making certain that the lubricating oil hole in the upper bearing cap and shell are lined up and that the two shells fit together in the proper position. Like the main and connecting rod bearings, camshaft bearings on Enterprise engines are precision constructed, and do not require fitting or shimming.

b. Reassemble the bolts and nuts in the camshaft bearing box according to their numbers, and tighten securely. Replace the lubrication oil connection to the upper half of the camshaft cap. Temporarily secure the camshaft cover, and run the engine for ten minutes. Then remove cover and feel replaced bearings. If no excessive heat is felt, secure the cover.

184. THE TAPPETS. ***a.*** As previously explained, the tappets are enclosed in guides. Every 30 days remove camshaft covers and inspect tappets and rollers. The clearances of the tappets in their guides should be checked with a feeler gauge, referring to the table of clearances in Sect. VIII. Raise the tappets with a pry bar and check the rollers for freeness on their pins and in the slots. The fuel pump tappet should return to position quickly due to the force of the fuel pump spring.

b. If inspections show that the tappets are sticking, or chatter, they must be inspected. The air, intake and exhaust tappets are housed in one cluster for each cylinder. Disconnect all oil lines to the cluster. Remove the nuts holding the cluster to the crankcase. Before removing place small pins in the holes provided in the exhaust and intake tappet guides to support the tappets as they are drawn away from the cams. Inspect the bushings and check their clearances with Sect. VIII. Replace bushings that do not meet these specifications. Test the springs for elasticity. Inspect the rollers, replacing rollers and pins that do not meet with table of specifications. One end of the roller pin is ridged to prevent it from turning. Test to see that the ridges are holding the pin stationary. Check the clearances between the tappets and the guides. If excessive, drive out the old guide liners and tap in new ones. On reassembly, be sure that the dowels that mate with the slot in the crankcase have not fallen out. Before tightening the nuts securing the cluster to the crankcase, be certain the flats of the dowels fit well in the slot.

c. To remove the fuel tappet, first disconnect oil lines to the fuel pump. Remove fuel pump. Disconnect lubricating oil lines to the tappet. Draw out tappet and guide, supporting tappet by placing pin in the hole in the guide. Test all clearances and replace liners or bushings that show excessive wear. In engines using the hydraulic governor, sealing rings similar to piston rings as shown in Fig. 58 are installed. These rings prevent the escape of compressed air that is used to lift the tappets off the cams if the overspeed governor operates. Examine these rings to be sure they are in good condition, maintain a close fit, and seat properly in their grooves. Replace any rings that show wear.

SECTION XVIII

FUEL TRANSFER PUMP AND TWO-WAY REVERSIBLE LUBRICATION OIL PUMP

185. DISMOUNTING LUBRICATION OIL PUMP. Remove all pipes from the pump by disconnecting the flange connections. Put a rope sling around the pump and secure the sling to a chain hoist or block and tackle. Take up the slack in the hoisting equipment to hold the pump in place while the capscrews are removed. Take out the capscrews that secure the unit to the gear case, and hoist the pump off the engine.

186. DISASSEMBLING LUBRICATION OIL PUMP. Although ruggedly designed and housed, lubrication oil pump parts are precisely fitted, as shown in Fig. 155, and require careful handling. Remove the upper chamber of the pump by removing the capscrews. Lift out the four poppet check valves. Remove the lower chamber by taking out the capscrews, and lift out the four poppet check valves located in this chamber. Remove the capscrews securing the front face, or pressure regulation valve side, and lift it out. Remove the driver gear from the pump shaft by driving out the tapered pin and tapping the gear off the shaft. Remove the rear face on the shaft housing side by taking out the capscrews securing it to the pump. Slide the face off the shaft.

187. DISASSEMBLING BOTH PUMPS. *a.* The lubricating oil pressure pump and the lubricating oil sump, or scavenger, pump are housed together and operated by one shaft. These steps described here are for the disassembly of the two pumps. The parts must be kept separate. The parts of the pump are shown disassembled in Fig. 156.

b. Remove the matched set of gears from the sump pump side of the housing. Keep them together with the shims and other parts. Remove the rotary nut, washer, and shims to take out the second matched set of gears which operate the high pressure pump. Put this set of gears aside, carefully preserving the shims, and remove the splined drive shaft. Take out the set screw located about midway in the lower part of the pump and remove the fixed shaft.

c. Wash all the parts thoroughly, remove all old gaskets. Inspect the poppet check valves for correct seating. Use a little blueing on all the valve edges and revolve them around in their own seats. Inspect to see if the blueing is transferred all around the valve seat. If spots on the seat will not take blueing off the valve use a 45° reamer to make a new seat. Check the work by the blueing method. Check all of the eight poppet valve seats in this manner.

d. Inspect the drive shaft for excessive clearance in the pump bushings and in the bushings of the shaft housing, or rear face plate. If the shaft is loose enough to slap around, tap out the old bushings and replace with new ones. Ream out the new bushing to size, and fit the shaft into them. Make sure that the fit is not too loose but not tight enough to bind the shaft when turned.

e. Inspect the front and rear faces of the

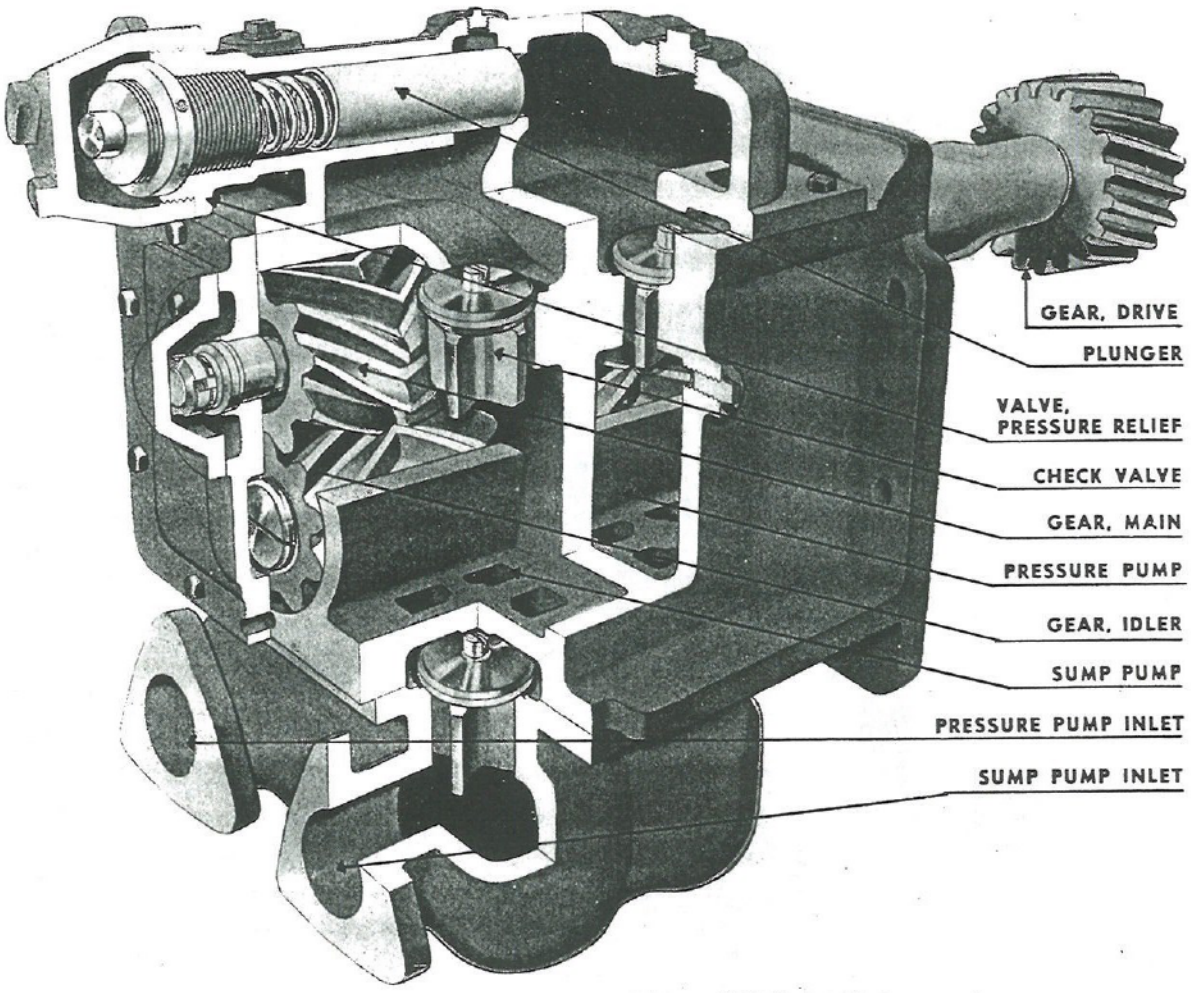


Fig. 155. Lubrication Pump Cut Away

pump. If the gears have cut a path in either face, machine them down to a smooth surface again. Inspect the matched sets of gears. If a gear is damaged, replace with a new set of matched gears. Do not attempt to salvage an old one for use with a new gear. They will not match.

f. Inspect the bushings of the lower gears of both the pressure and sump pumps. If they fit loosely on the fixed shaft, tap them out and replace with new bushings. These must be reamed and fitted, as already explained. When all parts have been inspected and repaired, the pumps are ready for reassembly.

g. While the unit is being examined, check the pressure regulation valve. After the front face of the pump is removed, completely unscrew the adjusting screw on the pressure regulation valve. Take out the spring and check valve inside it. Check the seat of the valve, using blueing for the test. If the valve does not seat properly, put a small quantity of grinding compound on the valve and rotate back and forth until a new seat is ground. Remove all traces of grinding compound and check with blueing, repeating this process until a perfect seat is obtained. Reassemble the pressure regulating valve in the opposite order it was taken apart.

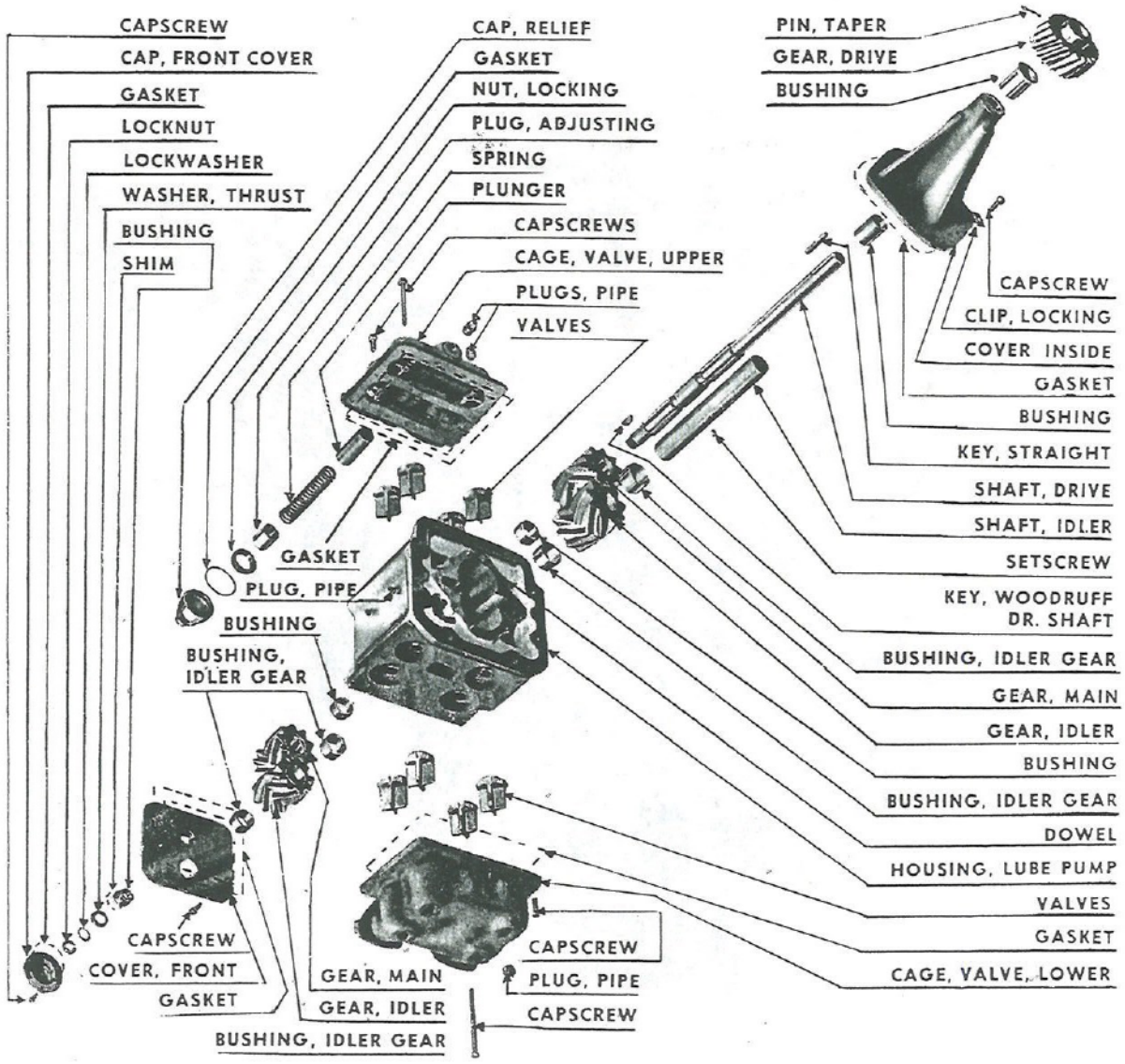


Fig. 156. Parts of Lubrication Oil Pump

188. REASSEMBLING THE PUMPS. ***a.*** Replace the fixed shaft and fasten it with the set screw. Replace the splined drive shaft with the long end of the shaft sticking out the sump pump side. Slide on the matched sets of gears at one time. Because of the shape of these gears they will not enter the housing separately but must be kept in mesh as they are installed. Oil the gears thoroughly. Make a new gasket out of .006 of an inch gasket material for the rear face of the pump shaft housing, using shellac to hold the gasket in place. When the gasket seal is well dried, coat the other side with a little graphite mixed with lubricating oil. Slide the rear face or shaft housing over the splined drive shaft until it connects to the pump. Be sure the dowels in the pump line up with the dowel holes in the rear face. Then insert the capscrews and tighten securely.

b. Replace the drive gear on the shaft so that the hole for the tapered pin is in line. Drive the tapered pin in snugly. Replace the

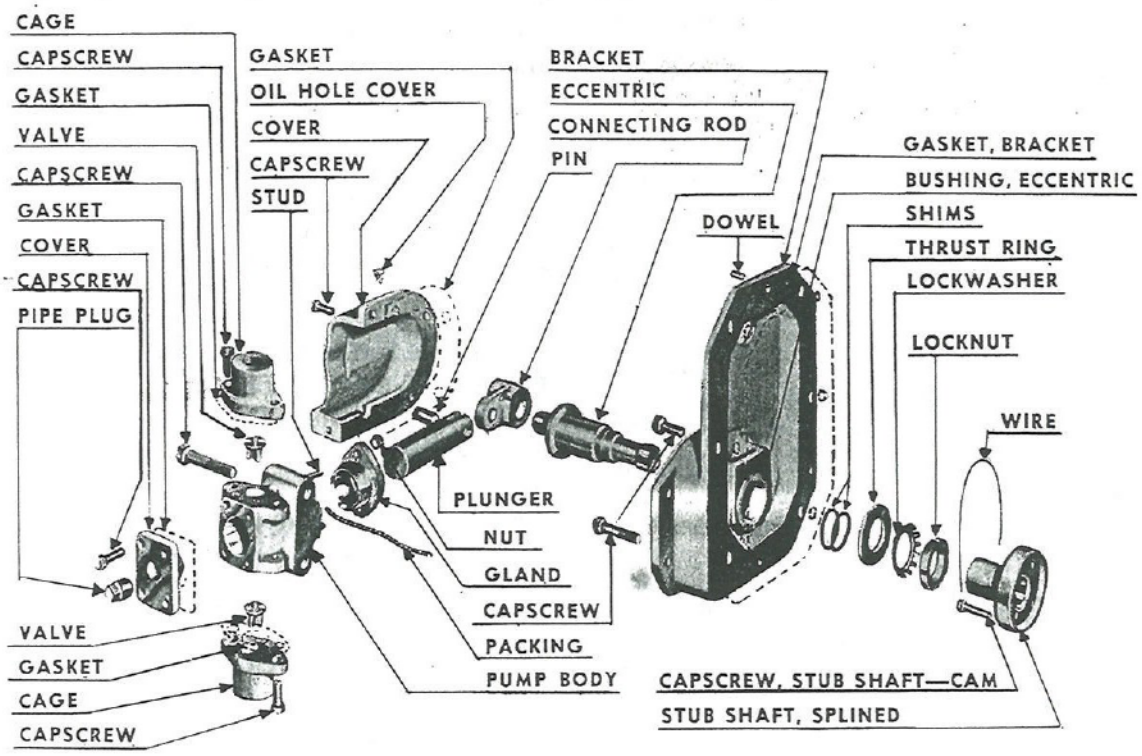


Fig. 157. Parts of Fuel Oil Transfer Pump

shims on the other end of the shaft followed by the washer and nut and tighten up. Test the shaft for clearance. This shaft should have .004 to .006 of an inch free travel from one end to the other. Add or remove shims until this clearance is obtained.

c. Make a new gasket for the front face from .006 of an inch gasket material and affix. Replace the capscrews and tighten them securely. Make a new gasket from 1/32 of an inch gasket material for the lower chamber. Shellac it in place, and coat the other side with graphite. Replace the four ball check valves, secure the chamber to the pump body, and tighten the capscrews securely.

d. Prime the pump by pouring about a half gallon of clean new lubricating oil over the top of the pump into the holes in which the ball check valves are located, and fill all chambers. Holding the pump in a rigid position, replace the four ball check valves into their seats. It is essential to hold the pump in a rigid position to prevent the ball check valves from being unseated and losing the prime. Prepare a new gasket for the upper chamber from 1/32 of an inch material, and shellac into place. Coat the dry side with graphite and lubricating oil mixture, and replace the top of the pump and the capscrews. The capscrews must be well tightened down. Reinstall the pump on the engine. When the engine is started the lubricating oil pressure must be regulated again to maintain a pressure of 25 to 28 pounds when the engine is thoroughly warmed.

189. DISASSEMBLING FUEL TRANSFER PUMP. a. After shutting off the flow of fuel from the fuel storage tank and the fuel accumulator tank remove all piping and tubing connected to the suction and discharge sides of the fuel transfer pump. This is done by taking out the capscrews securing the suction and discharge flanges. Remove the cap-

screws holding the pump case to the engine and lift the pump away from the engine.

b. Take out the capscrews securing the housing cover. Remove the cover. Remove the two capscrews securing the pump plunger to the case and pull the pump plunger out of the cylinder. Lift the plunger and connecting rod off the eccentric crank. Remove the two nuts securing the packing gland sleeve, and after taking off this sleeve pull out the pump gland packing. Take out capscrews in the cover and lift off the cover. This fuel transfer pump is now disassembled as shown in Fig. 157.

c. Examine the plunger for any scoring or deep scratches. If any are found, stone down the plunger until the surface is smooth. Fit the plunger into its cylinder and check the fit. If the fit is fairly snug the clearance is satisfactory, but if a loose fit is found, a new plunger and pump body should be used.

d. Examine the connecting rod bushing on the eccentric crank. If the fit is loose, replace with a new bushing reamed until it fits the eccentric crank pin without binding in any place. Also inspect the plunger bushing and replace if necessary. To replace, drive the ridged pin out to disconnect the plunger from the connecting rod. Press out the old bushing and press in the new one. The new bushing must be reamed until it fits the ridged pin snugly, but without binding.

e. Inspect the seating of the check valves. Place a little blueing on the valve edges and seat the valve, rotating it back and forth. Remove the valve and if the blueing is not seen all around the seat, grind in a new seat by putting valve grinding compound on the valve and rotating it around the seat. When a perfect seat is ground remove all traces of the grinding compound.

f. Before reassembling the fuel transfer pump, check the bushing holding the eccentric crank. Find the end clearance with a feeler gauge. If the clearance is more than .006 of an inch, or if the bushing is worn, disassemble the eccentric crank and replace the bushing. Bend back the locking washer and remove the lock nut, thrust ring washer and shims. Take the shaft out of the bushing housing. Press out the old bushing and press in the new one, reaming it to fit. Oil the eccentric crank thoroughly and replace it in its housing. Replace the shims, thrust ring washer, locking washer and locking nut. Tighten up the nut and check the end clearance. If the clearance is not .006 of an inch, remove the nut and washers and add or remove the necessary amount of shims. When the clearance is correct and the nut tightened, bend the locking ring tip into the grain of the locking nut.

190. REASSEMBLING THE FUEL TRANSFER PUMP. a. Wash all parts of the pump thoroughly. Be sure the oil hole in the housing is open. Drive the ridged pin through the connecting rod and plunger until it is flush on both sides. Install the packing gland sleeve on the pump and insert the plunger into the cylinder. Place the connecting rod on the eccentric crank pin and replace and tighten the capscrews securing the pump cylinder to the housing. Place new packing in the packing gland, but DO NOT TIGHTEN THE GLAND SLEEVE. Replace the pump cover and secure with capscrews. The pump is ready to replace on the engine.

b. Remove the last camshaft cover door. Carefully insert the splined shaft into the proper entrance with the spline lands and grooves matching the female counterpart on the end of the camshaft, pushing the shaft home when they match. Line up the dowels in the engine block with holes in the pump case and replace the pump, tightening the capscrews that fasten it to the engine.

c. Connect the suction and discharge cages on the pump, checking the check valves for correct position. If the old gaskets are not in good condition, replace them before inserting and tightening the capscrews.

d. Replace all piping and turn on the fuel at the accumulator tank and the storage tank. Tighten the packing gland sleeve slightly and when the engine is running tighten the sleeve further until only a drop leaks out on each stroke of the piston.

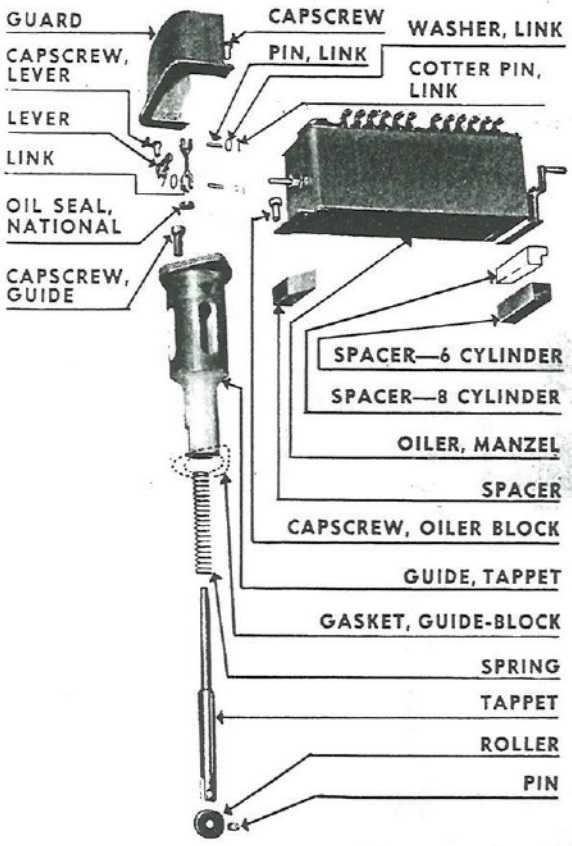


Fig. 158. Cylinder Oiler Tappet

191. THE CYLINDER OILER. a. The tappet for the Manzel cylinder oiler should be inspected every thirty days. Clearances given in Sect. VIII for the intake and exhaust valve tappets apply to the oiler tappet. To remove the tappet, first take out the four capscrews securing the guard over the lever arm on the end of the oiler. Remove the capscrew fastening the lever to the oiler shaft. The balance of the lever assembly can be taken apart by removing the cotter pins and pulling out the pins connecting the links. The tappet guide is held in place by two capscrews. Remove these and the guide, after which the tappet assembly can be pulled up from the camshaft. The tappet is shown completely disassembled in Fig. 158. Inspect all parts, replacing any that show excessive wear. Reassemble and replace the tappet assembly in the opposite order it was removed.

b. The oiler is secured to the engine block with capscrews. As the housing is merely a large metal box, it should never be necessary to remove the oiler as a unit. Each individual pumping unit in the oiler can be repaired individually. In Fig. 159 one of the pumping units is illustrated. The discharge valves can be lifted out without disturbing the rest of the assembly. Disconnect the tubing leading to the engine. Unscrew the discharge connection and lift out the renewable valve cages. Inspect the balls, checking their seating with blueing. If reseating is required, apply a little valve grinding compound to balls and rotate them around in their seats. Inspect the spring, testing its elasticity, replacing if necessary. Reassemble valves in cages and drop into place, replacing discharge connection. If the valves are too badly worn for repair, they should be replaced. To remove a complete pumping unit, take out the screws securing the sight glass and remove the glass. Disconnect the tubing to the engine. Unscrew the two securing capscrews which hold the pump to the oiler cover. Pry up the front end of the unit with a screw driver. Pull unit forward as far as possible and at the same time tilt the front end upward. The pumping unit will then lift out. Clean thoroughly. It may be necessary to unscrew the suction screen from the bottom of the suction tube and blow out with air. At the same time check the seating of the suction valve ball, reseating if necessary. Before replacing the unit, or installing a new one, pull the crosshead down as far as possible and slip unit into place, tilting lower part toward the front of the reservoir until crosshead slips over the eccentric. Push into place, replace securing capscrews and replace the sight glass. If the gauge glass on the side of the oiler leaks, unscrew the cap plug above the gauge glass and tighten up on the small plug underneath. If oiler lines to the engine are disconnected, they must be filled with oil again before starting engine. Open feed regulating screw to the widest position and turn hand crank about twenty times. Readjust feed regulating screw to deliver two drops per stroke after engine is started.

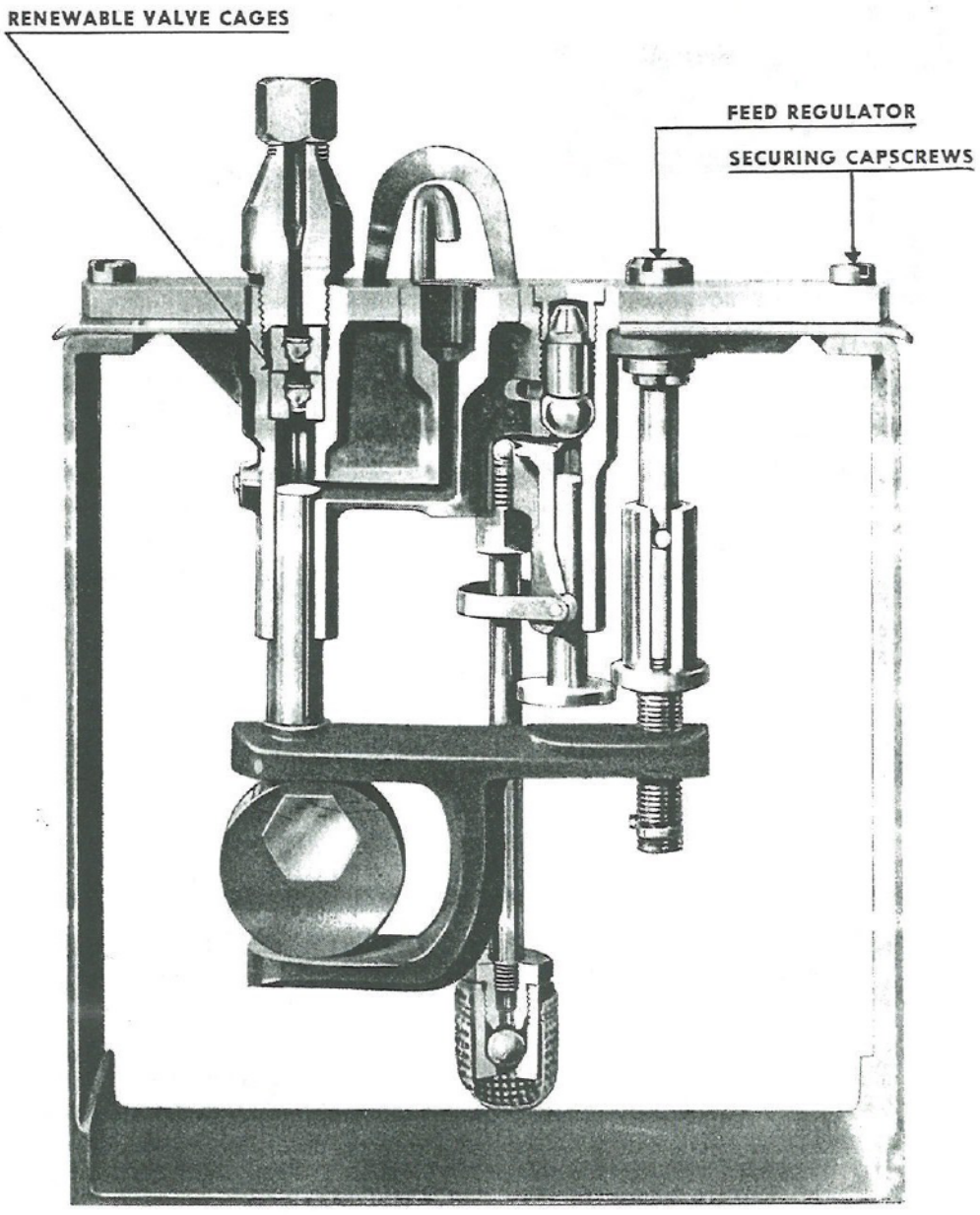


Fig. 159. Removal of Cylinder Oiler Pumping Unit

SECTION XIX
AIR COMPRESSOR AND UNLOADER

192. COMPRESSOR AND UNLOADER. a. The compressor and unloader unit is located at the rear end of the engine, and is driven by "V" belts from the flywheel. The sole function of the compressor is to maintain an adequate air pressure in the compressed air starting tanks. When the tanks are up to a pressure of 250 pounds the unloader prevents the compressor from delivering any more air into the tanks. Because the compressor is a highly precise piece of equipment, it should be operated only when needed. It can be stopped by disengaging the clutch. With the exception of the fact that the compressor depends on an outside source of power instead of the combustion of a fuel, it is similar to a two cylinder internal combustion engine and has its own lubrication and cooling systems.

b. The compressor is shown in Fig. 160 partly cut away to reveal the working parts. "V" belts fit into the grooves on the compressor sheave. On each side of the flywheel idler pulleys are mounted on the compressor base. These pulleys rotate on short stub shafts which are secured to flanges with slots for bolts and nuts permitting the adjusting of the belt tension to keep out slack, as shown in Fig. 161. Note that the idler pulleys are provided with grease fittings. These should be serviced weekly. As belts grow older they slacken. It is important that they always be kept tight. The belts are driven by contacting the top of the engine flywheel.

193. COMPRESSOR CYLINDERS. As shown in Fig. 160, the compressor contains two pistons, a large one called the low pressure piston and the smaller one called the high pressure piston. Each of these cylinders has an intake, or suction valve, and a discharge valve. Air is drawn into the compressor through a port to which is fitted a felt type air cleaner, as shown in Fig. 162, into the low pressure cylinder where a large quantity is compressed to about 80-85 pounds. This moderately compressed air then is forced out through the discharge valve of the low pressure cylinder, and goes through a manifold in the cylinder head to two loops of tubing fitted with cooling fins. These are located behind the flywheel. Here the air is cooled before it enters the intake valve of the high pressure cylinder. The cylinder compresses the air to 250 pounds and forces it to the storage tanks through the high pressure discharge valve.

194. THE COOLING SYSTEM. To protect the compressor from high temperatures, an air cooling system is used. It consists of two loops of finned cooling tubes, having common inlets and outlets through the flanged connections located underneath the cylinder head next to the flywheel, as shown in Fig. 160. The compressor sheave, in addition to turning the compressor, is also a part of the cooling system. It is built with flat spokes angled to provide a high pitch. These pitched spokes serve as fan blades to throw air onto the finned cooling tubes. Because of this function of the flywheel spokes, it is important that the compressor always be installed so that the flywheel rotates in the direction indicated by the arrow on one of the spokes. If the direction of rotation is reversed, the spokes will draw air away from the cooling tubes. It is also important that extreme care be used at all times to prevent the fins from being bent or damaged.

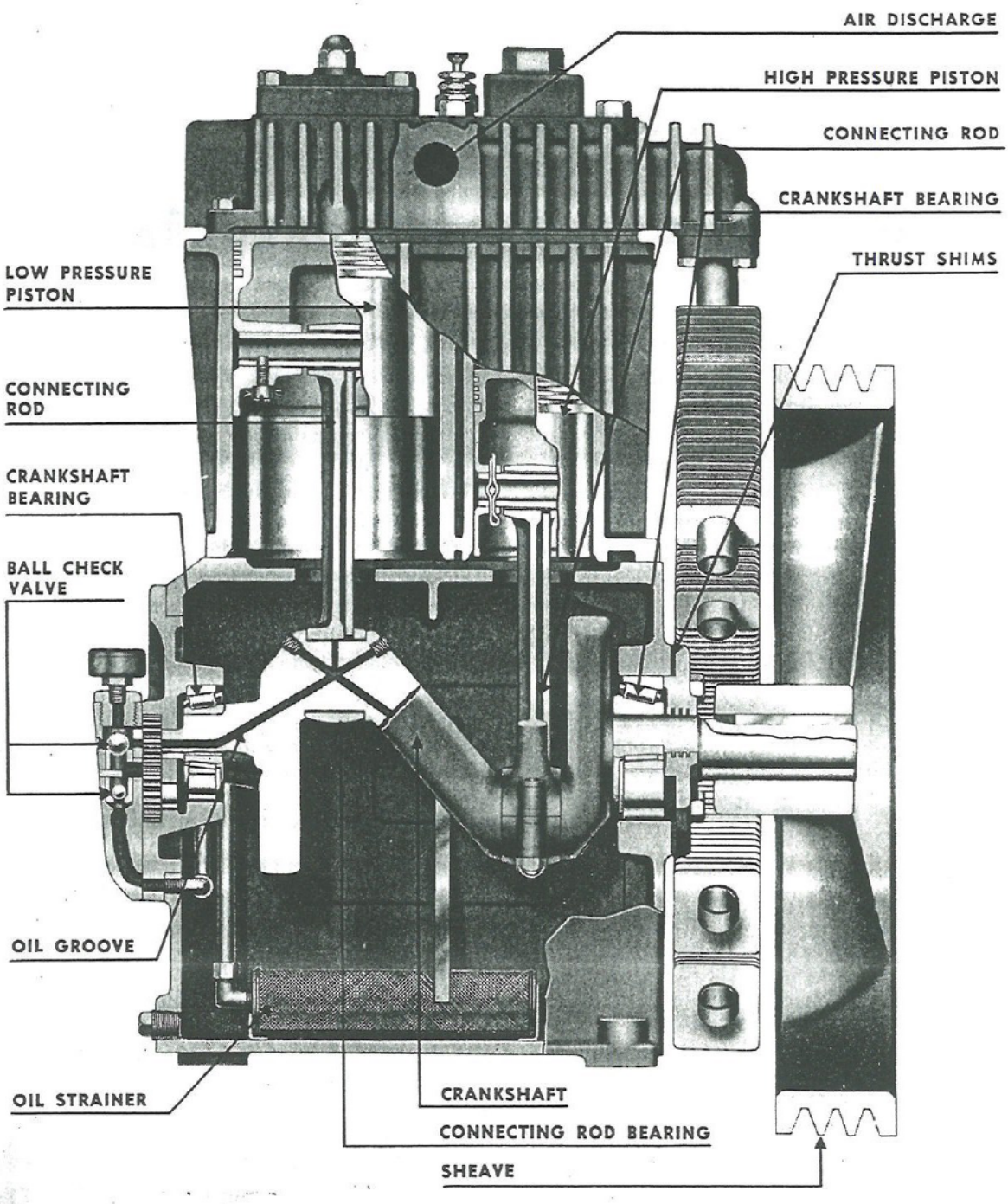


Fig. 160. Air Compressor Cut Away to Show Working Parts

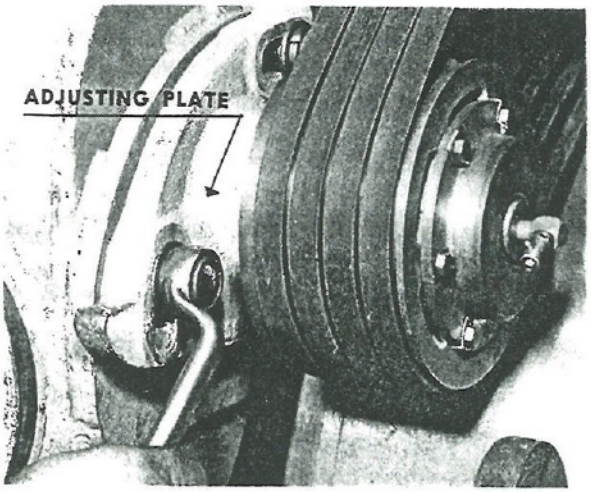


Fig. 161. Tightening Drive Belt on Air Compressor

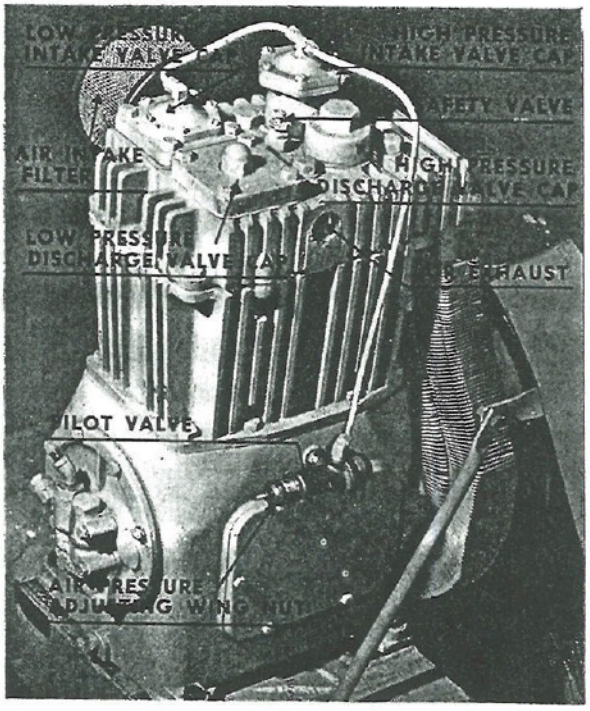


Fig. 163. Valve Plates on Air Compressor

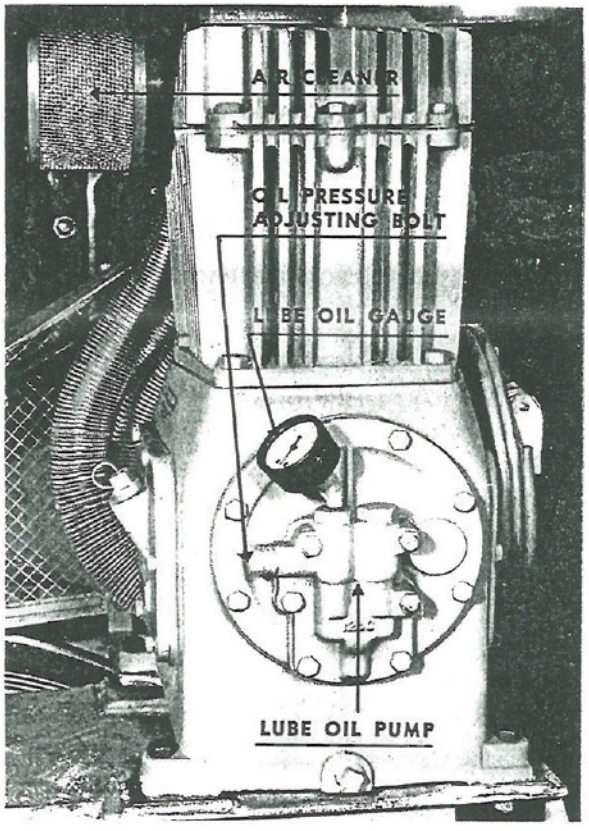


Fig. 162. Oil Pump Housing on Air Compressor

195. PILOT VALVE. a. When the storage tanks are filled to 250 pounds, the compressor, if not disengaged, will continue to operate but no more air will be delivered to the tanks while the 250 pounds pressure is maintained. In the event of difficulty with the compressor, the first step should be to inspect the unloader system.

b. First inspect the pilot valve. The pilot valve is on the side opposite the oil gauge, as shown in Fig. 163. Copper tubing from the pilot valve runs to the suction valve caps on the cylinder head and also to the air storage tanks.

c. The pilot valve is a small unit made of brass. With the compressor shut down, close the valve in the small line leading from the pilot valve to the storage tanks. There is a wing nut at the after end of the valve. Unscrew this wing nut and remove the spring, plunger, and piston. Inspect the spring to be sure it is not broken, or that it has not lost its elasticity. On the other end of the pilot valve,

remove a screw holding the front plate in place and take off the plate. Then remove a round felt filter enclosed on both sides by discs of screen. Inspect the felt filter and if clogged, either clean or replace it with a new one. Replace the filter and the front plate, after which re-install the piston and plunger, and tighten up the wing nut. Since this wing nut controls the tension of the spring, which in turn determines the pressure at which the air from the storage tanks forces back the piston to activate the unloader, it is necessary to adjust this wing nut until the compressor stops functioning when the tank pressure is 250 pounds.

196. THE DIAPHRAGMS. If the pilot valve is in working order, inspect the diaphragms covering the suction or intake valves on both the high pressure and low pressure cylinders. With the compressor shut down and the valve between the pilot valve and the storage tanks closed, disconnect the tubing leading to the intake valve caps on the top of the cylinder head, as shown in Fig. 163. Remove the screws holding down both of these plates, and raise the plates together. Directly underneath these plates are the diaphragms. They are flat pieces of rubber and composition with holes around the edges for the plate screws to go through. Inspect these diaphragms closely since they are the parts most likely to wear out. If torn, showing holes, or if they are lifeless, replace them. The diaphragms should be flat and not sagging. If the diaphragms appear to be in good condition, or if it has been more than 60 days since the valves have been cleaned, inspect the valves.

197. VALVE INSPECTION AND REPAIR. **a.** The air compressor housing is in three parts. The bottom block houses the crankshaft, the center the cylinder block, and the top piece houses the cylinder head. With the tubing still disconnected, remove the bolts holding the cylinder head in place and the bolts attaching the flanges of the finned cooling tubes to the head. Take the head to the work bench for inspection and repair.

b. A brass plunger is located underneath the diaphragm of the low pressure intake valve. When the air from the pilot valve presses down on the diaphragm this plunger is pushed down. Remove the plunger and the bumper plate underneath it. The valve cage is now exposed and can be lifted out of the head. The valve cage is round, and around its top edges there are three drilled holes containing brass plungers fitted with springs. These are the plungers which keep the valve from functioning when compressed air from the pilot valve is forcing the diaphragm down. The plungers and their springs are easily removed. If any of the springs are broken, replace them.

c. Next place the valve cage in the vise so that the bottom plate, which is also the valve seat, is held. Unscrew the rest of the valve cage from the bottom plate. The grooved valve seated in this bottom plate has three round holes in which conical springs of flat steel are fitted. They keep the valve, which is a thin disc of steel, from seating until sufficient pressure is developed to overcome the pressure of these springs. Inspect the springs and replace any that are broken, or have lost their elasticity. Clean the valve seat groove thoroughly and also the valve disc lightly with a piece of fine emery cloth. Inspect the valve disc, and if it is bent or warped, replace it.

d. When all is in order, place the conical springs in their retaining holes, replace the valve disc and hold it in place while the bottom plate is screwed back onto the rest of the valve cage. Now look down into the cylinder head where the entire valve assembly seats. Be sure the copper gasket on this seat is in place and in good order. Replace the valve cage assembly. Replace the plungers and their springs. Replace the bumper plate and the brass plunger, then cover with the diaphragm to prevent dirt from dropping in.

198. LOW PRESSURE DISCHARGE VALVE. Next remove the low pressure discharge valve. Take off the acorn nut to expose the retaining lock nut. Back off this nut two or three turns, and remove the four capscrews holding down the valve plate. Remove the spring at the top. This is held by the retaining lock nuts with sufficient pressure to prevent the valve cage from being moved upward by the air pressure.

If this spring is not in good order replace it. The low pressure discharge cage is composed of a top piece drilled for a cotter pin and a lower piece with a stem which is also drilled for the cotter pin. On removal from the cylinder head, take out the cotter pin. With the top and bottom disassembled, it is found that, like the low pressure intake valve, this valve is a thin circle of steel held in place by conical springs of flat steel. However, unlike the intake valve, the retaining holes for the springs are in the upper part of the valve cage and they hold the valve disc seated until air leaving the cylinder overcomes their pressure. Inspect these springs, making any necessary replacements, and also clean the valve disc and seat. If the valve disc does not seat true, replace with a new one. Hold the valve upside down while assembling it, and be sure that the hole in the stem of the lower body lines up with the hole through the upper body. Fasten it with a new cotter pin. Be sure the valve disc does not bind inside the cage. Check the copper gasket in valve assembly seat in the head before replacing. While intake valves do not have gaskets, the discharge valves are fitted on the head with gaskets of 1/16" material. Be sure the gaskets are in good condition. Replace them if necessary.

199. HIGH PRESSURE INTAKE VALVE. Use a 24-inch monkey wrench to unscrew the six-sided housing shown in Fig. 163. Remove the brass diaphragm plunger and the check valve cage. Remove the plunger from the valve cage and inspect the seat. If it is rough, dress it down lightly, or replace the plunger since the seat cannot be replaced. The intake valve proper is held in place by a slotted retaining sleeve. Place a flat piece of steel about 3/8" thick, two inches wide and about three inches long in these slots and unscrew the sleeve. The high pressure intake valve is identical to the low pressure intake valve except that it is smaller. It is taken apart and serviced in the same way. When the springs and the valve disc and seat are in order, reassemble the valve cage, replace the three brass plungers and springs, and re-install. Replace the retaining sleeve, using only a 10-inch crescent wrench to tighten. Replace the check valve cage and plunger and the brass diaphragm plunger. Cover with the diaphragm.

200. HIGH PRESSURE DISCHARGE VALVE. Remove the valve cap with a 1 3/8-inch six-sided socket wrench and then use a flat piece of steel to take out the retaining nut. Remove the valve cage. Be sure gasket is in good condition. Tighten the retaining nut well without exerting extreme pressure.

201. LUBRICATION. The compressor is full force lubricated with its own supply of oil contained in the base, or sump. The gear type lubrication pump is on the side opposite the flywheel. Oil is drawn by this pump from the sump through the strainer element, and passes through the ball check valve. The oil then goes through the drilled holes in the crankshaft. The oil goes through a hole in the top of the upper connecting rod bearing shell into copper tubes fastened to the connecting rods and to the piston pins where it lubricates the bushings. The piston walls are lubricated by the splash method. The drilled holes through the crankshaft also carry oil to the Timken roller bearings which serve as the main bearings.

202. OIL PUMP SERVICING. ***a.*** In Fig. 162 the oil pump housing is shown mounted on the end plate of the crankshaft block. The oil pressure gauge also is shown. The oil pressure should run between 10 and 15 pounds. If it drops below 5 pounds or operates considerably higher than 15 pounds, attempt to correct the trouble by adjusting the spring controlling the tension in the ball check valve. If this does not correct the situation, take out the six-sided bolts holding the oil pump assembly to the end plate. Inspect the balls to be sure they are not pitted, and see that they seat properly. If the seats are worn, work down with a little fine grade grinding compound or grinding rouge. Usually, if any trouble is found at this point, it will be a little dirt underneath the seat.

b. The pump gears can also be removed at this time and inspected. If the gears are worn, replace them. In re-installing the gears, be

sure to replace the thin paper shims before putting the check valve assembly back on. The shims permit the lubrication pump to have a thrust which should not exceed .005 of an inch. If the clearance is more than this figure, remove the paper shims until the proper clearance is obtained. Before re-installing the lubrication pump, remove the oil filter and either wash it thoroughly or replace with a new one.

203. SAFETY RELIEF VALVE. A spring loaded pressure relief valve of the "pop-off" type is located on the top of the cylinder head. This is placed between the low pressure stage and the high pressure stage, and is set to blow off at 110 pounds. If this valve opens, it is an indication the cylinder valves are not functioning properly. This valve is easily removed from the cylinder head and taken apart. Be sure the valve is seated properly, and replace the gasket. The pressure at which this valve will open is adjusted by the screw on top. The screw increases or decreases the spring pressure.

204. AIR FILTER. As shown in Fig. 162, air is drawn into the compressor through a port fitted with a felt type filter. The front plate and the felt filter element can be taken off by removing the ¼" screw in the middle of the front plate. This filter should be removed every 90 days, agitated in kerosene, and blown out thoroughly before being replaced.

205. PISTON AND BEARING DISASSEMBLY. **a.** The condition of the connecting rod bearings can be checked by removing the side plates. If it is necessary to disassemble the compressor further after the head is off, remove the six-sided capscrews securing the cylinder block to the crankshaft block. Then remove the cotter pins and nuts holding the connecting rod bearing boxes together, and pull out the lower bearing caps through the side plates.

b. Do not attempt to pull the pistons and connecting rods out of the cylinders. Instead, remove the cylinder block with the pistons in them. Set the cylinder block on one side and remove the piston and connecting rod assembly.

c. The connecting rod bearing shells are of the precision type and cannot be adjusted with shims. At one end of each shell there is a lug which fits into a notch in the end of the bearing caps to hold the shells in position. The shells should lift out easily, although a slight prying pressure by a screwdriver may be necessary. Examine the bearings for burning, or scoring. Measure their thicknesses and compare with the thicknesses of new bearings. If this shows that the total wear on the two shells exceeds .005 of an inch, replace both shells. The upper bearing shells have holes for the oil to reach the lubrication tubing serving the piston pins.

206. PISTON PINS. The piston pins are not of the full floating type, but are anchored. In the low pressure piston a screw and a cotter pin connect the piston pin to the piston. In the high pressure piston only a cotter pin is used to anchor it, as shown in Fig. 144. Remove these anchors and drive out the piston pins with light taps. The piston pin bushings should be inspected for damage. If the piston pins fit loosely in these bushings, they should be replaced. The old bushings must be driven out. Before inserting new bushings, drill a 1/16" hole in a position so that it will line up with the lubrication oil tubing on the connecting rod. Replace the anchor bolt and cotter pin on the lower pressure piston and the cotter pin anchor on the high pressure piston. Test the bushing fit by holding the pistons upside down and permitting the connecting rods to stand up in the air. If they fall over easily without binding at any one place, the bushing fit is correct. Be sure the oil tubings are not clogged with dirt.

207. PISTON RINGS. Each piston is fitted with three compression rings and one oil ring. They are of the automotive type. With the pistons in the cylinders, check for ring clearances. In the low pressure cylinder the piston ring clearance should not be more than .008 of an inch, and in the high pressure cylinder .006

of an inch. Replace with new rings if the clearances are over this amount, using the same method described for installing rings in the Diesel engine.

208. CRANKSHAFT. The crankshaft, if the proper oil level is maintained, should not give any trouble. If necessary to disassemble the crankshaft, remove the 5/8" capscrews holding together the split hub, and remove the key. Pull off the flywheel. Remove the rear plate, and then take off the front plate, carefully keeping together the light thrust shims found at the front end. The Timken roller bearings can now be removed. Examine the rollers and the Timken cones. If they are not functioning properly, are broken, or show excessive wear, replace them. In reassembling the crankshaft it is important to remember that the end opposite the flywheel end is fitted solidly into the end plate. The only thrust shims are in the end behind the flywheel. Remove or replace the shims until a clearance of .010 is obtained between the cylinder block and the end plate. Check this with a feeler gauge. Then secure the capscrews holding plate to the block. Replace the flywheel with the key and tighten the capscrews, making sure that the indicator arrow on the spoke points in the direction the flywheel will rotate.

209. REASSEMBLING UNITS. The units on the compressor are reassembled as follows: Replace the gasket between the cylinder block and the crankcase block, and insert the pistons in the block. Reassemble and place the lower bearing caps on the crankshaft journals. One side of both the upper and lower bearing caps have raised dots cast in them. These dots must be on the same side. When lined up, replace the bearing bolts, tighten up the nuts, and lock with cotter pins.

210. COMPRESSION CLEARANCE. The gasket between the crankcase block and the cylinder block is also the compression shim. Tighten the cylinder block to the crankcase block and then, one at a time, bring both pistons to top dead center. The top of these pistons should be exactly flush with the top of the cylinder block. When this is correct, bolt the head onto the cylinder block with a gasket between them. If the old gasket is badly worn, use a new gasket of 1/16" material. It is preferable that the combination copper and asbestos type gaskets furnished with the equipment be used. Tighten all bolts and capscrews securely.

211. SERVICING. The lubricating oil should be drained through the drain plug every three months. One gallon of clean lubricating oil, grade SAE-10, should be used to refill the reservoir. Take off a side inspection plate and remove the oil filter for cleaning or replacement every 30 days. Grease all fittings on the compressor pulleys weekly.

SECTION XX
WATER PUMPS

212. REMOVING THE JACKET WATER CENTRIFUGAL PUMP. Drain all the jacket water from the engine at the lowest point in the system, and disconnect the flanged pipe connections from the pump. Secure the pump with a chain hoist or block and tackle and remove the capscrews holding the unit in place on the engine. Hoist the pump clear of the engine.

213. DISASSEMBLING CENTRIFUGAL PUMP. **a.** Pull out the cotter pin locking the nut that holds on the gear. Remove the nut and washer with a wooden clamp to prevent the impeller from turning. Tap the impeller off the shaft with a lead hammer and remove the key. Take out the capscrews holding the casing and remove the casing. Since these parts fit very closely, it may be difficult to remove or replace this casing unless the parts are kept square to each other. The pump, completely disassembled, is shown in Fig. 164.

b. Remove the nuts securing the packing flange and pull the glands out on the shaft. Tap out the shaft. Continue to push the shaft until it is all the way out. Remove the housing from the shaft base by tapping. Do not remove a bushing in this pump unless it is to be replaced. These bushings are press fitted and are

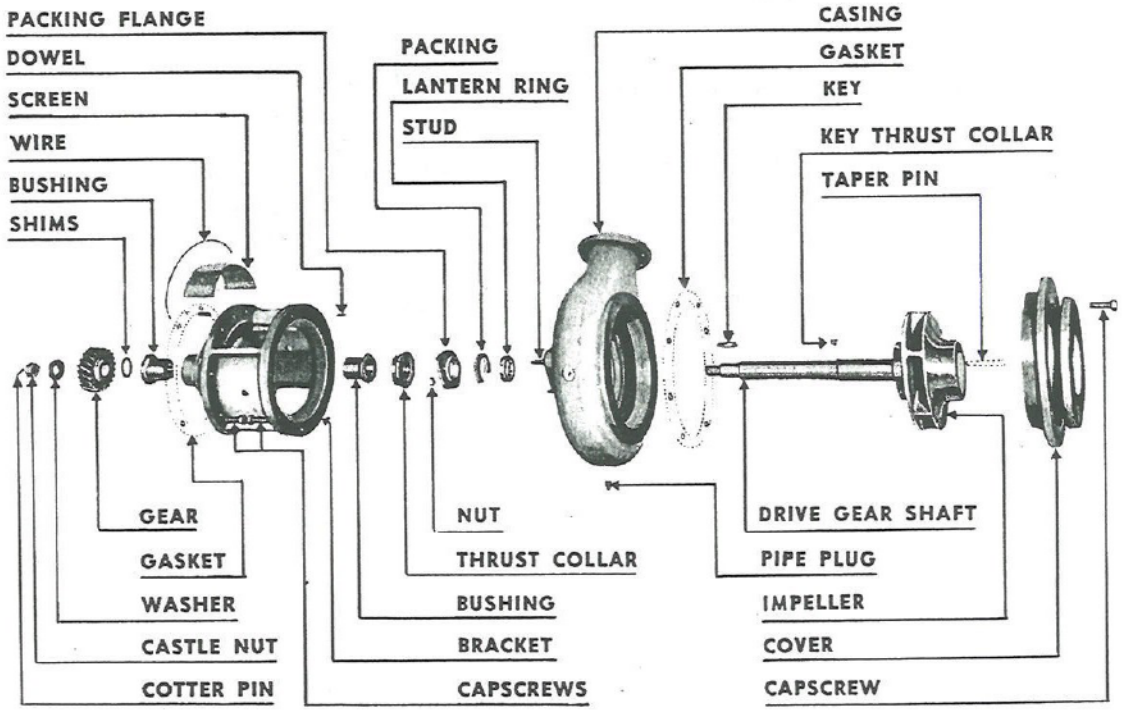


Fig. 164. Parts of Fresh Water Pump

tight in their receptacle. If they are removed, this tightness will be lost, with the result that the bushing might start turning with the shaft. This would destroy the bushing.

214. INSPECTION AND REPAIR. *a.* There is little to wear out in a centrifugal type pump except the bushings holding the impeller shaft. New bushings permit a clearance of .006 to .008 of an inch, and when this clearance is .015" or more, the bushing must be replaced. If the impeller shaft is damaged, both the shaft and the impeller should be replaced.

b. When replacing a bushing, coat the leading edges of the new bushing with white lead diluted with lubricating oil. Keep the bushing *square* to its receptacle to prevent bending or cocking, and tap the bushing in. Do not tap directly on the bushing, but place a piece of soft wood on the top of the bushing and tap on the wood. Continue tapping until the bushing is completely seated. The bushing is completely seated when a feeler gauge of about .003 of an inch will not enter the space between the thrust shoulder of the bushing and the thrust housing.

c. Slide the impeller shaft into the bushing and rotate it to make sure it is free. If the shaft binds, remove and scrape the bushing until the shaft will rotate freely. The shaft must be absolutely clean and free of burrs or other defects.

215. REASSEMBLING THE PUMP. *a.* Push the impeller shaft into the main housing, place the packing flange over the shaft, and follow it with the thrust collar. Be sure they are placed so that the flange will enter the gland and the thrust face of the thrust collar will face the bushing. Tap the thrust collar onto the shaft and over the key until it is flush with the shoulder on the shaft. Check the clearance with a feeler gauge, as was done with the bushings.

b. Slide the shaft through the pump bracket bushing and secure the pump housing to the bracket with the dowel and dowel hole lined up. Use a light coat of white lead as a water seal between these two pieces instead of a gasket. Place the gear on the shaft.

c. If new bushings are used, the shaft and clearance between the thrust side of the gear and the thrust collar at the other end will be changed and will require adjustment. The clearance should be .012 of an inch between the impeller and the thrust shoulder of the bracket bushing when the shaft is pushed so that the thrust collar has no clearance between itself and the thrust side of the bracket bushing. Add or remove shims until this clearance is obtained. When the proper clearance is obtained, tighten the nut securely on the shaft and lock it with a new cotter pin.

d. As the various pieces are assembled, make frequent checks to be sure the shaft is free to rotate. Replace the suction cover to the housing, using a new gasket if necessary, and secure with capscrews.

216. INSTALLING PUMP ON ENGINE. *a.* Oil the shaft well at the bushings. Hoist the pump into position on the gear case of the engine, and secure with only one or two capscrews until adjustments for back lash are made. Grasp the pump shaft gear through the hand hole in the gear and attempt to rotate it back and forth. If there is no movement the pump shaft impeller is too close to the driving gear. It must be backed away. Tap the pump housing in the direction necessary to increase the clearance. If the back lash is excessive, tap the housing to decrease the clearance. When the proper clearance of .001 to .002 has been obtained, tighten all capscrews and connect the pipe flanges, using new gaskets.

b. Inspect everything for tightness, and fill the engine jacket with water. If no leaks are found, start the engine and listen to determine if the pump impeller is noisier than it should be. If there is excessive noise, shut down and adjust the gear for less clearance. Feel the shaft and if excessive heat is found, shut down and adjust for more clearance. Heat is another indication that the gears are too tight.

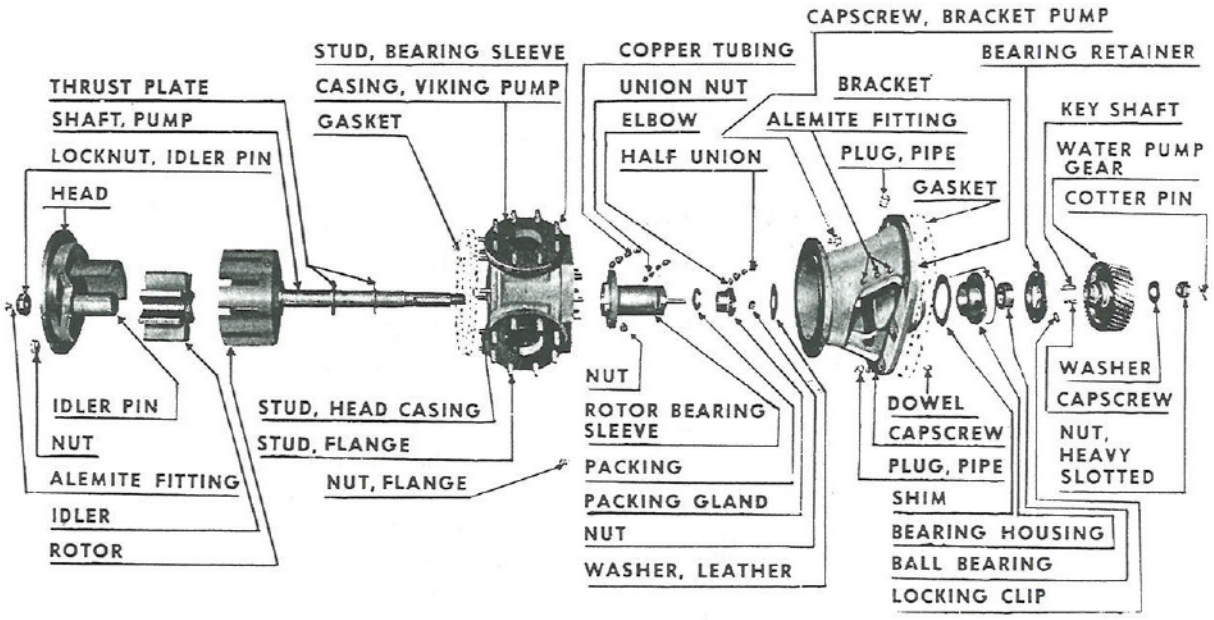


Fig. 165. Parts of Sea Water Pump

217. INSPECTION OF RAW WATER PUMP. *a.* This unit may be partially inspected by the removal of the side plate of the pump. For a complete examination, the pump and its bracket must be removed from the engine and the pump disassembled.

b. Shut down the engine. Shut off the valve admitting raw water to the system. Disconnect the flanges on the raw water pump valve and on both the suction and discharge side of the pump. Remove the raw water valve by taking out the capscrews securing it to the pump base. Secure a chain hoist or block and tackle to the pump and put a strain on the hoisting gear. Remove the capscrews holding the pump to the engine gear case and hoist the pump away from the engine.

c. Remove the nut holding the drive gear on the shaft. Tap the gear off the shaft with a piece of bronze or a lead hammer, taking care not to injure the gear or lose the key. Remove the four capscrews securing the thrust bearing sleeve retainer and the capscrews securing the pump to its base. Carefully retain and mark all shims that are under the pump so that they can be replaced in the same manner.

218. DISASSEMBLING THE RAW WATER PUMP. *a.* Remove the six capscrews securing the head plate to the pump. Take off the plate. Take the idler gear off its pin. Move the top of the shaft on the threaded end and drive out the shaft and rotor. Take off two nuts securing the packing gland and remove the gland. Drive the sealed oil thrust bearing off the shaft with a lead hammer or piece of bronze bar. Exercise care to tap only the inner surface. Tapping the outer edges may damage the bearing.

b. Do not remove the bushing in the pump housing unless it is to be replaced with a new one. If this bushing is replaced, tap the old one out. Be careful not to injure the walls of the pump housing. The pump is now completely disassembled, as shown in Fig. 165. This pump, under normal conditions, should give trouble-free operation for years. To deliver this service, the pump depends on three factors:

(1) That no gritty material or metal enters the pump.

(2) That it is properly aligned and free from stresses due to faulty piping installations.

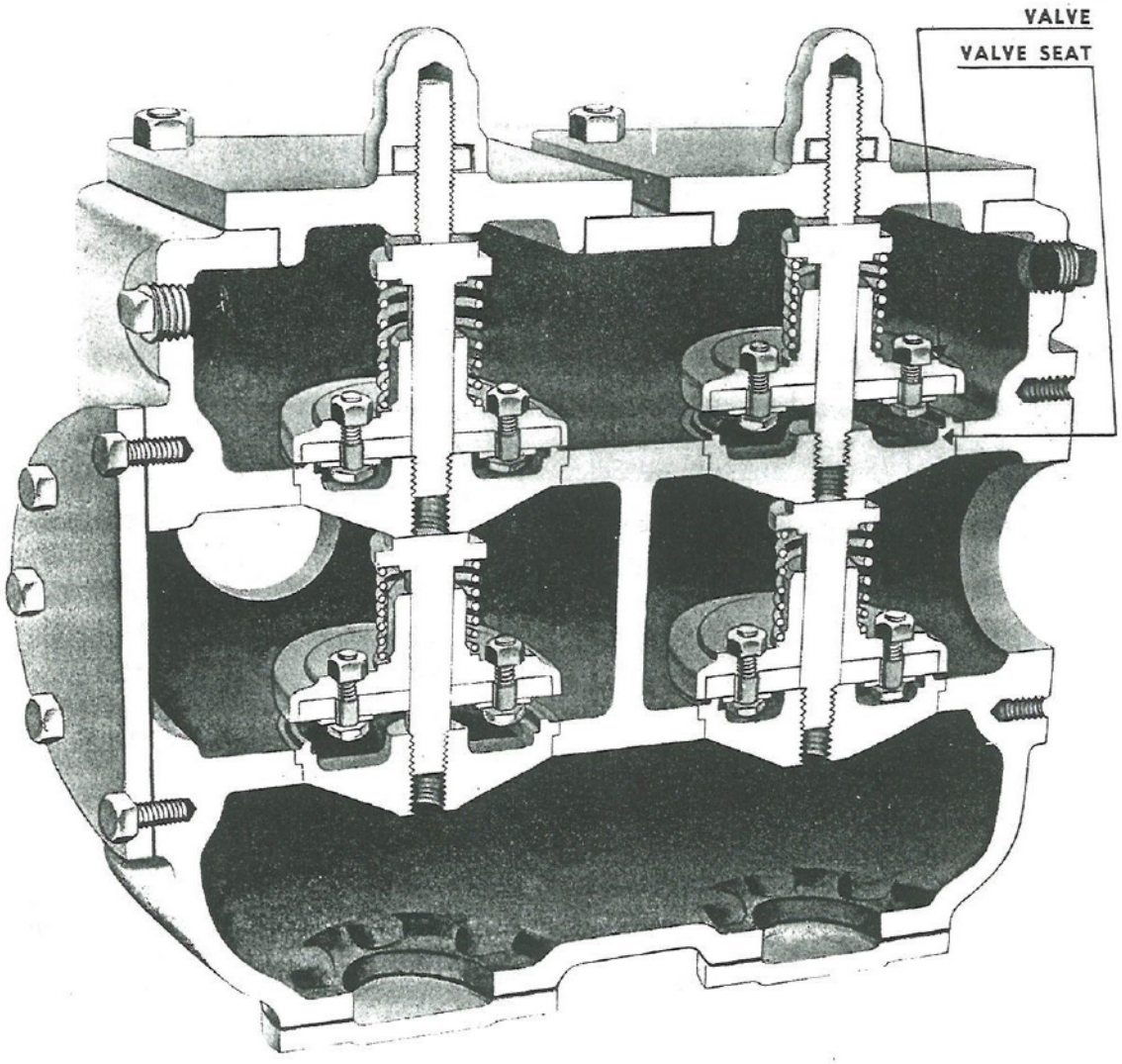


Fig. 166. Sea Water Pump Valves Cut Away

(3) That it receives proper lubrication at regular intervals.

The thrust bearing on the pump shaft is factory sealed, and requires no further lubrication. Make periodical inspections of the pump to determine the wear at the thrust bearings, and check the clearance to ascertain when it is necessary to replace parts.

219. REASSEMBLING THE RAW WATER PUMP. *a.* Press or drive a new bushing into the pump housing if the old one has been removed. Push the shaft through the new bushing to check for sufficient clearance and freedom from binding. If the shaft is too tight in the bushing, scrape lightly, using blueing for guidance, until a good fit is obtained. Install the shaft in the pump housing. Replace the idler gear and head. Use the old gasket if not damaged, but if necessary to install a new gasket be sure it is made of material of the same thickness or the pump may leak. The head must be bolted to the housing with the dowel hole in the correct position or the pump will not operate efficiently.

b. Tie some pieces of cloth over the suction and discharge sides of the pump to prevent any dirt or other foreign material from entering the pump during assembly. As soon as the pump is assembled, turn the shaft to determine if it can operate freely. Slide the packing gland over the shaft and install the gland nut.

c. Repack the gland with suitable packing material. Cut this material into pieces slightly less in length than the circumference of the shaft. Place the first length of packing into the gland in a way that leaves a gap between the two ends at the top of the shaft. Reverse this arrangement on the next piece so that the gap between the ends will be on the bottom of the shaft. Continue to stagger the gaps. Push the gland sleeve against the packing and secure the packing gland. Tighten up on the gland. At the same time rotate the shaft so that the packing material will compress to seal against leaks. Do not tighten to the extent that the shaft will bind.

d. Slide on the leather washer and place the thrust sleeve into its holder in the pump bracket, driving it down until it is against the shoulder in the end of the housing. Push the shaft of the pump through the hole in the pump base bracket and into the thrust bearing. Replace the shims under the pump and bolt it down securely. Rotate the shaft again to be sure it is still free. Secure the thrust bearing sleeve and rotate the shaft again for another check.

e. Lay the key in the shaft keyway, and place the gear on the shaft. One side of the gear is flat at the hub, and the other side has a gradual taper. The tapered side of the gear must face the pump. Replace the locking ring, washer, and tighten the nut securely, bending a side of the exposed washer against the nut to lock it.

220. EXAMINATION OF VALVE CAGE. The parts of the valve are held into their chambers by the cover of the cage, as shown in Fig. 166. By removing this cover and the gasket, the two valves on either side can be examined. One valve disassembled is shown in Fig. 167.

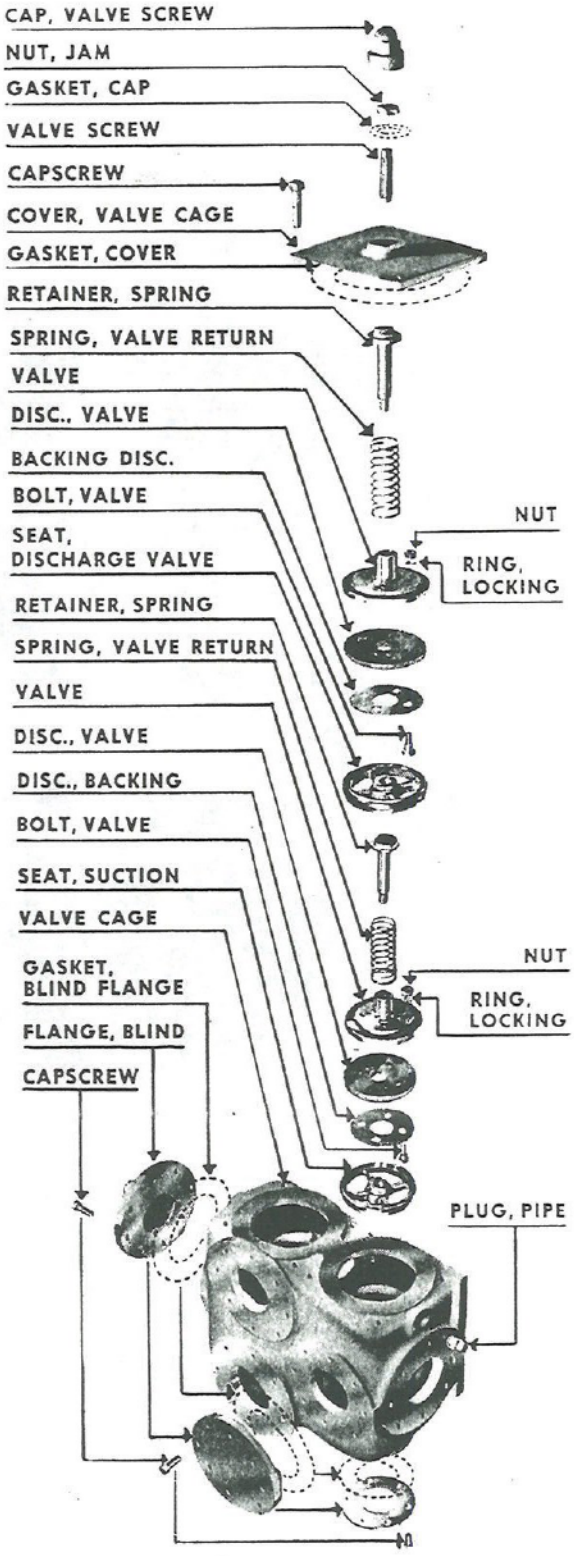


Fig. 167. Parts of Sea Water Pump Valve Cage

Replace broken spring, or springs that have lost their elasticity. Check the valve discs. Be sure they seat properly, using blueing to determine this point. If necessary, replace the round cork valve discs. When satisfied that the valves are working properly, replace the parts in the same order and secure cover plate, using a new gasket if the old one is worn.

221. INSTALLING PUMP ON ENGINE. **a.** Hoist the pump back to its proper place on the engine, and start all capscrews but do not tighten them. Check the backlash at the end of the pump shaft by removing the small hand hole cover at the right side of the gear case and determine by hand if the gears operating the pump are properly meshed. The gear and driving gear should allow some movement when moved by hand. If the gear cannot be moved, it is too tight. If it moves with a loud noise the fit is too loose. The proper clearance is listed in Sect. VIII.

b. When the adjustment is correct, tighten up the capscrews securing the pump to the engine. Connect the pump valve and all pipe flanges, using new gaskets. Be certain that everything is in order, and then open up the sea valve and check for leaks in the raw water system.

c. Start the engine and listen at the gear case for any strange noise not commonly heard in normal operations. Feel the shaft for heat. If there is no noise or heat the pump is functioning properly. However, if either one of these conditions is found, the gear is too tight and must be loosened to increase the backlash.

d. If the packing in the gland starts to leak after a few hours of operation, tighten up on the gland clamp a half turn or more. Be careful not to tighten it so much that all leaking stops. There should be a leakage of a drop every two or three minutes.

SECTION XXI
THE EIGHT-CYLINDER ENGINE

222. GENERAL. The Enterprise DMQ-36 and the Enterprise DMQ-38 engines operate in the same manner. Both have 16-inch pistons with 20-inch strokes. The eight-cylinder engine has two more cylinders than the six-cylinder model. All instructions in this manual are based on the operation and maintenance of the six-cylinder engine. Operation and maintenance of the eight-cylinder engine are identical, with the exception of the variations noted in this section.

223. LOCATION OF UNITS. Where the location of a unit, such as the fuel transfer pump, is described as near No. 6 cylinder, in the eight-cylinder engine the position will be near No. 8 cylinder.

224. PRINCIPLES OF ENGINE OPERATION. They are the same, except that instead of a power stroke every one-third of a revolution, there is a power stroke every one-fourth of a revolution.

225. LUBRICATION SYSTEM. The system is the same, with the exception of more piping and tubing to care for the two extra cylinders.

226. COOLING SYSTEM. The cooling systems are the same.

227. FUEL SYSTEM. Same, with exception of more piping and usually larger fuel storage capacities. In addition, the six-cylinder engines are all equipped with the mechanical governor only, while some of the eight-cylinder engines are equipped with hydraulic governors.

228. AIR INLET AND EXHAUST, STARTING AND MANEUVERING. The engine is operated in the same manner, with the exception the operator has to look after two more cylinders. The pyrometer, instead of registering temperatures in six cylinders, records this data on eight cylinders.

229. ENGINE OPERATION. Operation is same, except that turbochargers operate at different rates. Consult Sect. VIII.

230. SPECIFICATIONS AND CLEARANCES. They are the same with the exception of two more cylinders. All pressures, temperatures and clearances are identical with the exception of the thrust bearings and turbochargers. Consult Sect. VIII for these differences.

231. TOOLS AND FITTINGS. Same.

232. ADJUSTMENTS, TIMING, MAINTENANCE ROUTINE. **a.** The maintenance routines and adjustments are the same. However, the big difference in the eight-cylinder and six-cylinder engines is in the timing. The timing of the fuel pumps starts with the pump serving No. 1 cylinder. However, if the camshaft is to be balanced, No. 1 and No. 8 pumps are removed, as these are located on the extreme ends of the camshaft.

b. Instead of three pairs of cranks working together, the eight-cylinder engine has four pairs of cranks that are in the same positions at the same times. The cylinder pairs are Nos. 1 and 8, 2 and 7, 3 and 6, and 4 and 5. Therefore, these numbers are paired on the flywheel markings.

c. The firing order of the eight-cylinder engine is 1-4-7-3-8-5-2-6 in ahead running, and 1-6-2-5-8-3-7-4 in astern running. In timing the fuel pumps, using the ahead firing order, cylinder Nos. 1 and 8 are put into position to time No. 1 fuel pump, then 4 and 5 are brought into position to time No. 4 pump, 2 and 7 are put into position to time No. 7 pump, 3 and 6 are put into position to time No. 3 pump, 1 and 8 are again put into position to time No. 8 pump, 4 and 5 are again put into position to time No. 5 pump, 2 and 7 are again put into position to time No. 2 pump, and 3 and 6 are again put into position to time No. 6 pump. When timing, the engine must always be barred in the rotation of the ahead running.

d. The schedule of maintenance is the same for the eight-cylinder as the six-cylinder engine.

SECTION XXII
TURBOCHARGER

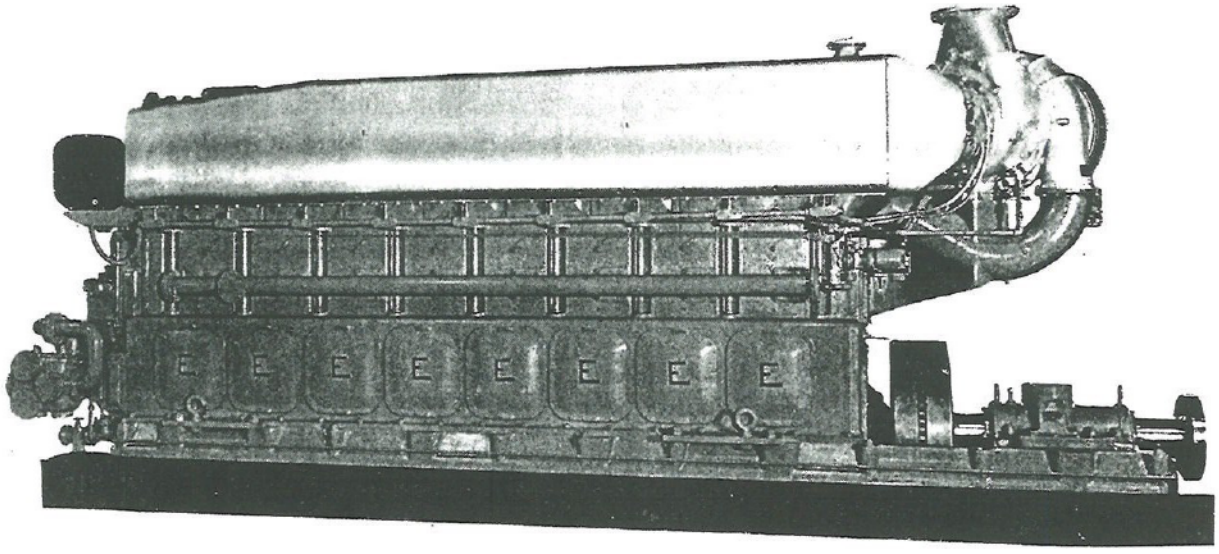


Fig. 168. Turbocharger Manifold

233. GENERAL. In Fig. 168 the DMQ-38 engine is shown from the exhaust side, illustrating the appearance of the turbocharger when fully installed on the engine. The exhaust pipes carrying the exhaust gases to the turbocharger turbine are enclosed by the cover, as shown. Except on a rare occasion, or when the engine is being completely dismantled, it should not be necessary to remove these covers. They are attached by capscrews.

234. BEARING INSPECTION. **a.** In Fig. 169 the BF-34 Turbocharger is shown disassembled. For the purpose of inspecting the bearings, however, the turbocharger need not be removed from the engine. The oil reservoir should be drained to facilitate handling. On the front of the silencer a lubricating oil tube cover is secured by capscrews. Remove this cover and disconnect the oil delivery line. Disconnect the tachometer cable from the fitting on the top of the tachometer gauge. Remove the water line from the lubricating oil tank connecting flanges. Two men should support the silencer and oil reservoir with their hands and then remove the stud nuts that secure the silencer casing to the blower casing. Pull the silencer and oil reservoir out straight to prevent it from resting on the oil pump, and place on the deck.

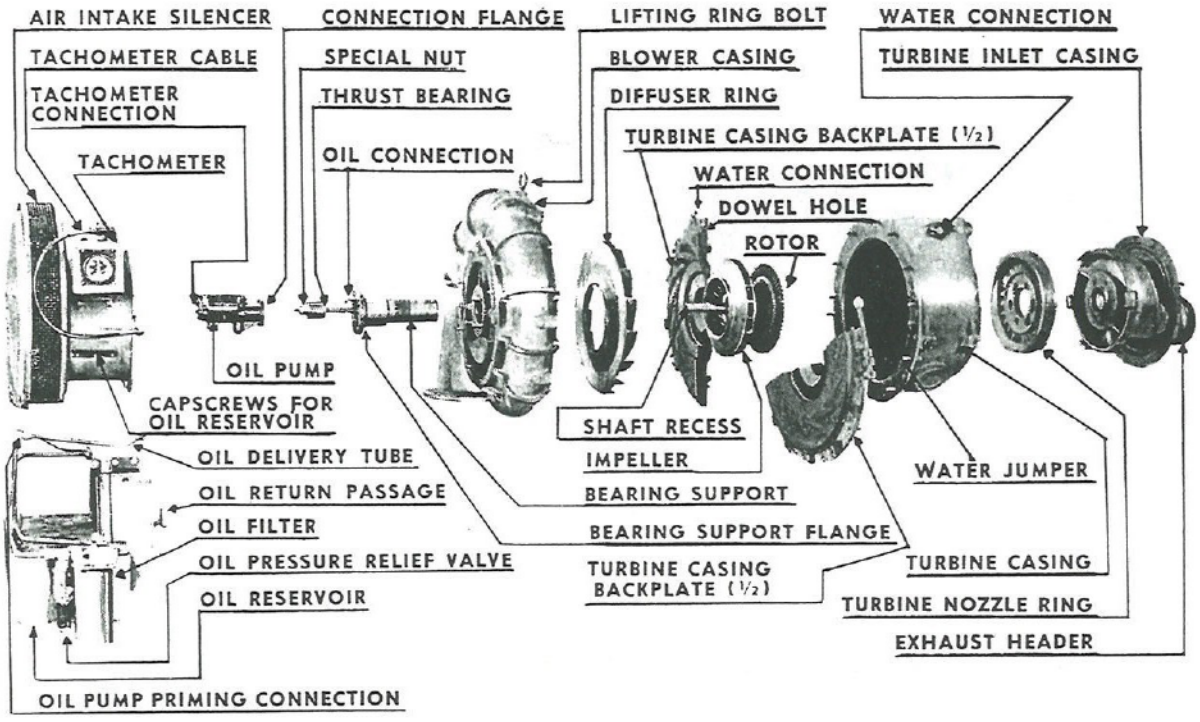


Fig. 169. Parts of Turbocharger

b. Remove the tachometer cable from the oil pump. On the top edge of the bearing support a special lubrication fitting is located. Unscrew and turn this connection to a vertical position as shown in Fig. 169. Remove the screws securing the pump flange to the bearing support. Pull pump out straight until the coupling is clear, then tilt pump upward to clear the special oil connection.

c. After removing the pump, remove the special nut which has a right hand thread. The rotor must not be jammed to prevent its turning while this nut is removed. Tap the wrench to start the nut. With the nut off remove the locking tube, thrust collar and thrust bearing which is shown in Fig. 170.

d. Remove the stud nuts which secure the bearing support to the blower assembly and insert jacking screws into these holes. By tightening up on these jacking screws evenly, the bearing support assembly is pulled out of the blower casing assembly. Support the assembly by hand when the first shoulder is clear of the blower casing to prevent damage to the bearings. When the bearing support is removed, the turbine will rest on the backplate and should not be rotated. Preserve all gaskets found.

235. EXAMINATION OF BEARINGS. Clean all parts thoroughly. The bearing support is fitted with bearing sleeves. Inspect their surfaces, without removing them, for pitting, scoring or excessive wear. Check clearances with the table given in Sect. VIII. If it is necessary to replace bearing shells, remove the two screw dowels securing each shell. The outer bearing shell must be driven from its seat. To remove the inner bearing, remove the oil baffle nut

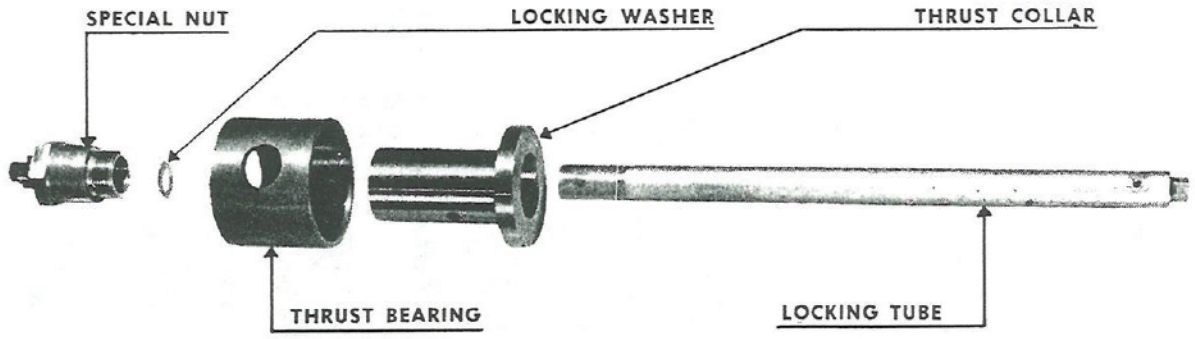


Fig. 170. Turbocharger Thrust Bearing

and the oil baffle and then drive out bearing. Inspect the thrust collar and thrust bearing shown in Fig. 170 and check with the table of clearances.

236. REASSEMBLY OF BEARINGS. If new bearing shells are being installed in the bearing support, be sure that the side of the shell with a 45° chamfer should enter the hole first. A scribe line located on the side of the bearing shell must be lined up with the chisel mark adjacent to the bearing shell seat in the bearing support. The oil holes in the bearing shell and bearing seat must also be in alignment. After pressing in the new shell, check this alignment by passing a small piece of bent wire through the holes. Replace the set screws securing the bearing shells. Replace the oil baffle, making sure that the locating pin in the bearing support passes into the locating hole in the oil baffle. Install the oil-proof rubber gasket and the oil baffle nut. Tighten down oil baffle nut and center-punch at the thread to lock into place. Oil the exterior of the bearing support and replace in the blower casing, checking to be sure that the oil drain slot adjacent to the bearing support flange is down and registering with the drain ribs in the blower casing. Cover a block of wood with a piece of cloth and hold against the bearing support. Drive the bearing support in carefully until the stud nuts can be started and the flange can be pulled down to its seat by the studs. Replace the thrust collar and thrust bearing. Be sure the thrust collar key is properly placed. Install the locking tube and the copper locking washer as shown in Fig. 170, and the special nut. Tighten the special nut by tapping on the wrench, as the rotor must not be blocked. Replace the gasket between the bearing support and oil pump flange and replace the capscrews. If a new gasket is used, make it out of material .020" thick. Check the thrust by dial indicator to obtain the clearance specified in Sect. VIII. Adjust gasket thickness to secure this clearance. It can also be secured by the thickness of the special copper washer located inside the special nut. With the bearings in place, replace the intake silencer and bolt securely. Connect the oil feed line to the oil pump. Before replacing the cover on the end of the silencer, remove the priming plug and pour about a quart of oil into the system to prime the pump.

237. COMPLETE DISASSEMBLY OF TURBOCHARGER. *a.* To completely disassemble the turbocharger, perform the work described in par. 234. Next, disconnect all piping between the turbocharger and the engine.

b. In Fig. 169 a lifting ring bolt is shown. Pass a sling through this ring and attach to hoisting gear, putting a slight strain on to hold the unit. Next remove the bolts connecting the flanges of the turbocharger to the exhaust and inlet manifolds of the engine. Also remove other bolts securing unit to engine. Remove enough of the exhaust manifold cover so that the exhaust headers can be disconnected. On the six-cylinder engine there are two, and in the eight-cylinder engine, four. When all the bolts and connections to the engine are removed, lift turbocharger by the hoisting gear away from the engine and lower onto the deck, taking care that this is done gently.

c. Remove capscrews holding the turbine inlet casing to the turbine casing, and remove the inlet casing and the turbine nozzle ring. Before pulling the two apart, supply some support to the turbine nozzle ring to prevent it from falling. Reach into the turbine casing and pull the rotor assembly as far to the rear as possible. Remove bolts connecting turbine and blower casing. Remove the bolts securing the backplate to the turbine casing. At the top and bottom of the backplate there are water connections and short pieces of tubing serving as water jumpers. Disconnect these. Support the turbine and impeller assembly while a pry is used in the top and bottom joints of the backplate. Pry the two halves of the backplate loose, then pull them apart, keeping them straight to each other as they are fitted with dowels. The turbine and impeller assembly can now be removed and set aside carefully. The diffuser ring should also be set aside.

d. Clean the impeller, diffuser and shaft with a solvent dry cleaner, USA-Spec. 2-120, to remove all deposits of dirt, carbon and oil. Do not scrape the parts, as this will remove the anodized protective coating. Remove all grease, gum and burrs from fitting and contacting surfaces. Flush out the oil drain passages in the blower casing and also the water passages in the turbine casing and the backplate halves. DO NOT ATTEMPT TO TAKE APART THE ROTOR AND IMPELLER, AS THEY ARE BALANCED TOGETHER AT THE FACTORY BY SPECIAL EQUIPMENT. ANY TAMPERING WITH THEM WILL DESTROY THIS BALANCE, CAUSING TROUBLE. IF THEY ARE DAMAGED, THEY CAN ONLY BE REPAIRED AT THE FACTORY.

e. Disconnect the lubrication reservoir from the intake silencer by removing the three capscrews on each side. Drain and flush lubrication tank, removing cooling coil and cleaning it with a stiff brush. Install a new filter cartridge in the filter. Disassemble the pressure relief valve and be sure that it is in working order. Remove the inside cable from the tachometer cable and grease lightly. Examine the turbine nozzle ring, but do not remove unless absolutely necessary. If the blades are distorted, drill out the copper locking dowels, remove the capscrews, and install a new ring. The backplate is cut with a groove to seat a round metal ring called a labyrinth ring. It is important that this ring seats securely. Check clearances of labyrinth rings, oil baffle bores and radial clearances with Sect. VIII.

238. REASSEMBLING TURBOCHARGER. Reassemble the turbocharger in the opposite manner that it was taken apart. Before assembling the two halves of the backplate, coat the contacting surfaces lightly with a heat-resistant gasket material. Coat the backplate split capscrew threads with a light grease. Support the rotor-impeller assembly while the backplate is joined around the shaft between them. Coat the faces of the blower casing and the backplate with a light application of heat-resisting gasket cement and lay two 1/32" strands of asbestos cord on the face of the turbine casing counterbore. In connecting the parts of the turbocharger, be sure that the rotor is not damaged and that all connections are secure. Hoist back into place on the engine and secure all connections. Be sure the water lines are right. Reassemble bearings, bearing support, oil pump, oil lines and other units as explained in par. 234. Be sure to prime oil line before starting engine.

SECTION XXIII
RECONDITIONING AN ENGINE THAT HAS BEEN SUBMERGED

239. EXTENT OF WORK. If an engine has been submerged for a long period of time, it should be sent to a shipyard for repair. The following instructions are presented to meet an emergency where shipyard repair may not be possible, or where the submersion has only lasted a short period. Performance of the work explained here will aid in salvaging the engine even if it is to be repaired in a shipyard. The work should start as soon as the engine room has been pumped completely dry since the parts, unless cared for at once, will deteriorate very rapidly.

240. TEMPORARY SAFEGUARDS. All parts should be wiped dry and protected with a coating of oil. No time should be lost in doing this. The explanations given from this point on will guide the operator if the ship has to proceed under its own power.

241. ENGINE DISASSEMBLY. **a.** Shut off the main valve in the air starting system. Remove all covers and manifolds from the engine to expose all working parts except the combustion chambers in the cylinders. Open the relief valves in each cylinder head and remove the drain plug at the end of the exhaust manifold where the stack is connected. Disconnect all lubricating oil lines. Drain the engine jacket water.

b. Bar the engine over to force out any water that may be in the combustion chambers or cylinders. Remove the nozzles from each cylinder and pour approximately a half gallon of clean lubricating oil down each nozzle hole. Bar the engine over again about twelve times to coat the cylinder walls and pistons thoroughly with this oil.

c. Working through side doors at the base of the engine, mop out all the water in the base or sump. When the sump is completely mopped out, go over all parts with dry cloths to pick up the remaining moisture and then go over the parts with oil saturated cloths. Examine the parts for possible damages.

242. RECONDITIONING THE FUEL SYSTEM. Remove all fuel oil supply lines and fuel pumps from the engine. Take apart the pumps and nozzles one at a time and clean thoroughly. Bathe them in cool, clean fuel oil before reassembling and installing in the engine. Blow out all the injection tubing before re-connecting. Drain the fuel accumulator tank, and thoroughly dry it. If the fuel storage tank is contaminated drain and refill it with clean, new fuel and drain all lines up to the engine. When the lines are filled with clean fuel vent the entire system of air, including the pumps and nozzles.

243. RECONDITIONING THE LUBRICATION SYSTEM. Remove the lower and upper portions of the lubricating oil pump containing the check valves, and mop up any water found in them. Dry the checks and the seats thoroughly and fill the pockets or chambers of the pump with clean, new lubrication oil so that the pump will be primed for operation. Drain the lubrication oil storage tank and mop well. Drain the lubrication oil cooler of oil and leave

the drain open until it is thoroughly empty. Drain the lubrication oil filter, removing the filter element to clean out the tank part. Drain all lines in the lubrication system. Reconnect all lubrication oil piping starting at the oil pump. Install a new element in the lubrication oil filter, and fill the filter tank with new, clean lubrication oil. Replace the drain plug in the lubrication oil cooler. Fill the lubrication oil storage tank to the halfway mark with clean lubricating oil, and pour about twenty gallons of clean oil into the base or sump of the engine. Replace all engine covers.

244. RECONDITIONING THE AIR STARTING SYSTEM. Carefully inspect the starting air valve, disassembling and cautiously wiping off parts with soft cloths. Drain out air lines and air storage tanks. Drain the air compressor before starting to pump out the lines. Drain the oil out of the air compressor, and remove the cylinder head to inspect the valves. Make certain that they are free. If there is water or rust on the cylinder walls, wipe the walls down with an oily rag. Be careful not to let excessive amounts of oil remain on the walls. Replace the cylinder head, put new oil into the compressor, and prime the lubrication pump. Inspect the "V" belts on the compressor, tightening or replacing as necessary.

245. RECONDITIONING THE THRUST BEARING. Remove the oil seals and drain the oil out of the oil reservoir. Carefully dry off the bearings and working faces of the thrust bearing. replace the oil seal, and fill to the proper level with new lubricating oil.

246. STARTING THE ENGINE. Refill with fresh water system and start the engine in the usual manner. Watch more closely than usual the oil pressure gauge and the circulation in the lubrication oil storage tank. Add more oil if necessary.

247. FUTURE OPERATIONS. After an engine has been submerged and reconditioned in the emergency manner described here, there is always the possibility that trouble will be encountered later. Parts which appeared to be in good condition may fail. At the first convenient time, the engine should be completely overhauled by machinists having full facilities available.

SECTION XXIV
TROUBLE SHOOTING

ENGINE FAILS TO TURN OVER WHEN CONTROL LEVER IS DEPRESSED TO STARTING POSITION

	PROBABLE CAUSE	REMEDY
1.	AIR PRESSURE IN TANKS LOW	Shut off tanks always in use and open up spare tank. CAUTION: close usual tanks before opening spare. Pump up pressure to 200-250 pounds.
2.	VALVES CLOSED IN AIR SUPPLY SYSTEM	Start from the engine and open all air valves between the engine and storage tanks.
3.	AIR STARTING VALVE STUCK OR LEAKING	This will be indicated by a hissing noise. Remove all bonnets and, while someone depresses control handle for starting, listen to detect faulty valve. Remove and replace with spare as shown in Sect. X.
4.	AIR NOT BEING BLED FROM AIR STARTING CONTROL VALVE	If this condition exists, gauge may show good air pressure. Inspect pilot valve on top of air starting valve and check for clogs in line. If trouble is not found, open up air starting control valve and inspect for a stuck valve, first shutting off the air supply to engine. Clean all parts well and reassemble.
5.	AIR STARTING VALVES IMPROPERLY TIMED	Adjust timing.

ENGINE TURNS OVER ON AIR BUT FAILS TO START

	PROBABLE CAUSE	REMEDY
1.	LACK OF FUEL	Check storage tank for fuel supply, see if valve is open. If no trouble here, bleed entire system, as explained in Sect. V.
2.	FUEL INLET PIPE OR FILTER CLOGGED	Check filter first. If clogged, clean or replace, after blowing out the supply line to remove any clogs in it.

PROBABLE CAUSE	REMEDY
3. AIR IN FUEL LINES	Bleed fuel system as explained in Sect. V.
4. WATER IN FUEL	Drain fuel system and refill with clean fuel, bleed system as in Sect. V.
5. FUEL CONTROL LINKAGE STUCK IN OFF POSITION	Find obstruction holding linkage closed and remove. Move linkage in and out and oil at necessary places to aid in freeing linkage.
6. STUCK PISTON RINGS	This should only occur after 5,000 hours of operation. Remove pistons and clean, remove rings, clean grooves, and replace as explained in Sect. XI.
7. INJECTION PUMP TIMING IMPROPERLY SET	Adjust timing.
8. LACK OF COMPRESSION DUE TO VALVE STICKING	Free valves and deposit oil on stems.
9. VALVES RIDING OPEN	Adjust hydraulic lifters.
10. VALVES NOT SEATING PROPERLY	Reseat valves.
11. INCORRECT CLEARANCE BETWEEN TOP OF PISTON AND TOP OF CYLINDER BLOCK	Adjust clearance.
12. RINGS OR CYLINDER LINERS WORN	Same as No. 6.
13. CRACKED PISTON	Replace.

ENGINE STOPS OR SLOWS DOWN WHILE RUNNING

PROBABLE CAUSE	REMEDY
1. FUEL TANK RUNNING DRY	If necessary refuel. If there is fuel in the tank, check to see that vent is not obstructed or plugged. If tanks are not vented, air does not replace liquid drawn off, creating vacuum that holds contents in tank.
2. AIR INTAKE MANIFOLD OBSTRUCTED	Remove air intake filters, wash out dirt, and replace.

PROBABLE CAUSE	REMEDY
3. **PISTON SEIZURE**	Usually noticed by the piston giving off a high pitched squeak until it freezes. If squeak is heard, put engine control handle into neutral. To find cause, check temperature of jacket water and lubricating oil as well as lubricating oil pressure, since the trouble has been caused by the failure of the cooling or lubrication system. Remove piston as explained in Sect. XI, and if necessary replace both the piston and cylinder liner. Make indicated repairs to lubrication and cooling system. When ready to start up again, make visual inspections of raw water discharge, jacket water circulation and lubrication oil circulation. If these systems are not functioning, shut down until trouble is corrected.
4. **FOULED PROPELLER**	If engine is running normally and suddenly acquires a new load and then gradually dies and stops, the propeller should be inspected and any cable, rope, etc., removed.
5. **EXHAUST MANIFOLD CLOGGED**	Clean manifold.

ENGINE RUNNING NORMALLY SUDDENLY DROPS LOAD AND SPEED IS NORMAL

PROBABLE CAUSE	REMEDY
1. **PROPELLER LOST OR SHAFTING BOLTS SHEARED**	If propeller is lost, tow to port if possible, although in certain vessels and under the proper conditions new propeller can be installed. If shaft coupling is disconnected because of sheared bolts, replace with new bolts. If new bolts are not available, remove half of bolts in the next coupling to secure disconnected couplings. CAUTION: If this is done, do not run engine more than half speed either ahead or astern, as shafting is in weakened condition.

ENGINE FIRES IRREGULARLY OR MISSES

PROBABLE CAUSE	REMEDY
1. **BLEEDER VALVE OPEN**	Use pyrometer to find missing cylinder, and close bleeder valve.

PROBABLE CAUSE	REMEDY
2. **AIR INTAKE OR EXHAUST VALVES NOT CLOSING**	Readjust zero lash units as explained in Sect. IX, finding faulty cylinder with pyrometer.
3. **AIR NOT VENTED FROM FUEL LINES**	Make certain accumulator tank vent is open. Bleed all pumps and nozzles as explained in Sect. V. Check for leaks on suction side of fuel transfer pump.
4. **FUEL STORAGE TANK RUNNING DRY**	Cut vessel speed to reduce pitching of ship and permit engine to utilize remaining fuel without missing. Refuel as soon as possible.
5. **WATER IN FUEL**	Remembering oil floats on water, periodically drain out water from drainage valve on the bottom of the fuel accumulator tank as a temporary measure, but drain and refuel when possible. Correct condition permitting water to get into fuel.
6. **HIGH PRESSURE FUEL LINE CONNECTION LEAK**	Find missing cylinder by using pyrometer and examine fuel line serving it from fuel pump to nozzle for leak. If line leaks, replace. If connection leaks, tighten, but only use sufficient pressure to stop leak as connections can be damaged by too much tightening.
7. **CRACKED SEAT ON BALL BLEEDER VALVE**	Find missing cylinder with pyrometer, shut down and replace nozzle holder with spare as explained in Sect. XV.
8. **FUEL NOZZLE PLUGGED; VALVE STUCK**	Shut down engine and replace with spare as explained in Sect. XV.
9. **FUEL CONTROL LEVER IMPROPERLY SET**	Check pyrometer and adjust control lever as explained in Sect. XVI.
10. **FUEL PUMP DIRTY, DAMAGED OR WORN**	Replace with spare pump as explained in Sect. XV.
11. **FUEL TAPPET ROLLER BUSHING BURNED OUT**	This results in inability of fuel pump to complete stroke. Remove cam cover over suspected tappet and replace with spare.
12. **LACK OF COMPRESSION**	If all other inspections fail to locate the trouble, it must be considered due to internal causes, check compression. Remove piston as explained in Sect. XI and replace with spare.

SMOKY EXHAUST

PROBABLE CAUSE	REMEDY
1. **AIR INTAKE FILTERS DIRTY**	This results in the engine's inability to burn all fuel due to lack of air. Remove filter and wash in solvent, drain thoroughly, and replace: CAUTION: DO NOT USE GASOLINE FOR CLEANING AS SOME MAY BE SUCKED INTO ENGINE AND AN EXPLOSION MAY BLOW OFF THE ENGINE HEAD.
2. **NOZZLE VALVE NOT CLOSING**	This permits fuel to drip which is not burned. Replace with spare as explained in Sect. XV.
3. **FUEL TAPPET ADJUSTMENT INCORRECT**	As the fuel is being injected too early or too late, adjust fuel tappet as explained in Sect. IX.
4. **ENGINE OVERLOADING**	Since more fuel is being injected into engine than it can consume, reduce the load. If towing too heavy a load, get help if possible. Overloading of engine more than 10% for short periods only is dangerous.
5. **ONE OR MORE FUEL PUMPS DELIVERING MORE FUEL THAN OTHERS**	Adjust fuel pump control lever as directed in Sect. IX.
6. **RINGS STUCK, OIL SCRAPER RINGS CLOGGED**	In this case, lubricating oil is being forced into firing chamber where it burns. Use bleeder valve on nozzle to cut out one cylinder at time until smoking one is located. Remove the piston, free the rings, and service as explained in Sect. XI.
7. **WORN PISTON RINGS**	Remove piston and install over-size rings. If liner shows wear of more than .040 of an inch, install new liner and regular size rings as explained in Sect. XI.
8. **WRONG FUEL**	Change to type of fuel specified by the manufacturer in Sect. VIII.

ENGINE KNOCKING

PROBABLE CAUSE	REMEDY
1. **FUEL PUMP TIMING WRONG**	As the timing of the fuel pump is too far advanced, causing a knock or ping, check timing as explained in Sect. IX, making necessary adjustments.
2. **NOZZLE STICKING OPEN**	This results in injection reaching cylinder before the proper time to pre-ignite or develop power before piston reaches top dead center. Replace nozzle as directed in Sect. XV.
3. **FUEL CETANE TOO LOW**	Knocking resulting from pre-ignition of the fuel is remedied by using a fuel with a cetane rating recommended by the manufacturer in Sect. VIII.
4. **PISTON PIN BUSHING BADLY WORN OR BURNT**	Bleed fuel nozzles to find affected cylinder, remove piston and connecting rod, and fit new bushing in connecting rod as explained in Sect. XI.
5. **CONNECTING ROD BURNED OUT OR BADLY WORN**	Bar engine to bring suspected cylinder to top dead center. Using a bar as a lever and the bottom edge of the door as a fulcrum, attempt to pry connecting rod upwards. If excessive clearance is found in this manner, change connecting rod bearing shell as explained in Sect. XII.
6. **MAIN BEARING BURNED OUT OR BADLY WORN**	Remove upper bearing cap on suspected cylinder and examine bearing shell. If burned or badly worn remove lower half and replace with new bearing shells as explained in Sect. XIII.

LUBRICATION OIL GAUGE SHOWS LOW OR INSUFFICIENT PRESSURE

PROBABLE CAUSE	REMEDY
1. OIL STORAGE TANK RUNNING DRY	When this condition exists it will be noted that the lubricating oil gauge fluctuates markedly due to pump sucking up a mixture of oil and air. Check amount of oil in storage tank.
2. SUMP PUMP CLOGGED WITH SLUDGE	Open side cover at No. 1 cylinder and clean sump; if necessary, remove and wash out the sump pipes.
3. AIR LEAK IN SUMP PUMP CONNECTION	Check line between the oil sump connection and sump pump, tightening any connections where leaks are found.
4. LUBRICATION OIL FILTER CLOGGED	Clean out lubrication oil filter and replace elements.

LUBRICATION OIL PRESSURE FAILURE

PROBABLE CAUSE	REMEDY
1. SUMP PUMP WORN	Check clearances in sump pump with table in Sect. VIII. If clearances are over maximum allowable, repair.
2. PRESSURE REGULATING VALVE ON LUBRICATION OIL PRESSURE PUMP STUCK OR IMPROPERLY ADJUSTED	In this event oil will be almost flowing over in service tank. Remove lubrication oil pressure regulator, take apart, and clean thoroughly. Replace, start engine, and screw in regulating screw as explained in Sect. XVIII until pressure is normal.
3. LUBRICATION SYSTEM PLUGGED	Drain lubrication oil storage tank and look for rags, waste, etc., plugging outlet pipe and remove. Refill tank to safe level.
4. WORN BEARINGS ON MAIN AND CONNECTING ROD BEARINGS	This condition results in excess clearances through which the oil pressure dissipates. Screw in regulating adjusting screw on lubrication system pressure regulator until normal and as soon as possible replace bearings as explained in Sects. XII and XIII.

PROBABLE CAUSE	REMEDY
5. **AIR LEAK BETWEEN OIL STORAGE TANK AND PUMP**	Check for leaks and tighten pipes found loose or leaking.
6. **LUBRICATING OIL PRESSURE PUMP WORN OR DEFECTIVE**	Check clearances against table of clearances in Sect. VIII. If worn beyond limitations, replace pumps. The lubrication oil and sump oil pumps are the two most efficiently lubricated units in the engine and their failure is improbable except when the engine is worn out.

LUBRICATION OIL PRESSURE EXCESSIVE

PROBABLE CAUSE	REMEDY
1. **LUBRICATION OIL PRESSURE REGULATOR IMPROPERLY ADJUSTED OR STUCK**	Remove and wash regulator thoroughly. Replace and start engine and adjust to normal pressure as explained in Sect. XVIII.
2. **PUROLATOR LUBRICATING OIL STRAINER PLUGGED**	Remove, wash strainer thoroughly, and replace.
3. **MAIN FUEL OIL HEADER PIPE CLOGGED**	Remove, clean out, and replace.

INSUFFICIENT JACKET WATER PRESSURE REGISTERED ON GAUGE

PROBABLE CAUSE	REMEDY
1. **DEFECTIVE GAUGE**	Remove gauge and, if defective, circulation of jacket water in surge tank can be checked visually as it discharges from engine. Replace gauge with spare.
2. **JACKET WATER PUMP AIR BOUND**	Vent the air out of the jacket water pump until water comes out of vent. Check quantity of water in surge tank and fill to normal level if required.

JACKET WATER PRESSURE CORRECT BUT TEMPERATURE EXCESSIVE

PROBABLE CAUSE	REMEDY
1. THERMOSTATIC VALVE INCORRECTLY ADJUSTED	Readjust thermostatic valve to correct operating temperature as explained in Sec. IV.
2. RAW WATER GAUGE FAILS TO RECORD ANY PRESSURE	If gauge is working properly, raw water pump supplying heat exchanger is airbound. Vent air from raw water pump until water comes out of vent.
3. SUCTION END OF RAW WATER PIPE PLUGGED	Clean out suction end of raw water pipe and also clean out sea chest. Reassemble sea chest and suction line, vent air from pump.
4. LEAK IN RAW WATER SECTION LINE ADMITTING AIR	Check raw water suction line for leaks and tighten. Vent pump until water comes out.
5. DISCHARGE SIDE OF RAW WATER PUMP CLOGGED	Clear overboard discharge line.
6. WATER PASSAGES IN ENGINE CLOGGED	Clean out jacket water system of engine with solvent to remove scale and other foreign materials and refill system with clean, fresh water.

ENGINE SPEED NOT CONSTANT

PROBABLE CAUSE	REMEDY
1. GOVERNOR REACTING SLOWLY AT LOW ENGINE SPEEDS	This condition is normal. At low speeds the governor is slow to react. It may be as slow as 25 RPM.
2. PUMP AND CONTROL LINKAGE STIFF OR STUCK	Free all linkage and oil linkage well. The shorter the linkage, the faster the governor will react to speeds and loads.
3. GOVERNOR LINKAGE WORN	Replace all linkage to reduce the slack and be sure it is free and well oiled.
4. FUEL PUMP CONTROL ROD STUCK	Replace fuel pump with spare as explained in Sect. XV.

LUBRICATION OIL PRESSURE CORRECT BUT TEMPERATURE EXCESSIVE

PROBABLE CAUSE	*REMEDY*
1. **FOUR-WAY VALVE TURNED TO BY-PASS OIL COOLER**	Turn four-way valve so oil will flow through lubrication oil cooler, or heat exchanger.
2. **RAW WATER PASSAGES IN OIL HEAT EXCHANGER CLOGGED**	Remove both ends of lubrication oil heat exchanger or cooler and clean out raw water passages.

WATER IN LUBRICATION OIL

PROBABLE CAUSE	*REMEDY*
1. **CRACKED CYLINDER HEAD**	If cylinder head is cracked, jacket water will escape from passages into oil. Replace cylinder head as explained in Sect. X.
2. **SAND HOLE IN LINER**	Inspect suspected liner and replace if hole is found as explained in Sect. XI.
3. **RUBBER RING SEAL IN LINER GONE**	If rubber ring seal missing or damaged in liner replace as explained in Sect. XI.

EXCESSIVE SMOKE FROM ENGINE BREATHER

PROBABLE CAUSE	*REMEDY*
1. **PISTON RINGS STUCK**	Remove piston from suspected cylinder, free and clean rings as explained in Sect. XI.
2. **CRACKED PISTON**	Replace with spare as explained in Sect. XI.
3. **CYLINDER LINER AND PISTONS WORN EXCESSIVELY**	Replace with new liner and rings, if necessary, as explained in Sect. XI.

REVERSING MECHANISM FAILURE

PROBABLE CAUSE	*REMEDY*
1. **REDUCING VALVE SUPPLYING AIR TO AIR MOTOR INSUFFICIENT IN PRESSURE**	Adjust screw on pressure reducing valve until gauge in air line to air motor registers normal. If at sea when failure occurs, use capstan to reverse cams.
2. **REVERSING MECHANISM FAILS TO MAKE COMPLETE REVOLUTION**	Use capstan. Refer to Sect. XVI for adjustment of reversing mechanism.

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