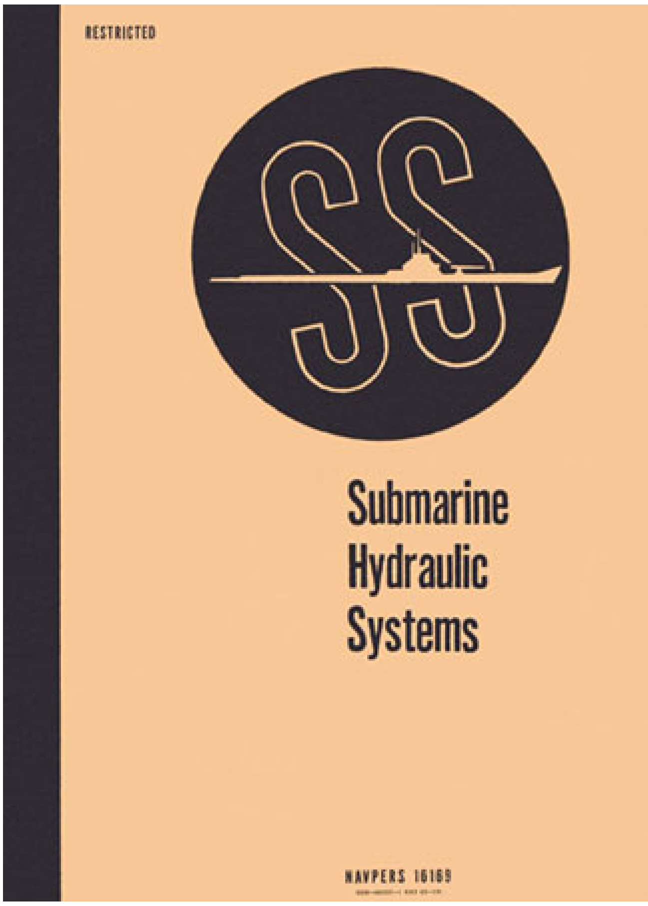
The Fleet Type Submarine Online
Submarine Hydraulic Systems



Folks,

Submarine Hydraulic Installations, Navpers 16169, is one of a series of submarine training manuals that was completed just after WW II. The series describes the peak of WW II US submarine technology.

In this online version of the manual we have attempted to keep the flavor of the original layout while taking advantage of the Web's universal accessibility. Different browsers and fonts will cause the text to move, but the text will remain roughly where it is in the original manual. In addition to errors we have attempted to preserve from the original (for example, it was H.L. Hunley, not CS Huntley), this text was captured by optical character recognition. This process creates errors that are compounded while encoding for the Web. Please report any typos, or particularly annoying layout issues with the Mail Feedback Form for correction.

Our thanks to Shelly Shelstad, creator of History on CD ROM for permitting us to use images he has scanned, particularly the oversized images that were meticulously pieced together. History on CD ROM sells a very nice CD or thumb drive version of this manual in PDF format for easy access off the web and for a printing. Thanks also to IKON Office Solutions (now Ricoh USA http://www.ricoh-usa.com) for scanning services.

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SUBMARINE

HYDRAULIC SYSTEMS

June 1946

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This is one of a series of Submarine Training Manuals. The series includes:

1. The Fleet Type Submarine — NavPers 16160
2. Submarine Main Propulsion Diesels — NavPers 16161
3. Submarine Electrical Installations — NavPers 16162
4. Submarine Refrigerating and Air-Conditioning Systems — NavPers 16163
5. Submarine Distilling Systems — Navpers 16163A
6. Submarine Air Systems — NavPers

PREFACE

This manual, prepared at the Submarine School, New London, Connecticut, is designed for use in both instruction and servicing. It includes complete descriptions of most submarine hydraulic systems of both Portsmouth and Electric Boat Company design as well as discussions of their operating principles and a detailed description of the operation, installation, and repair of each part. Trouble shooting is presented as a separate chapter, outlining in chart form, troubles, causes, and remedies.

Step-by-step work sheets, or job analyses, are included by systems for the more common inspection, service, and repair routines. Free use is made of cutaway and schematic drawings to define operating principles and maintenance procedures.

It is recognized that equipment design is subject to change as new requirements are taken into account, and as recommendations of the forces afloat are acted upon. Consequently, the descriptions and discussions included must be considered as generally typical rather than as final and specific in all details.

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A. INTRODUCTION

1A1. Increasing use of hydraulic power in modern submarines. In the development of the submarine from pre-war classes, many changes and improvements have occurred. One of the outstanding differences is the large variety of submarine devices which are now operated by hydraulic power. In early classes, there was no hydraulic system, and power requirements were met by means of air or electricity. Along with constantly improving submarine design has gone a constant extension and diversification of the use of hydraulic power.

1A2. Other sources of power available on submarines. Why this noticeable trend toward hydraulics? Obviously hydraulic actuation is not the only means of transmitting power throughout the submarine, and the tasks now being done by the hydraulic system were originally performed by hand, electricity, or compressed air.

a. Hand power. Some equipment on a submarine is still operated exclusively by hand, but this practice is rapidly disappearing. This is because the power requirements exceed that which manual effort can provide over electrical units are required. Also it is not ideal when instantaneous stopping of a driving mechanism is demanded, since electric motors have a tendency to "overtravel," or "drift," making fine control difficult to achieve. A further disadvantage in the operation of electrical units is the noise made by relays and magnetic brakes in starting and stopping, and by shafting and other mechanical power transmission units.

c. Pneumatic power. Since compressed air must also be used aboard a submarine for certain functions, this system, which consists of the compressors, high and low pressure air bottles and air lines, provides another source of auxiliary power. However, pneumatic or compressed-air power also has definite shortcomings. Pressure drop caused by leakage, and the mere fact that air is a compressible substance, may result in "sponginess" or lag in operation. The high pressure necessary for compressed-air storage increases the hazard from ruptured lines, with consequent danger to personnel and equipment. Another disadvantage of air systems is that the air compressors require greater maintenance and are relatively inefficient.

long periods of time, and because power operation is faster and can be remotely controlled, thus greatly reducing the communication necessary between crew members.

b. Electric power. Since the electrical plant occupies such a prominent place in the submarine power system and must be used for propulsion in any event, it would be reasonable to expect that electricity would also be used to operate all of the auxiliary equipment as well.

Electricity is ideally adapted for submarine equipment that has few or no moving parts, such as lamps, radios, cooking facilities, and similar devices. But electricity is not so ideal when it is necessary to move heavy apparatus such as rudders, and bow and stern planes, because heavy, bulky

d. Comparative advantages of hydraulic power. Hydraulic systems possess numerous advantages over other systems of power operation. They are light in weight; they are simple and extremely reliable, requiring a minimum of attention and maintenance. Hydraulic controls are sensitive, and afford precise controllability. Because of the low inertia of moving parts, they start and stop in complete obedience to the desires of the operator, and their operation is positive. Hydraulic systems are self-lubricated; consequently there is little wear or corrosion. Their operation is not apt to be interrupted by salt spray or water. Finally, hydraulic units are relatively quiet in operation, an important consideration when detection by the enemy must be prevented.

Therefore, in spite of the presence of the two power sources just described, hydraulic power makes its appearance on the submarine because of the fact that its operational advantages, when weighed against the disadvantages enumerated for electricity and air in the preceding paragraphs, fully justify the addition of this third source of power to those available in the modern submarine.

e. Comparative summary. If we draw up a table of the characteristics of the three power systems, a comparison will reveal the superiority of hydraulics for the operation of auxiliary mechanisms.

FACTOR	AIR	ELECTRICITY	HYDRAULICS
Reliability	Poor	Good	Good
Weight	Light	Heavy	Light
Installation	Simple	Simple	Simple
Control	Valves	Switches	Valves

Mechanism		and solenoids	
Maintenance	Constant attention necessary	Difficult, requiring skilled personnel	Simple
Vulnerability	High pressure bottle dangerous; broken lines cause failure and danger to personnel and equipment	Good	Safe; broken lines cause failure
Response	Slow for both starting and stopping	Rapid starting, slow stopping	Instant starting and stopping
Controllability	Poor	Fair	Good
Quietness of Operation	Poor	Poor	Good

B. THEORY OF HYDRAULICS

1B1. Familiarity of hydraulic principles. For many centuries, man has utilized hydraulic principles to satisfy common, everyday needs. Opening a faucet to fill a sink with water a practical application of hydraulics. Water moves through a dam in accordance with well-known principles of fluid motion. There are hydraulic principles that explain the action of fluids in motion and others for fluids at rest.

We are chiefly concerned, however; with that branch of hydromechanics which is called simply Hydraulics and is defined in engineering textbooks as the engineering application of fluid mechanics. It includes the study of the behavior of enclosed liquids under pressure, and the harnessing of the forces existing in fluids to do some practical dentist chairs are raised and lowered hydraulically; so is an automobile when placed on a hydraulic rack for a grease job. Stepping on the brake pedal in an automobile creates the hydraulic power which stops the rotation of the four wheels and brings the car to a halt.

For an understanding of how a hydraulic system works, we must know the basic principles, or laws, of hydraulics, that is, of confined liquids under pressure. This will be made easier, however, if we first examine the somewhat simpler laws governing the behavior of liquids when unconfined, that is, in open containers.

1B2. Liquids in open containers.
a. Density and specific gravity. The first characteristic of an unconfined liquid which interests us is its density. The density of a

task such as steering a submarine or opening the outer door of a torpedo tube.

Examples of hydraulically operated equipment are familiar to all. Barber or fluid is the weight of a unit volume of it. The unit of volume normally used in this text is the cubic foot; the unit of weight normally used is the pound. The standard of density, to which the

densities of all other liquids are referred, is that of pure water at zero degrees centigrade (32 degrees Fahrenheit), and at sea-level atmospheric pressure.

Let us fill a container with a cubic foot of pure water (see Figure 1-1). We weigh

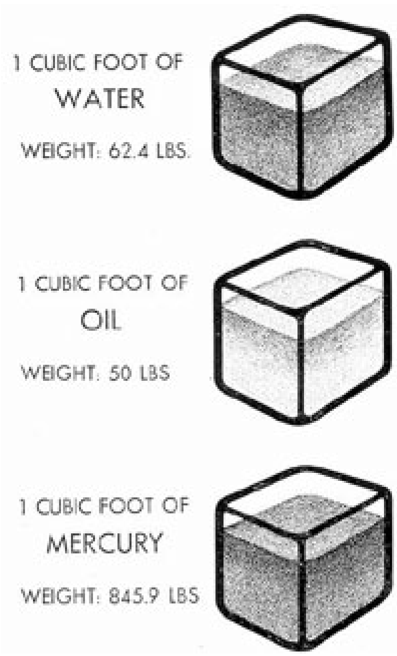

Figure 1-1. Liquids of different densities.

the contents and find it to be 62.4 pounds. This is the density of water. Under the same conditions, a similar volume of oil, such as is used in a submarine's hydraulic system weighs approximately 50 pounds; therefore its density is less than that of water. Under the same conditions, a cubic foot of mercury weighs 845.9 pounds; its gravitational pull upon them is compared to the gravitational pull upon an equal volume of water. Water, therefore, is said to have a specific gravity of 1 and the specific gravity of any other substance is its density relative to that of water. Oil has a specific gravity of (50 x 1)/62.4, or approximately 0.8; that is, its density is 0.8 of that of water. This explains why oil floats on water. Mercury, on the other hand, has a specific gravity of (845.9 x 1)/62.4 or about 13.5; that is, its density is 13.5 times as great as that of water; consequently, it sinks rapidly.

These calculations of the weights of water, oil, and mercury were made at zero degrees centigrade (32 degrees Fahrenheit) and at sea level. At other temperatures and altitudes, different results would be obtained. In some engineering calculations, cubic centimeters and grams are used instead of cubic feet and pounds. This does not affect specific gravity, as the relationship between the weight of a unit volume of any other material and of water would be the same no matter what measuring unit were used.

b. Force and pressure. A liquid has no shape of its own. It acquires the shape of its container up to the

density obviously exceeds that of water.

When we speak of the weight of substance, we actually mean the force, or gravitational pull, exerted on the substance at the earth's surface. Every material responds to the earth's gravitational attraction. To express the relative density, or specific gravity, of various liquids and solids, the

level to which it fills the container. However, we know that liquids have weight. This weight exerts a force upon

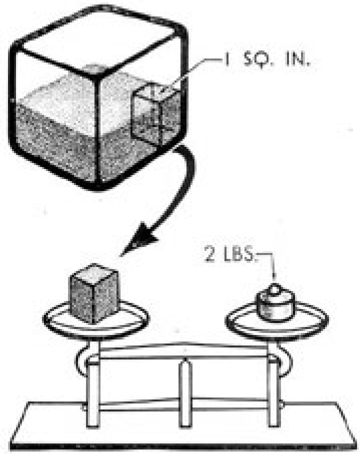

Figure 1-2. Weight of an isolated column of water.

all sides of the container, and this force can be measured.

Let us measure this force in a given container of water (see Figure 1-2).

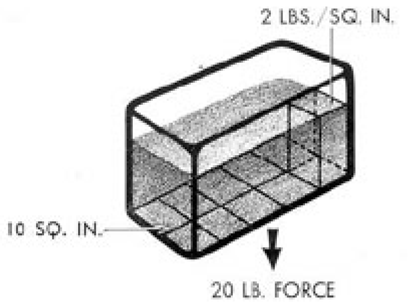

Figure 1-3. Weight=Total Force.

Theoretically, we isolate a vertical column of water whose base is 1 square inch, extending from the bottom of the container to the surface of the liquid. If it were possible to weigh this

pressure, when not otherwise qualified, means pressure in pounds per square inch.

If the bottom of the container has an area of 10 square inches and the pressure on each square inch is 2 pounds, then the force exerted by the water on the bottom of the container is 20 pounds (see Figure 1-3). This is called the total force and is obtained by the formula:

Total Force = Pressure X Area

The pressure exerted by a liquid on the bottom of a container is independent of the shape of the container, and depends only on the height and density of the liquid. In all the dissimilar vessels shown in Figure 1-4, the pressures are identical as long as the liquid levels are equal in height.

What happens if the levels are not equal? Then we do have a difference in pressure. Suppose we have two containers in which the

fluid in A is twice as high as in B (see Figure 1-5). Let us again assume that we have

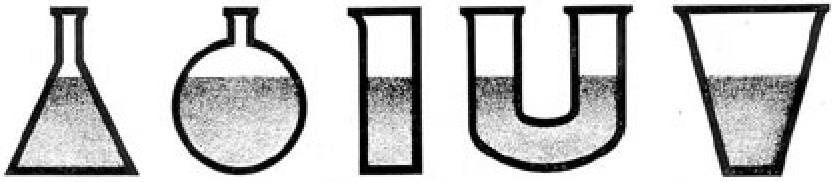

Figure 1-4. Equal levels produce equal pressures.

column and we found the weight to be 2 pounds, we would be able to say that the one inch-square column of water exerts a pressure of 2 pounds per square inch.

Therefore, for unconfined liquids, that is, liquids in open containers, the pressure in pounds per square inch exerted by the liquid on the bottom of the container is equal to the weight of the liquid on each square inch of the bottom of the container. It must be emphasized that the weight of the liquid is here thought of as a force exerted on the bottom of the container. Expressed as a formula, we have:

Pressure = Force per unit area

In this text, as in general engineering practice, it is understood that the word

weighed a one-inch square column from each container. The column from jar A weighs 2 pounds and the column from jar B weighs only 1 pound; therefore the pressure in A is

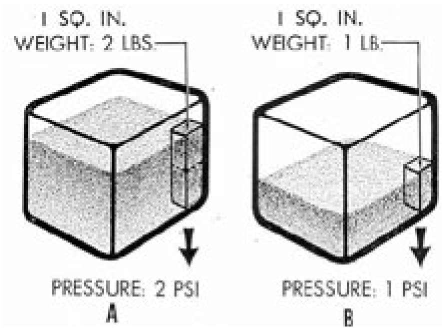

Figure 1-5. Unequal levels produce unequal pressures.

2 pounds per square inch while the pressure in B is only half of that, or 1 pound per square inch.

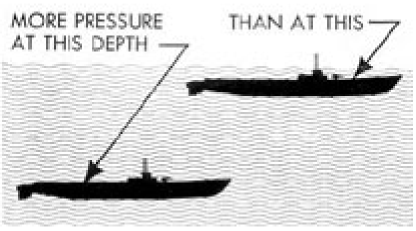

Figure 1-6. Pressure on

other container we have a pressure of 2 pounds per square inch applied to an area of only 5 square inches; and the total force is again 10 pounds. We see, therefore, that a high pressure directed against a small area can be just as effective as a low pressure directed against a large area. It follows from this important law that we are able to

submerged body increases with increasing depth.

In other words, the greater the depth, the greater the pressure will be at that depth. A practical example of the working of this law is seen when a submarine submerges. The deeper the submarine goes, the greater the pressure exerted on its hull by the surrounding water (see Figure 1-6).

The difference in liquid pressures at various levels can also be illustrated in the following way: If we have a tank with openings of equal size at different heights, as shown in Figure 1-7, we find that the liquid will flow out of the lowest opening, where the pressure is greatest, with much greater velocity than from the top opening, where the pressure is lowest.

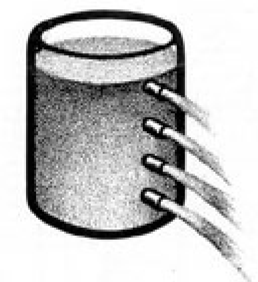

Figure 1-7. Pressure increases with depth.

The importance of this principle of hydraulics can be better understood by considering its following application.

Figure 1-8 shows two containers. In one container, we have a pressure of 1 pound per square inch exerted on an area of 10 square inches; the total force is 10 pounds. In the reduce the size of hydraulic units by merely increasing the pressures in order to obtain the same required working force-one of the many great advantages offered by hydraulic power for applications where the saving of space is a consideration.

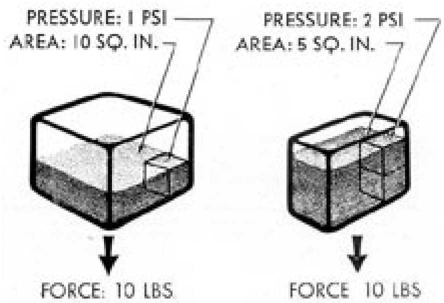

Figure 1-8. Equal total forces from unequal pressures.

1B3. Liquids in enclosed systems. Some of the general properties of liquids in open containers have been described. It remains to discuss how a liquid will behave when confined, for, example, in an enclosed hydraulic system.

a. Liquids are practically incompressible. The following two basic principles will help to explain the behavior of liquids when enclosed:

1. Liquids are practically incompressible in the pressure ranges being considered. Stated simply, this means that a liquid cannot be squeezed into a smaller space than it already occupies.

2. Therefore, an increase in pressure on any part of a confined liquid is transmitted undiminished in all directions throughout the liquid (Pascal's principle). For example, if pressure is applied at one end of a long pipe, the liquid, being practically incompressible, will transmit the pressure equally to every portion of the pipe.

Figure 1-9 shows a simple experiment which illustrates both these principles. A thin bottle is filled to the top with a liquid and tightly corked. A lever is pressed against the

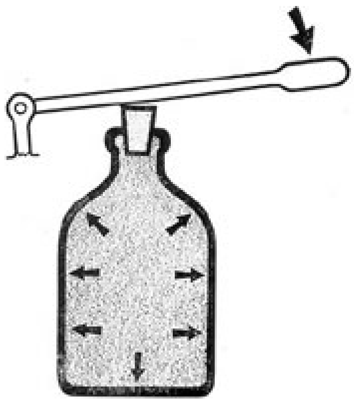

Figure 1-9. Applied pressure Is exerted equally in all directions.

cork to apply a downward force. If sufficient pressure is exerted, the bottle will suddenly shatter into a number of pieces, showing that:

a) Liquids are practically incompressible.
b) The applied pressure is transmitted equally in all directions at once.

Figure 1-10 illustrates the application of these principles to a closed hydraulic system. Two cylinder each having a base whose area is 1 square inch, are connected by a tube. The cylinders are filled with liquid to the level shown, and a piston with a base of the same area (1 square inch) is placed on top of each column of liquid. Then a downward force of 1 pound is applied to one of the pistons. Since this piston has an area of 1 square inch, the pressure upon it is 1 pound per square inch; and the piston in the smaller cylinder; and again the pressure exerted is 1 pound per square inch. Now, since this pressure is transmitted equally in all directions throughout the confined liquid, an upward pressure of 1 pound per square inch will be exerted on the piston in the larger cylinder; and since this larger piston has a total area of 10 square inches, the total force exerted on the larger piston is 10 pounds. Actually, what is happening is that an upward force of 1 pound is being exerted against each square inch of bottom surface of the larger piston; and since the area of this surface is 10 square inches, the total force is equal to the downward pressure on the small piston (1 pound per square inch) multiplied by the area of the larger piston (10 square inches); or, 1 (pounds per square inch) X 10 (square inches) = 10 pounds (total force exerted on larger piston). In other words, the ratio between the force applied to the smaller piston and the force applied to the

since the other piston is of equal area, the same pressure, 1 pound per square inch, will be imposed upward upon it.

b. Increase of force with area. We are now ready to consider a remarkable fact which follows from the principles just discussed, and which is illustrated in a simplified manner in Figure 1-11. Here a cylinder whose base has an area of 1 square inch is connected to another cylinder whose base has an area of 10 square inches. Again a force of 1 pound is applied to

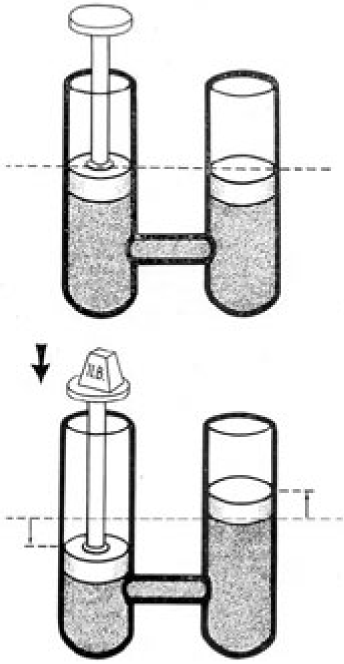

Figure 1-10. Transmission of equal pressures to equal areas.

larger piston is the same as the ratio between the area of the smaller piston and the area of the larger piston. Expressed as a proportion, then, we have:

Force on larger piston/Force on smaller piston =
Area of larger piston/Area of smaller piston

This means that the mechanical advantage obtainable by such an arrangement is equal to the ratio between the areas of the two pistons.

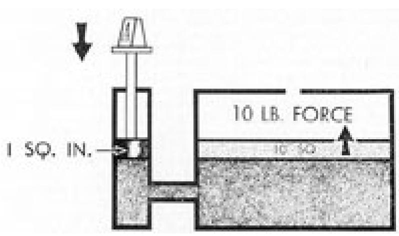

Figure 1-11. Equal pressure transmitted to larger area.

It is this principle, discovered by Pascal, which makes possible the tremendous forces attainable in certain hydraulic devices, such as the hydraulic press, and hydraulic hoists.

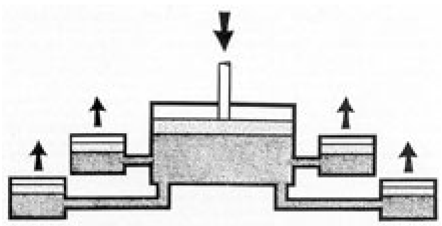

Figure 1-12. Multiple units from a single source of power.

Now let us once more consider the arrangement shown in Figure 1-10. Since the cylinders (and pistons) are of equal area, pushing the liquid down a distance of 1 inch in one cylinder will force it upward a distance of 1 inch in the other cylinder. In other words, the displacements of liquid are equal. But, in Figure 1-11, since the area of the larger cylinder is 10 times as great as that of the smaller cylinder, pushing the smaller piston downward

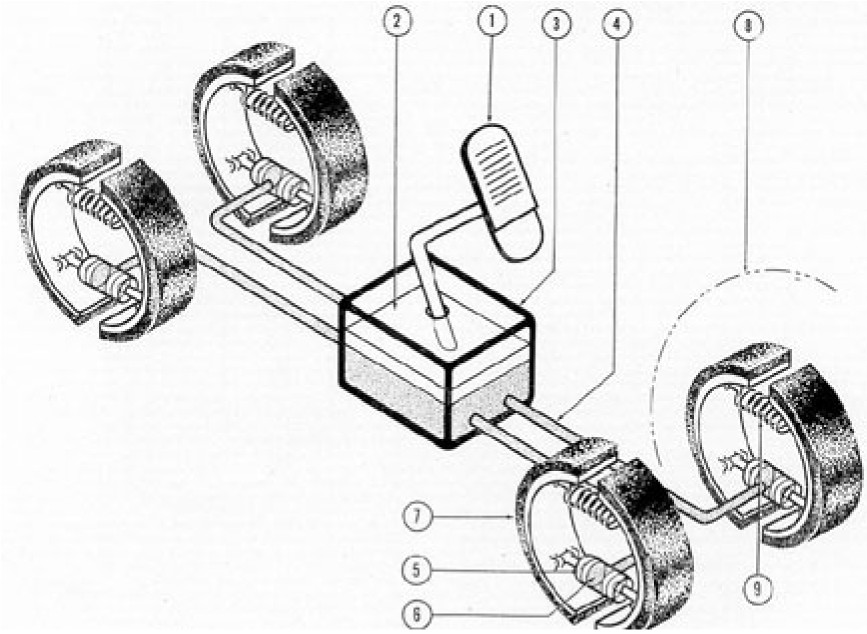

Figure 1-13. Automobile hydraulic-brake system.
1) Brake pedal; 2) piston; 3) master cylinder; 4) hydraulic line; 5) brake cylinder; 6) brake piston; 7) brake band; 8) wheel; 9) return spring.

a distance of 1 inch will move the larger piston upward only 1/10 of an inch. The ratio between the displacement of liquid in the smaller cylinder and the displacement of liquid in the larger cylinder is once again equal to the ratio between their areas.

Therefore, we may say that what the larger piston gains in force, it loses in distance traveled, so that the amount of work (force X distance) done by the larger piston is exactly the same as the amount done by the smaller piston.

c. Multiple units. It is not necessary to confine our system to a single line from the source of hydraulic power. Hydraulic power may be transmitted in many directions to do multiple jobs.

Let us connect one cylinder to four others as in Figure 1-12.

elementary methods are practical enough where small forces or small volumes of fluid are required. However, more often a far greater passage of energy, more or less continuous in its delivery of fluid, is needed in a system.

In other words, in practice we usually need some device which will deliver, over a

Here we apply a force against the piston in the large cylinder. The pressure from the large cylinder is transmitted equally to each of the pistons in the other four cylinders.

This is actually the method of operation of an automobile hydraulic-brake system (see Figure 1-13). The foot pressure on the brake pedal (1) depresses a piston (2) in the master cylinder (3). Fluid is forced through the lines (4) into each of the brake cylinders (5). At the brake cylinder, two opposed pistons (6) attached to the brake shoes are forced outward, pressing the brake bands (7) against the inside of the wheels (8) to stop their rotation by friction. Removal of the foot pressure allows springs (9) at each wheel to restore the pistons to their original positions and returns the fluid to the master cylinder where it is stored in preparation for the next braking operation.

1B4. Pumps. a. Need for pumps. In all our illustrations, we have seen that in an enclosed system a working force was created by the displacement of fluid. A weight, acting on a piston in one cylinder, forced fluid through a line, thus moving a piston elsewhere in the system. In the hydraulic brake system, foot pressure on the pedal displaced the fluid in the master cylinder and forced it into the brake cylinders to stop wheel rotation. These

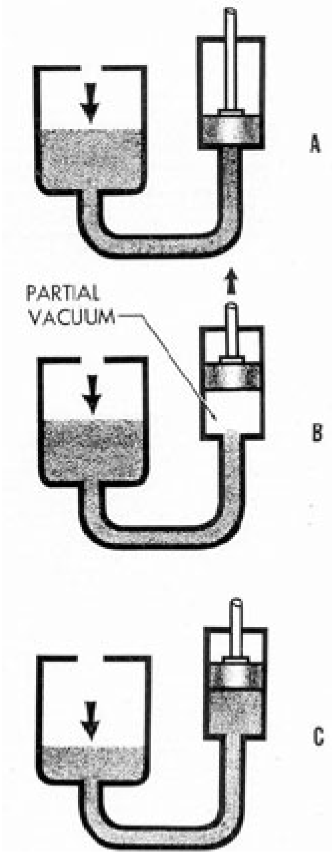

Figure 1-14. Principle of a suction pump.

period of time, a definite volume of fluid at the required pressure, and which will continue to deliver it as long as we desire it to do so. Such a device is called a pump.

b. Basic principles of pumps. A hydraulic pump is a mechanical device which

forcibly moves, or displaces, fluids. Various pumping principles are employed in the different types of hydraulic pumps, but one fundamental principle applies to all: a volume of fluid entering the intake opening, or port, is moved by mechanical action and forced out the discharge port.

The basic principle underlying the action of a hydraulic pump is illustrated by the simplified device shown in Figure 1-14. The larger chamber, or reservoir, is connected by a pipe to the smaller chamber, or cylinder. A piston, free to slide up or down within this cylinder, is connected by a piston rod to a pump handle (not shown). The reservoir is filled with liquid to the height shown.

The illustration shows the device in three different conditions. At A, the piston is assumed to be resting squarely on top of the column of liquid, that is, there is no intervening space between piston and liquid. At B, the piston has just been pulled upward by the pump handle, creating a lower pressure in the lower half of the cylinder, that is, in the space now left between the bottom face of the piston and the top of the column of liquid. At C, the pressure of the atmosphere, acting on the surface of the liquid in the reservoir, has forced the liquid up into the cylinder, filling the empty space with a compensating amount of liquid out of the reservoir; the level in the reservoir consequently falls, as shown.

leakage to a minimum, since excessive leakage destroys the efficiency of a pump. Both the inlet and outlet ports are equipped with check valves which permit the liquid to flow in one direction only, as shown by the arrows.

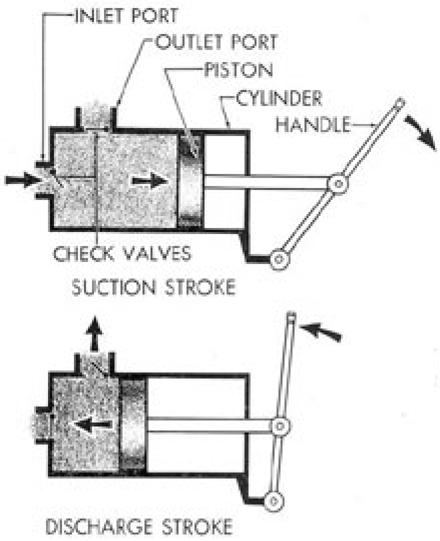

Figure 1-15. Hand-operated reciprocating pump.

Assume that the intake side of the pump is connected to a supply of liquid. When we move the piston to the right, lower pressure is created in the chamber formed by the piston. Higher pressure on the fluid outside the chamber forces fluid in through the inlet port and fills the chamber. Moving the handle forward in the opposite direction forces the fluid out. A check valve at the inlet port prevents flow there and, since the fluid must find an outlet somewhere, it is forced out through the discharge port. The check valve at the discharge port prevents the entrance of fluid into the pump on the subsequent suction stroke. The back-and-forth movement of the piston in the pump is referred to as reciprocating motion, and this type of pump is generally known as a reciprocating-type piston pump. It may have a single piston

It should be clearly understood that the illustration (Figure 1-14) greatly exaggerates the size of the empty space, or partial, vacuum, left by the, piston as it rises in the cylinder. Actually, if a working model of the illustrated device were to be constructed of glass, no space of any kind could be observed because as the piston rises in the cylinder, the liquid rushes in practically instantaneously follow the rise of the piston.

c. The reciprocating pump. The simplest practical application of this principle is seen in the hand-operated reciprocating pump, a simplified version of which is illustrated in Figure 1-15. Here the inlet and outlet ports in the cylinder, or pump body, are both in the same side of the piston. The piston makes a close sliding fit within the cylinder, reducing or be multi-pistoned. It may be hand-actuated or power-driven. The reciprocating piston principle is conceded to be the most effective for developing high fluid pressures.

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d. The theory of suction. In a discussion of reciprocating pumps, the word suction may be frequently used. Some writers use it as though it referred to an independent force created in the pump itself. It must be emphasized that suction is merely an expression of the difference between two unequal pressures. In this case, the atmospheric pressure, amounting to 14.7 pounds per square inch at sea level, acts as a downward force on the liquid in the reservoir.

Raising the piston, that is, pulling it away from the surface of the liquid, creates a partial vacuum, operating principle is illustrated, in simplified form, in Figure 1-16. Here the mechanical action which moves the fluid is furnished by the teeth of the rotary gears. The oil is trapped by the gear teeth and carried by them around the outside channels of the pump body. This sucks in oil at the inlet port (the left-hand port in the figure), and discharges it at the outlet port (the right-hand port in the figure). The oil cannot get back through the outer channels to the inlet side of the pump because the gear teeth fit too closely against the pump body. On the other hand, the oil cannot pass back between the gear teeth themselves at the point where

or an area of lower pressure, between the liquid and the bottom surface of the piston.

Therefore, as the piston moves upward in the cylinder, atmospheric pressure forces the liquid in the connecting pipe to follow the piston. This fact is the basis of a simple pumping operation involving "suction." It also explains why there is a limit to the height to which a suction pump can move a liquid under atmospheric pressure, since the liquid cannot be "pulled" to a greater height by the pump than atmospheric pressure will push it.

For water at sea level this limiting height is theoretically 33 feet, but this figure is never attainable in practice. The imperfections of actual pumps reduce the limiting height to 25 feet or less, depending on the efficiency of the individual pump.

For liquids other than water, the limiting height varies inversely as the density (weight per cubic foot) of the liquid; in other words, the lighter the liquid, the higher atmospheric pressure will push it when the liquid is pumped.

e. The gear pump. Another widely used type of pump is the rotary gear pump whose they mesh with each other because they mesh so closely that, in effect, they form a continuous seal at this point. Therefore a continuous flow of oil is set up in the direction shown by the arrows. This flow continues as long as the gears continue to rotate. Pumps using the gear principle are popular because of their quiet performance and because their simplicity of design results in relative freedom from service troubles.

1B5. Hydraulic fluids. Almost any free-flowing liquid is suitable as a hydraulic fluid, as long as it will not chemically injure the hydraulic equipment. For example, an acid, although free-flowing, would obviously be unsuitable because it would corrode the metallic parts of the system.

Water, except for its universal availability, suffers from a number of serious defects as a possible hydraulic fluid. One such defect is that it freezes at a relatively high temperature, and, in freezing, expands with tremendous force, destroying pipes and other equipment. Also, it rusts steel parts; and it is rather heavy, creating considerable amount of inertia in a system of any size.

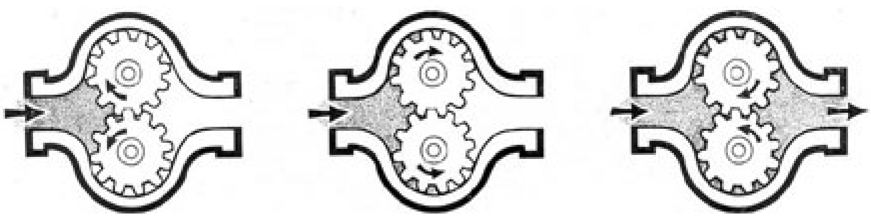

Figure 1-16. Rotary gear pump.

The hydraulic fluid used in submarine hydraulic systems is a light, fast-flowing lubricating oil, which does not freeze or even lose its fluidity to any marked degree even at low temperatures, and which possesses the additional advantage of lubricating the internal moving parts of the hydraulic units through which it circulates.

Since this oil, a petroleum derivative, causes rapid deterioration of natural rubber, synthetic rubber is specified for use in these systems as packing and oil seals.

1B6. A simple hydraulic system. On the basis of the explanation of basic hydraulic principles just given, it is possible to construct a simple, workable hydraulic system which will operate some mechanical device. For example, such a system might open and close a door, and hold it in either position for any desired interval.

a. Basic units of a hydraulic system. Such a system is illustrated in Figure 1-17. It necessarily includes the following basic equipment, which, in one form or another, will be found in every hydraulic system:

1. A reservoir, or supply tank, containing oil which is supplied to the system as needed and into which the oil from the return line flows.

2. A pump, which supplies the necessary working pressure.

3. A hydraulic cylinder, or actuating cylinder, which uses the hydraulic energy developed in the pump to move the door.

4. A cut-out valve, by means of which the pressure in the actuating cylinder may be maintained or released as desired.

5. A check valve, placed in the return line to permit fluid to move in only one direction.

6. "Hydraulic lines," such as piping or hose, to connect the units to each other.

The supply tank must have a capacity large enough to keep the entire system filled with oil and furnish additional oil to make good the inevitable losses from leakage. The tank is vented to the atmosphere; thus atmospheric pressure (14.7 pounds per square inch) forces the oil into the inlet, or suction, side of the pump, in accordance with the principle explained in connection with Figure 1-14. The tank is generally placed at a higher level than the other units in the system, so that gravity assists in feeding oil into other units.

The pump is the hand-operated, reciprocating piston type illustrated in Figure 1-15.

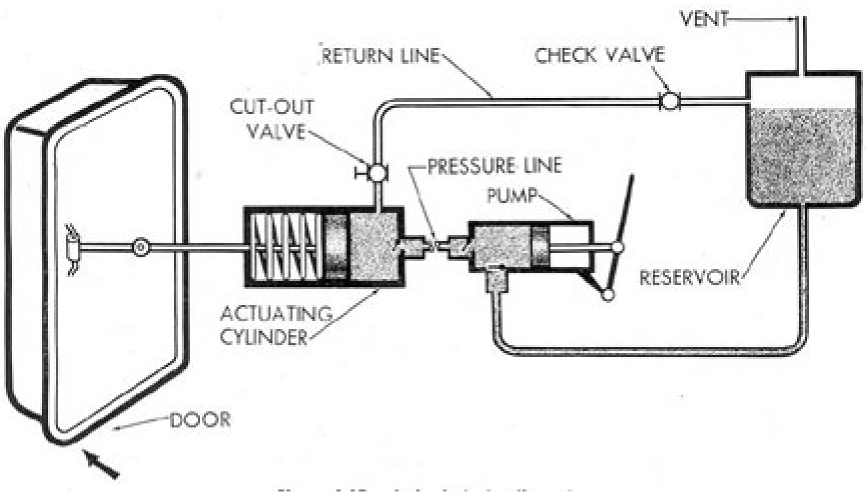

Figure 1-17. A simple hydraulic system.

The surface of the pump piston in contact with the hydraulic fluid has an area of 1 square inch.

The hydraulic cylinder (see Figure 1-18), which is the simplest type of hydraulic motor, contains a spring-loaded piston, with a piston. rod that extends through one end of the

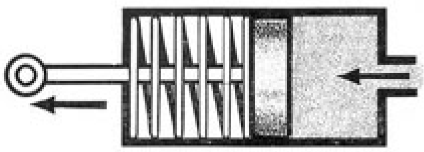
Figure 1-18. Single acting hydraulic cylinder.

cylinder. This piston rod, when connected to the door, supplies the mechanical motion which opens and closes the door. The surface of the piston in contact with the hydraulic fluid has an area of 2 square inches.

The cut-out valve is hand-operated. When closed, it shuts off the line between the actuating cylinder and the supply tank, preventing the oil under pressure in the cylinder from escaping into the return line; when opened, it releases this is forced into the actuating cylinder at a pressure of 100 pounds per square inch. This, then, is the working pressure of the system, the pressure at which fluid is delivered to the actuating cylinder.

Since the piston in the actuating cylinder presents an area of 2 square inches to the fluid -twice as great as the area presented by the pump piston- the total force acting against the piston of the actuating cylinder is 200 pounds, enough to overcome the resistance of the loading spring and close the door. To operate the system, the cut-out valve is closed and the pump handle is moved to the right, drawing in a quantity of oil from the reservoir ("suction stroke"). Then the handle is moved in the opposite direction ("pressure stroke"). The check valve to the reservoir line closes and the check valve to the pressure line leading to the actuating cylinder opens, delivering oil to the actuating cylinder at a pressure of 100 pounds per square inch. The check valve in the actuating cylinder opens,

pressure, allowing the loading spring inside the cylinder to expand, and the oil in the cylinder to escape back into the supply tank.

The check valve (see Figure 1-19) is of the ball spring type. It is shown in two positions. At A, fluid entering the right-hand port under pressure sufficient to overcome the tension of the spring has unseated the ball, allowing oil to pass out through the other port in the direction shown by the arrow. At B, lower pressure on the line entering, the right-hand port has caused the oil pressure and tension spring to reseat the ball check, blocking off the right-hand port, and preventing movement of oil in that direction. The ball, machined to a smooth finish, fits closely into the seat, making a tight seal.

b. Operation of the system. Let us assume that the force necessary to move the door is 200 pounds. Let us further assume that the mechanical advantage of the handle and the muscular effort applied to it result in a force of 100 pounds exerted against the pump piston. Therefore, oil from the piston

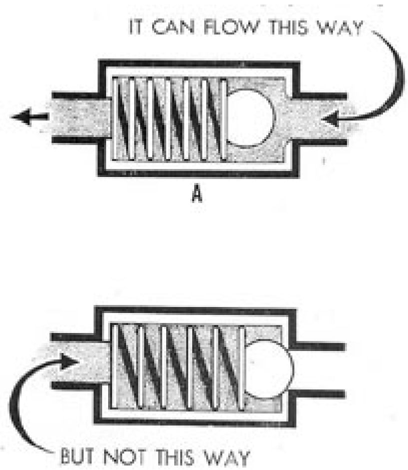

Figure 1-19. Ball check valve.

allowing the oil to enter. The closed cut-out valve prevents the oil from entering the return line, and the oil, acting against the actuating cylinder piston with a total force of 200 pounds, pushes it to the left, overcoming the resistance of the loading spring and closing the door.

The door will remain shut as long as the cut-out valve is in the closed position. As soon as the valve is turned to OPEN, the piston in the actuating cylinder is returned to its original position by the spring. The door opens. Fluid that was locked in the cylinder will be forced out

Automatic pumping will give immediate pressure for use at the actuating cylinder whenever it is needed.

In the simplified system, the door was actuated by a single acting cylinder. Oil was kept in or released from the cylinder by a

through the return line back to the reservoir. It cannot return through the pump because of the check valve. Back-flow of the fluid from the tank into the return line is also prevented by a check valve.

1B7. A power-driven hydraulic system. The door-operating system illustrated in Figure 1-17 is far simpler than is usually found in actual service. It has the obvious disadvantage that instantaneous opening of the door is not possible because pressure is built up slowly by hand pumping.

a. Units of a power-driven hydraulic system. Figure 1-20 illustrates a system in which a motor-driven pump is substituted for the hand pump, a double acting actuating cylinder for the spring-loaded single acting cylinder in Figure 1-17, and including a control valve, an unloading valve, and an automatic relief valve, in addition to the supply tank, or reservoir, and the return line check valve, which are the same as in the first system.

simple "on-and-off" valve. For more efficient and positive actuation, this will be replaced by a double acting cylinder (see Figure 1-21). In such a cylinder, the piston can move in either direction to open or close the door. The piston is locked in the desired position by the hydraulic fluid, which enters either side of the piston as required and remains there until forced out. Since the flow of the fluid must be directed to either of two sides, a valve, which selects the direction of flow, is installed in the line. This is called a control valve. Control valves vary with the specific application, but generally they are equipped with four ports. Two are connected to the actuating cylinder at either side of the piston. A third port is the pressure port and receives fluid from the pump. The fourth port returns surplus fluid either back to the reservoir or elsewhere in the system. Figure 1-22 shows a piston-type, or spool-type, control valve, so called because of the internal piston, or spool, which, as it slides into various positions

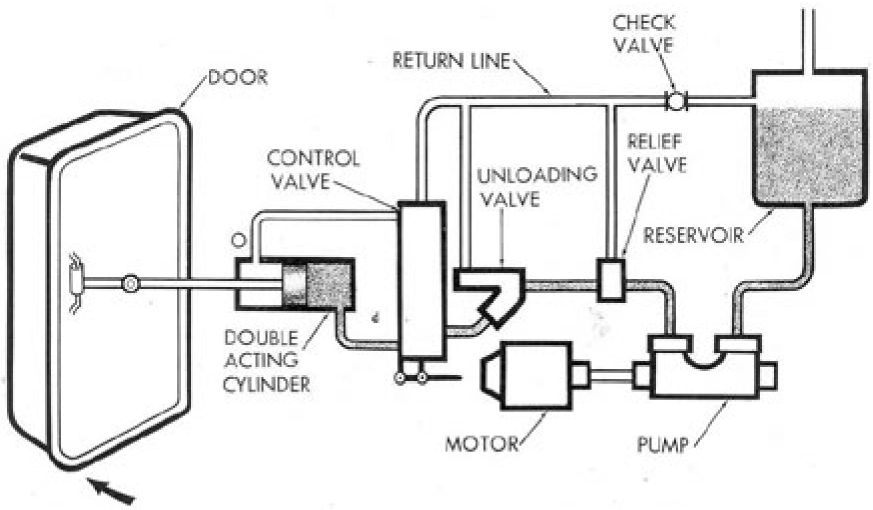

Figure 1-20. Power-driven hydraulic system.

inside the valve body, directs the flow of fluid by opening and closing the desired combination of ports. The grooves permit flow between two of the ports, while the lands at

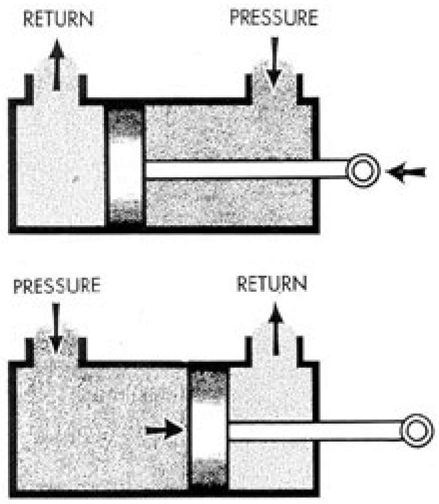

Figure 1-21. Double acting hydraulic system.

both ends of the spool block off the remaining ports.

NOTE: There are types of spool valves other than the type shown in Figure 1-22.

In order to have pressure at all times for the immediate operation of the door, the power-driven pump turns continuously. However, a pressure of 100 pounds per square inch in the cylinder is all that is necessary to move the door, and any pressure greatly in excess of this may damage some of the equipment. To guard against this danger, a relief valve is placed in the pressure line beyond the pump.

The usual construction of a relief valve consists of a valve body containing a valve which is held against a seat by a spring whose tension can be adjusted for any desired operating pressure (see Figure 1-23, A). When the fluid pressure is greater than the spring tension, the spring is compressed and unseats the valve (see Figure 1-23, B), thus bypassing the fluid back into the reservoir.

b. Friction, turbulence, and thermal expansion. Oil, or in fact any liquid driven at high speed through an enclosed system, soon rises in temperature. This is caused by two factors:

1. Friction of the oil against the interior of the pipe lines, valves, and other parts. 2. Turbulence of the oil itself; for example, the swirls and eddies caused in the oil by its coming into contact at relatively high velocity with internal bends, its sudden emergence into wider or narrower places in the system, and so forth.

Friction is caused by the collision of individual oil molecules with the solid walls of pipes and other parts.

Turbulence causes another kind of friction, which is the result of the collisions of oil molecules with each other. Both kinds of

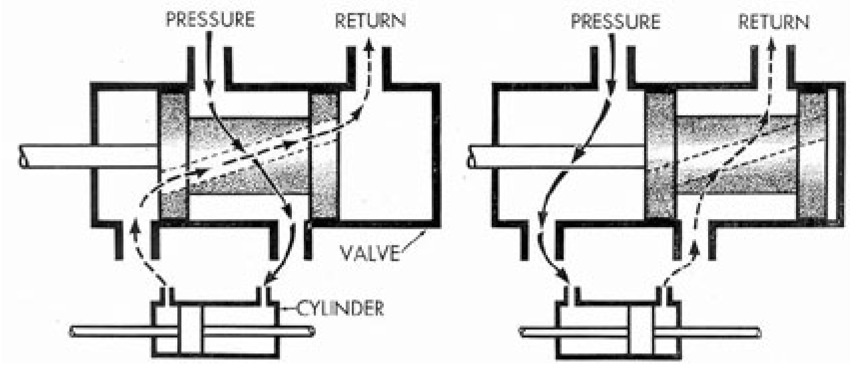

Figure 1-22. Spool-type control valve.

friction cause a loss of power through heat. The rise in temperature of the oil is caused by this friction-heat. The heat also causes a thermal expansion of the oil. Therefore, both heating and expansion inevitably occur whenever hydraulic fluid is pumped continuously through the system, even though it is not in use.

c. Power losses. When we compute the power necessary to operate our system, allowance must be made for power losses which

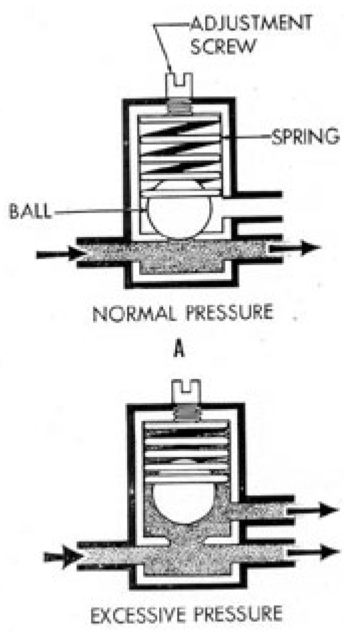

Figure 1-23. Principle of the relief valve.

in fairly straight lines. At high rates of flow, the flow becomes turbulent and friction losses increase. Friction and turbulence losses usually range between 10 percent and 20 percent of the developed power. Instead of getting a 200-pound force to open the door in our system, we may obtain a force of only 160 pounds because of these losses. Therefore, in conformance with good hydraulic design, we must either increase the pump pressure, enlarge the piston area in the actuating cylinder, or increase the size of the pipes and passages to compensate for the loss of energy.

d. Need for a bypass valve in a power-driven system. Since friction always increases with rate of flow, it follows that the greater the rate at which oil circulates in the system -all other things being equal- the more the oil will be heated. Also, the greater the length of the circuit traveled by the fluid during this free, or no-load, circulation, the greater the friction surface and consequent heating. To reduce both the pressure and the length of circuit to a minimum, a bypass valve is provided. This valve returns the oil from the pressure side of the pump directly to the reservoir, or

cannot be prevented. A pressure of 100 pounds per square inch acting upon a piston whose base has an area of 2 square inches should theoretically provide a working force of 200 pounds. However, this is possible only theoretically.

In practice, as fluid passes through the hydraulic lines, it meets resistance from the inner pipe walls. Some of the energy imparted to the oil by the pump is lost in friction. At low rates of flow, the fluid will flow

supply tank, without its first having traveled through the rest of the system. Thus, the bypass valve in effect "short-circuits" the oil pressure from the pump, leaving the oil in the remainder of the system inactive, and reducing the pressure at which the oil circulates to atmospheric pressure.

A bypass valve may be operated by hand or automatically in the same manner as a relief valve, or by remote control. When automatic, it is known as an automatic bypass or unloading valve. In actual practice, an automatic bypass arrangement requires more complex equipment than is shown in Figure 1-23. It is shown here merely in a schematic view, greatly simplified for explanatory purposes.

e. Operation of system using power-driven pump. Since the power-driven pump has been turned on and has come up to its operating speed, hydraulic power at the working pressure becomes constantly and instantaneously available. The automatic bypass,

or unloading valve, and the relief valve will relieve any pressure greatly in excess of this.

To close the door, the control valve handle is turned so that fluid under pressure is directed to the side of the actuating cylinder which is marked d; the movement of the piston closes the door. It also pushes out the fluid which has been trapped on the side of the cylinder marked o. The expelled fluid reenters the

in principle from the simple system we designed and discussed.

Actually a submarine employs not one, but four separate hydraulic systems:

1. The steering system, which operates the rudder.

2. The stern plane system, which tilts the stern diving planes to dive or rise.

system through the return line of the control valve and flows back to the reservoir. To lock the door shut, the control valve handle is turned to its neutral position; the door will then remain shut until the control valve is moved to the OPEN position.

To open the door, the control valve is turned so that fluid enters the actuating cylinder at o. This moves the piston back to the d side of the cylinder and forces out the fluid, which was delivered there when the door was originally closed. The fluid is then returned to the system.

Observe that the two lines connecting the actuating cylinder to the control valve have a dual function. Depending upon which way the hydraulic fluid is directed, one side becomes the pressure line and the other the return line. A change in direction reverses their functions.

During those intervals between opening and closing the door, the fluid circulates between the pump and the reservoir; the automatic bypass valve short-circuits the pressure from the pump, as explained above.

1B8. Practical hydraulics on the submarine. In an extremely simplified form, we have, just described a basic hydraulic system. In actual appearance the hydraulic equipment installed aboard a submarine may not closely resemble such basic units. Nevertheless, the same principles govern both systems.

In a submarine, a single system actuates a multitude of devices and appears to be far more

3. The bow plane tilting system, which tilts the bow diving planes to rise or dive.

4. The main hydraulic system, which operates the following equipment.

a. Flood and vent valves.
b. Main air induction valve.
c. Bow plane rigging.
d. Windlass-and-capstan in bow.
e. Main engine outboard exhaust valves (in some installations hydro-pneumatic).
f. Torpedo tube outer doors.
g. Emergency power for steering system if failure occurs.
h. Emergency power for bow plane tilting system.
i. Emergency power for stern plane tilting system.
j. Periscope hoists.
k. Vertical antenna hoist.
l. Sound heads.

These functions may vary somewhat among different submarine classes. They represent an accurate picture of the usefulness of hydraulics as applied to the submarine. Moreover, the functions of hydraulics are constantly increasing because hydraulics has proved to be superior as a source of power. Let us summarize its advantages:

a. Lighter weight of units.
b. Controllability in small movements.
c. Low inertia of moving parts.
d. Simplicity.
e. Positive operation.

complete. Stripped to its essentials, each unit is moved by a hydraulic motor which receives its power in the form of fluid pressure from a central pumping plant. The liquid moves through pipes and its flow is directed by valves. Essentially, therefore, the submarine hydraulic system does not deviate

f. Self-lubrication.
g. Little wear or corrosion.
h. Relatively silent operation.
i. System not apt to be disrupted by salt spray or water.
j. Less maintenance.

We are now ready in succeeding chapters to examine each of the systems in detail to see how each system works and how to keep it working in the vent of trouble.

2
SOURCES OF HYDRAULIC POWER

A. INTRODUCTION

2A1. Hydraulic motors. The pressures required to operate the hydraulic equipment are developed by electric motor-driven pumps.

Hydraulic motors, such as actuating cylinders, are generally regarded as the power units. Like other motors, they do not actually create their own power. They merely convert hydraulic power which has been built up elsewhere into mechanical energy. Pumps, therefore, act as the central power supply for the entire hydraulic system by creating pressure in the system.

B. IMO PUMPS

2B1. General description. The IMO pump (see Figure 2-1) is a power-driven rotary pump, consisting essentially of a cylindrical casing, horizontally mounted, and containing three threaded rotors which rotate inside a close-fitting sleeve, drawing in oil at one end of the sleeve and driving it out at the other.

2B2. Detailed description. a. The rotors. The rotors of the IMO pump, which resemble worm gears, are shown in Figure 2-2. The inside diameters of the spiral "threaded portions" of the rotors are known as the troughs of the

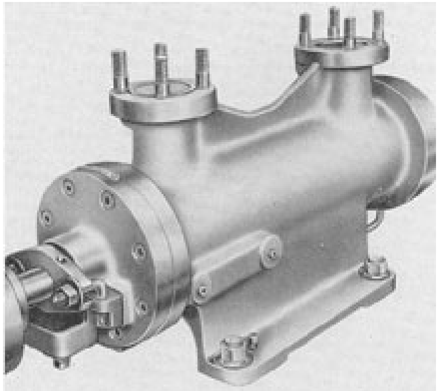

Figure 2-1. IMO pump.

power-driven; its shaft is direct-coupled to an 18-horsepower electric motor which drives it at 1750 revolutions per minute. The other two rotors (6), known as idlers, are driven by the center rotor which, through the intermeshing of its threads with those of the idlers, communicates the shaft power to the idlers and forces them to rotate in a direction opposite to that of the center rotor. The rotation of the center rotor is clockwise as viewed from the motor end of the coupling shaft, while the rotation of the two idler rotors is counter-clockwise.

The end of the power rotor nearest the motor rotates in the guide bushing (9); the rotor shaft extends out through the end-plate, where it couples to the shaft of the electric motor which drives it. Leakage around the shaft is prevented by five rings of 3/8-inch

thread; the outside diameters, or crests, are known as the lands. The troughs and lands of the adjacent rotors are so closely intermeshed that, as they rotate, the meshing surfaces push the oil ahead of them through the sleeve, forming, in effect, a continuous seal, so that only a negligible fraction of the oil trapped between the lands can leak back in the direction opposite to the flow.

A cutaway view of the, pump is shown in Figure 2-3. The center rotor, (5) is

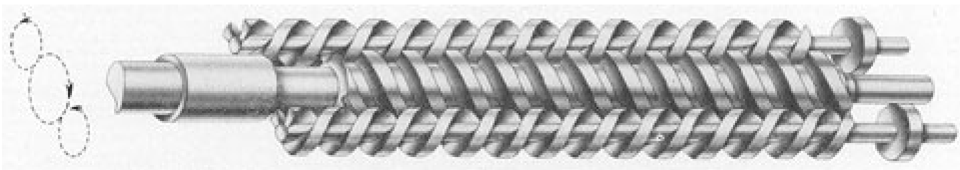

Figure 2-2. IMO rotors.

square flexible metallic packing (8) which is held in place by a packing gland (7). Any oil which does leak through the packing falls into the drip cup (13).

b. The sleeve. It should be emphasized that the rotors are not housed directly within the casing itself (1), but within a removable two-piece sleeve (4) which fits snugly inside the casing proper and can be quickly removed and replaced as soon as it shows signs of wear. The two pieces of which the sleeve consists are bolted together near the center of the casing, as shown, by the sleeve bolts (14). The sleeve is secured against longitudinal drift by the two adjusting bolts, one of which (10) is shown in the cutaway. Rotary motion is prevented by three

The casing contains two ports, the suction port (15), which receives oil from the supply tank at a pressure of from 10 to 25 pounds per square inch, and the discharge port (16) from which it is discharged into the system.

c. Elimination of axial thrust; the balancing connection. It must be remembered that the function of a pump is merely to displace fluid by mechanical action. This displacement will of in itself create any pressure throughout the fluid being pumped unless the movement of the fluid encounters resistance somewhere in the system beyond the point at which it is discharged from the pump. The working pressure of the main hydraulic system, of which the two IMO pumps are the power supply units, runs between 600 and 700

taper pins (not shown in the cutaway) which project into the sleeve and bearing block from the casing.

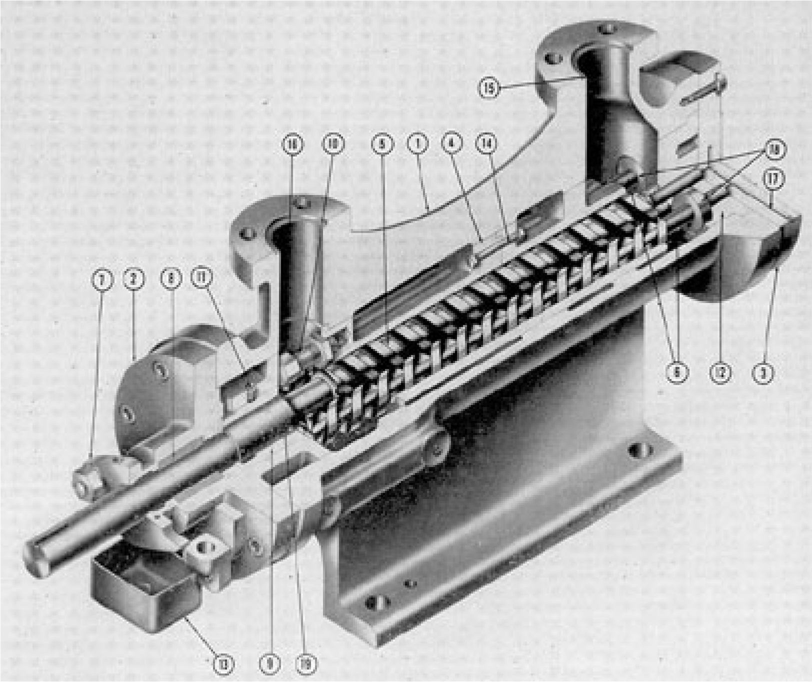

Figure 2-3. Cutaway of IMO pump. 1) Casing; 2) end cover; 3) end cover; 4) rotor housing; 5) power rotor; 6) idler rotors; 7) packing gland; 8) packing; 9) guide bushing; 10) adjusting bolts; 11) jam screw; 12) bearing block; 13) drip cup; 14) sleeve bolts; 15) suction port; 16) discharge port; 17) equalizing channel; 18) collars; 19) bearing journal.

pounds per square inch. It is prevented from exceeding this value by relief valves and an automatic bypass, or unloading, valve (see Chapter 1, page 15). But it will not reach this working pressure, or in fact any pressure above the 10- to 25-pound "back-pressure" at which the oil enters the suction side of the pump from the supply tank, unless the oil being driven out of the discharge side of the pump encounters a corresponding resistance somewhere else in the system. In short, when the hand bypass valve is open, the oil circulates at no-load, that is, at the same pressure as the involved. Therefore this axial thrust must be equalized or balanced in some way.

To supply this balancing or equalizing force, a small pipe, called the balancing connection is provided. This connection permits oil from the discharge end of the pump to flow into the equalizing channel (17, Figure 2-3) in the end-plate at the suction side of the pump. Figure 2-4 shows the balancing connection.

The cutaway, Figure 2-3, shows the equalizing channel (17) in the end-plate. A study of the cutaway will show that from the equalizing channel, three lines open from the endplate into the bearing block at

pressure existing in the supply tank or reservoir.

Since pressure existing anywhere in an enclosed liquid is transmitted equally in all direction's (see Chapter 1, page 5), it follows that any pressure which the intermeshed rotors have developed in the oil by the time it reaches the discharge end of the sleeve will be exerted against every surface with which this oil is in contact, including the threads of the rotors themselves. In other words, if the full working pressure of from 600 to 700 pounds per square inch is developed at the discharge port, a pressure equal to 600 to 700 pounds per square inch would necessarily be exerted against the rotors in the direction

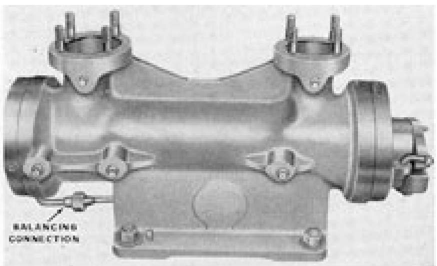

Figure 2-4. IMO pump showing pipe plugs and balancing connection.

opposite to which the oil was being moved by the rotors. This pressure would then express itself as an axial, or longitudinal, thrust tending to force the rotors against the bearing block (12, Figure 2-3). This would naturally result in excessively high friction, with consequent rapid wear of all moving parts the points where the ends of the rotor shafts extend into it. The function of this equalizing channel is to allow the oil to bear against the ends of the rotor shafts at the suction side of the pump with the same pressure which it is exerting against them at the discharge end. In effect, the three rotors are floated between equal oil pressures exerted against their opposite ends, thus eliminating axial thrust. The ends of the shafts of the idler rotors (6) are fitted with collars (18) to locate the axial position of the rotors. Another compensating area for elimination of axial thrust against the center rotor is seen at the bearing journal (19), which forms a shoulder on the shaft just at the point where the journal enters the guide bushing.

The IMO pump is ideally adapted for continuous, long-term service. It is quiet and efficient in performance, requiring a minimum of attention.

2B3. Operating instructions. Before an IMO pump is started for the first time, the motor wiring should be checked for proper rotation as indicated by the arrow on the pump casing. To start the pump, open the quick-throw valve at the supply tank, and the-quick-throw valve and hand bypass valve on the main supply manifold. Then turn the motor switch to ON. If the pump is unusually noisy when started, it should be shut down immediately and the system investigated for a clogged line, dirty strainers, or a closed valve which prevents the flow of hydraulic fluid.

2B4. Maintenance. Once the pump is in service, it requires no attention other than an occasional inspection for leakage at the packing gland. If, however, excessive leakage occurs, the packing must be replaced.

To replace packing, remove the two packing-gland nuts as shown in Figure 2-5. Pull out packing gland and remove the packing.

After new packing has been assembled, the nuts should be tightened enough to seat the metallic packing rings, and then backed off and set up again without using a wrench. Excessive gland pressure on the packing causes scoring of the shaft as well as rapid deterioration of the packing. Adjust the gland nuts about finger tight. The final adjustment should be made with the pump running.

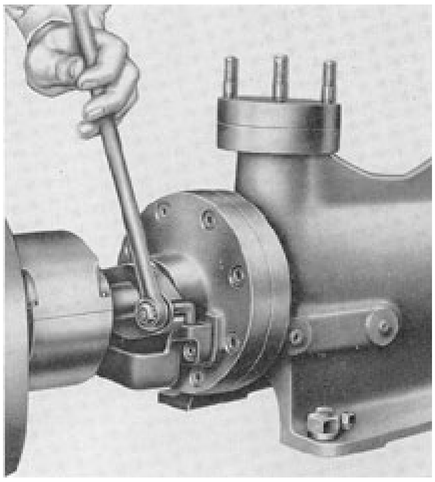

Figure 2-5. Removing packing gland nut.

2B5. Disassembly and re-assembly. When it becomes necessary to overhaul the IMO pump, its disassembly is quite their positions should be marked with a prick-punch so that they may be replaced in their original holes.

b. Removing end-plates. Taking off the two end-plates (2 and 3) then frees all of the inner parts for removal.

c. Removing sleeve. The two halves of the sleeve (4, Figure 2-3), which are shown bolted together in the illustration, are fitted together in a step joint. Mark the parts with a prick-punch so that they may be reassembled in their original arrangement. The sleeve is maintained in its correct longitudinal position within the casing by the adjusting bolts (10). The settings of the adjusting bolt should not be altered during disassembly.

d. Replacing guide bushing. When replacing the guide bushing (9), be sure it is firmly secured by the jam screw (11).

e. Renewing sleeve. When it is necessary to renew the sleeve, the two halves of the new sleeve must be carefully fitted so that the inner and outer surfaces of the one half line up with those of the other. They are then bolted together and installed in the pump, and aligned longitudinally by the adjusting bolts. These should be so adjusted that the shoulder on the discharge end of the sleeve fits tightly against the counterbore at that end of the casing. These adjusting bolts are necessary to correct for individual differences in longitudinal dimensions resulting

simple (see Figure 2-3). Proceed as follows:

a. Removing taper pins. On one side of the pump (see Figure 2-4), are three pipe plugs. Each one holds in place one of the taper pins mentioned in Section 2B2b, which must be removed as the first step in disassembly. These pins are individually fitted to their holes to insure correct alignment of the sleeve and bearing block. Before removal,

from tolerances allowed in manufacture.

Also, the length of that portion of the adjusting bolt which protrudes from the tapped hole in the sleeve must be sufficient to bear tightly against the inner face of the end-plate. It must be tight enough to hold the sleeve in position, but not sufficient to prevent the end-plate from being bolted solidly to the casing. In practice, the proper adjustment of the adjusting bolt is determined by taking a trial setting. First, bolt on the end-plate, without the paper gasket; then estimate the additional clearance needed between the end-plate and the casing, allowing for the thickness of the gasket; screwing in the adjusting screws to the estimated clearance around in the trial setting will then bring the sleeve into longitudinal alignment.

C. THE WATERBURY SPEED GEAR

2C1. Introduction. The actuation of the various hydraulically operated units on board a submarine often requires great precision of control, and transmission of power at variable speeds and pressures, without any sharp steps or gradations. The hydraulic machine used for many of these operations is the Waterbury speed gear, a quiet, efficient mechanism which furnishes instant, positive, and accurate hydraulic power transmission.

2C2. A-end pumps and B-end motors. The Waterbury speed

a fluid displacement to any required point, where it is reconverted into rotary motion, with a positiveness and fineness of control which could not be achieved by the use of electric motors alone.

The size of the Waterbury A-end speed gear, used in the submarine hydraulic system. primarily as a pump, is designated as No. 5-A. The sizes of B-end motors used are designated as No. 5-B and No. 10-B.

Inasmuch as this chapter is devoted to sources of hydraulic

gear may be used either as

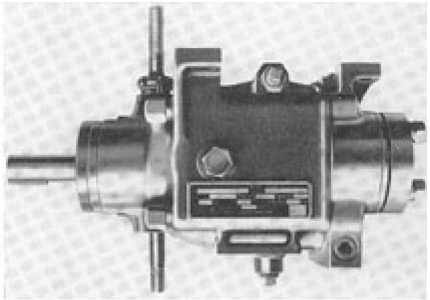

Figure 2-6. Waterbury A-end.

a pump (converting rotary mechanical motion into hydraulic fluid displacement), or as a hydraulic motor (converting hydraulic fluid displacement into rotary mechanical motion).

The type of Waterbury speed gear generally used as a pump is designated as a Waterbury A-end speed gear (see Figure 2-6). The type generally used as a hydraulic motor is designated as a Waterbury B-end speed gear, or Waterbury B-end hydraulic motor (see Figure 2-7). In one special installation, the A-end type is used as a hydraulic motor, but since this is not generally the case, it will be convenient to describe the A-end type primarily as a hydraulic pump.

A-end and B-end speed gear are often used together to form a pair of power transmission units, separated by any required length of hydraulic piping to suit the needs of a particular installation. So used, they receive rotary mechanical motion from an electrical motor at one point and transmit it as power, we shall here

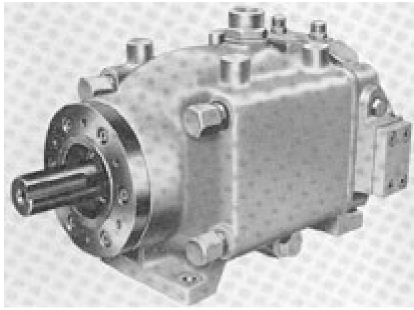

Figure 2-7. Waterbury B-end.

concern ourselves primarily with the Waterbury A-end speed gear in its use as a pump. It will then be convenient to consider briefly the operation of the Waterbury B-end speed gear as a hydraulic motor; this will be readily understood as a not very extensive departure from these principles.

2C3. The Waterbury A-end pump. a. Use of the Waterbury A-end pump in submarine hydraulic systems. The Waterbury A-end. pump is operated by a rotating shaft which may be driven either by an electric motor or by hand.

Three motor-driven and three hand-driven Waterbury A-end pumps are used in the submarine-one of each type in the steering system, stern plane system, and bow plane system. In operation by normal power, the two types are used in each system as team; the motor-driven unit transmits oil for the power actuation of the system, while the hand-driven unit fitted with a large handwheel

and designated as a telemotor, or telemotor pump, transmits oil

The socket ring and cylinder barrel are mounted on the drive shaft so

to a control cylinder to provide fine control of the output of the motor-driven unit. The hand-driven unit is also used, alternatively, to operate the system by hand whenever it is desired not to use the motor-driven pump.

b. Operating principle. Although the Waterbury A-end speed gear is actuated by rotary motion, in principle it is actually a reciprocating multiple-piston type of pump. It consists of a casing containing three basic elements:

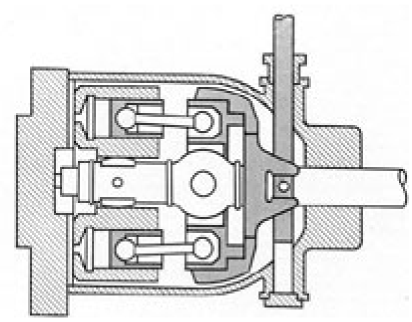

Figure 2-8. Tilt-box at neutral.

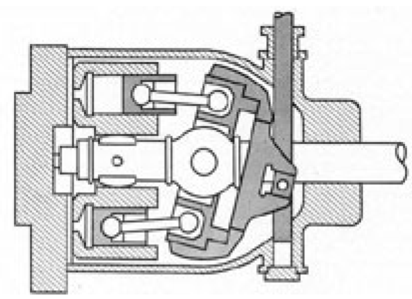

Figure 2-9. Maximum tilt.

1. A socket ring, which in ball sockets holds seven or nine piston connecting rods, arranged roughly in circle around the driving shaft as a center.

2. A cylinder barrel, in which are bored the seven or nine corresponding cylinders.

3. A tilt-box, which alters the angle and direction of the socket ring with respect to the cylinder barrel.

that they rotate together. The socket ring is so arranged that it can be made to rotate either parallel to the cylinder barrel or at an angle to it. Connected to the tilt-box is a control shaft extending through the pump casing. When the control shaft is pushed up or down, it determines the angle and direction of the tilt-box.

The diagrams, Figures 2-8 and 2-9, will help to clarify the manner in which pumping action is obtained. The socket ring rotates within the tilt-box on the radial and axial thrust bearings. As long as the tilt-box is maintained in the vertical position, as shown in Figure 2-8, the socket ring and cylinder barrel will rotate parallel to each other, and there will be no reciprocating motion of the pistons within the cylinder barrel.

However, when the tilt-box is tilted in either direction away from the vertical, as in Figure 2-9, the socket ring no longer rotates in the same plane as the cylinder barrel. This means that as a ball socket on the socket ring reaches that point in its rotation which is closest to the barrel, the piston belonging to it will be driven down into the corresponding cylinder, and then, as this same ball socket recedes to the point farthest away from the barrel, the piston will be withdrawn again.

Figures 2-10, 2-11, and 2-12 will help still further to clarify this action. They show the tilt-box tilted away from the vertical, and illustrate the course of a single piston, whose motion we are able to follow as the socket ring turns through a half-cycle (180 degrees).

As the piston rises to its uppermost position, as shown in Figure 2-10, it occupies a progressively smaller space in the cylinder, until it reaches the point at which the socket ring and barrel are farthest apart. The partial vacuum in the chamber, produced by the outward movement of the piston, causes the fluid to be forced into the cylinder.

In moving from its uppermost position to its intermediate position, Figure 2-11, the piston moves into the cylinder and begins to displace the fluid accumulated there. At its

lowest point, Figure 2-12, the piston occupies almost the entire cylinder. The expulsion of the fluid through the discharge port is now complete. The piston again rises from this position for the suction stroke.

The repetition of these movements in sequence by all of the pistons results in a smooth, nonpulsating flow of hydraulic fluid.

Now that the pumping principle of the Waterbury A-end speed gear has been illustrated diagrammatically, we are ready to consider in detail the parts of which it is composed.

c. Basic differences between A-end and B-end. For the sake of simplicity and clarity of explanation, the mechanism of the speed gear is illustrated, in Figure 2-13, by a cutaway view of the B-end (hydraulic motor) type. The B-end motor has been of the cylinders in the cylinder barrel, in the two types of speed gear, of which a detailed explanation is given in Section 2C4b.

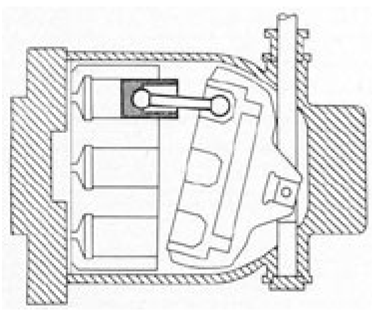

Figure 2-10. Piston on top.

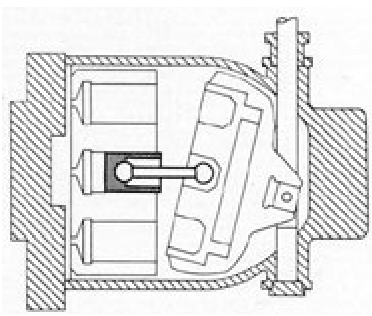

Figure 2-11. Piston in middle.

selected for the cutaway view instead of the A-end pump because the actual appearance of the tilt-box and control shaft parts in such a view of the A-end pump would appear too complicated. Therefore, a word of explanation is needed here as to the basic structural difference between A-end and B-end speed gears.

In the A-end type, as already explained, the angle between the socket ring and the cylinder barrel-which determines the amount of displacement caused by the pistons in the cylinders as these elements rotate is determined by a tilt-box whose angle is, in turn, controlled by a control shaft. The A-end is therefore said to have variable displacement of the pistons.

In the B-end type, this tilt-box is replaced by an angle-box (see Figure 2-14), which may be loosely described as a "permanently tilted tilt-box." This angle-box is bolted solidly to the inside of the case, presenting its vertical side to the end of the case, and its slanted face to the socket ring which rotates against it. The important point is that, unlike the tilt-box, it is immovable, so that its direction and angle of tilt are fixed and permanent. Therefore it does not need a control shaft.

There is also a difference between the spacing of the sockets in the socket ring, and

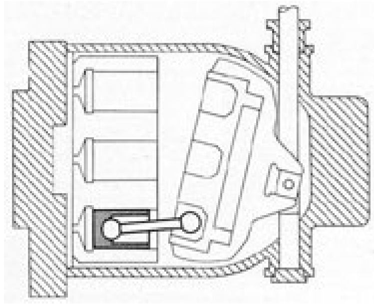

Figure 2-12. Piston of bottom.

However, the basic structural differences between an A-end pump and B-end motor may be summed up as follows:

1. The A-end has a variable tilt-box and a control shaft.

2. The B-end has fixed angle-box and no control shaft.

Once this structural difference roughly into a square, boxlike shell

between A-end and B-end is clearly understood, the cutaway view, Figure 2-13, which shows the B-end with the angle-box can then be used to illustrate our discussions of the A-end pump with which it is identical in all other details.

2C4. Detailed description of parts. a. The case. The case, or casing (15, Figure 2-13), is a light metal casting tested to a pressure of 80 pounds per square inch and formed with an opening at each end. As can be seen in Figure 2-13, the far end, in the view shown, is considerably smaller than the near end.

The inside surface of the case is rough machined.

The larger end is finish-machined to take the valve plate (16) which is held to the case by four heavy studs, or tie-bolts, called the case bolts (21). The case bolts extend all the way through the case beyond the squared

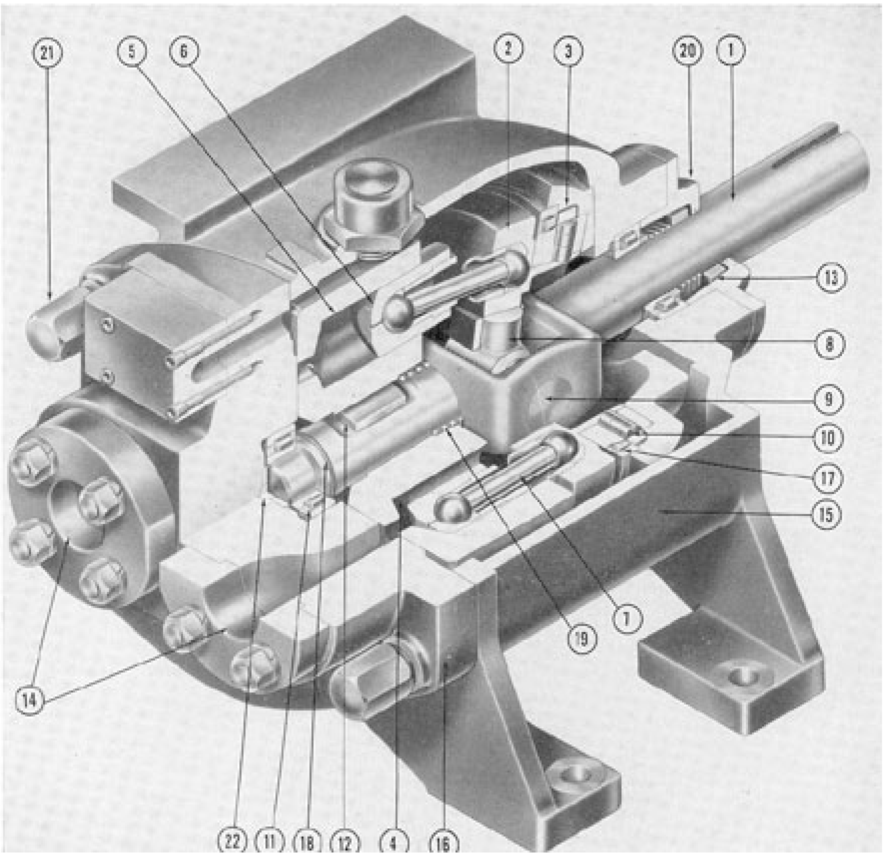

Figure 2-13. Cutaway of Waterbury B-end. 1) Main shaft; 2) socket ring; 3) angle-box; 4) cylinder barrel; 5) cylinder; 6) piston; 7) connecting rod; 8) universal joint; 9) pin; 10) axial thrust bearing; 11) roller bearing; 12) chaff keys; 13) oil seal; 14) ports; 15) case; 16) valve plate; 17) radial thrust bearing; 18) spring lock; 19) barrel spring; 20) end-plate; 21) case bolt; 22) intershaft disk.

shoulder near the smaller end, where spot-faced surfaces are provided to serve as seats for the stud-ends. end of the case itself, and the other in the valve plate.

The smaller end is finish-machined to take the end-plate (20) which is screwed to the case by six small Allen-head screws that fit down into countersunk holes in the endplate so that, when secured, they come down flush with the plate. This end also contains a finished surface to receive the main shaft roller bearing.

In the center of the case, as viewed from the top, is a tapped hole which receives a fitting from a vent and replenishing line. A similar tapped hole in the bottom of the case serves as a drain. When the pump is mounted bottom-side up, the functions of these two holes are reversed.

Cast integral with the case are tie mounting brackets. These have drilled and spot-faced mounting holes.

The smaller end of the A-end pump also has vertical holes drilled through the top and bottom, 1 3/4 inches to the right of the center line of the shaft as viewed from the shaft end, machined and tapped to take the control shaft bearing and guides (not shown in Figure 2-13). Either the top or bottom hole may be used to provide a passage for the control shaft, depending on which way the pump is mounted, and on other installation limitations. Whichever hole is used for the control shaft the opposite one is generally, though not necessarily, used for the shaft which operates a centering device mounted over it. When the second hole is not used, it is closed by a plug.

At the point where the shaft intersects the socket ring, it forms a closed yoke to which the universal joint (8, Figure 2-13) is held by the shaft pin (9). The shaft is flattened and perforated on two sides to provide for the barrel keys (12) which drive the barrel. A grooved section on the shaft receives the barrel lock spring (18, Figure 2-13) which serves only to prevent the barrel from slipping off the shaft.

The correct amount of end-play for the main shaft, amounting to 0.015 of an inch, is insured by inserting a spacer in the bearing recess of the valve plate beyond the shaft bearing. The thickness of this disk is determined after the rest of the parts have been fitted to each other, so that it can compensate for end-play error caused by tolerances in the manufacture of the other parts.

c. The socket ring. The socket ring, (2, Figure 2-13) contains the sockets into which the large ball-ends of the connecting rods are secured.

Four arms extend inward from the socket ring body to form slots or pockets which receive the bearing blocks. Allen-head screws secure the bronze bearing blocks which support the main shaft trunnions. The universal joint consists of a shaft-trunnioned block oscillating with the pin (9) in the yokes of the main shaft. The trunnions of the trunnion block operate on the bearing surfaces cut into the main shaft yoke. The working torque of the shaft is transmitted through the socket ring, the universal joint trunnions, and the main shaft pin. The back of the socket ring is

b. The main shaft. The main shaft (1, Figure 2-13) is direct-coupled to the electric driving motor. It is rotated clockwise as viewed from the motor end of the shaft. The function of this shaft is to drive the revolving group of which it is a part. The revolving group consists of the following units: shaft (1), universal joint (8), cylinder barrel (4), pistons (6), connecting rods (7), barrel spring (19), socket ring (2), and barrel keys (12).

The main shaft rotates in two roller bearings, one of which is contained in the smaller equipped with a roller track with two roller faces. These become the outer races of the axial thrust bearing (10) and radial thrust bearing (17).

An examination of the socket ring will disclose that the sockets are spaced unequally around the main shaft. The reason for this irregularity in the location of the sockets is that when two parts connected by a universal joint rotate in different planes-that is, on different axes-their angular velocities

(number of degrees through which they turn in a given length of time) are not equal throughout all phases of a cycle.

In other words, if one of these parts is driven at a constant speed of rotation, the part which it drives through the universal joint will alternately lag behind, and then catch up with, the part which is driving it.

The mathematical or geometrical proof of this fact is too complex to be given here. The fact remains that this is exactly what happens in the relationship between the rotational speed of the main shaft of the Waterbury speed gear and that of the socket ring which it drives, whenever the tilt-box is tilted away from vertical; the main shaft is driven by an electric motor at constant speed, while the socket ring, when tilted away from vertical, alternately lags between zero and maximum, the amount of inequality is proportional to the degree of tilt. Obviously the spacing or calibration, of the socket, can be correct only for one particular angle, and becomes less and less accurate as the socket ring is tilted either way from this angle. For the A-end speed gear used in the submarine, the calibration angle is 10 degrees (in either direction from neutral).

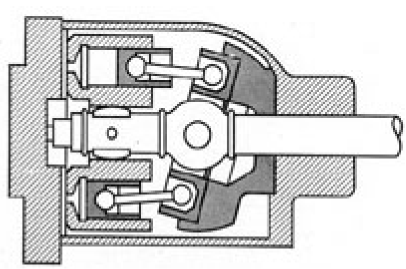

Figure 2-14. Diagram of B-end.

2. The second factor of error results from the fact that the inequality of motion between the two rotating parts is continuous throughout any given cycle, or revolution, while the location of

behind it and catches up, during each full revolution of the shaft.

The greater the angle of tilt away from vertical, the greater the inequality of motion between the two parts during a given revolution. If this irregularity were not corrected, the delivery of fluid would rise and fall in volume throughout each complete revolution, resulting in uneven surges instead of smooth, uninterrupted flow.

Therefore, in order to reduce this irregularity in the pumping action of the pistons to a minimum, they are spaced in such a way that the inequalities in the distances between them will just compensate for the inequalities of motion between the shaft and the socket ring. The cylinders, of course, are also unequally spaced in the cylinder barrel to correspond with the spacing of the sockets.

A little study will show that this compensation can be only approximate, for two reasons, which result in two separate factors of error:

1. The first factor of error results from the fact that the amount of inequality of motion between the two rotating parts varies with the angle of tilt. At zero degrees' tilt, the inequality is zero, as the two parts are then rotating in the same plane. At maximum tilt in either direction, the inequality is at its maximum. And at any intermediate angle

the sockets, and of the cylinders in the barrel, is discontinuous. Therefore it would be impossible to make the calibration exact-even neglecting the first factor of error- unless the number of sockets and cylinders was infinite, so that they formed a continuous, irregular line around the circumference of the socket ring and cylinder barrel.

In this connection, there is a further structural difference between the A-end and B-end speed gears besides those already noted in Section 2C3c. The sockets in the A-end are located at unequal distances from each other, but at the same distance from the centerline of the shaft. The sockets in the B-end, however, are located at unequal distances not only from each other but also from the center. In other words, the spacing of the A-end sockets is unequal but concentric, while that of the B-end sockets is not only unequal but eccentric as well. The reason for the double calibration is that the calibration of the B-end must compensate not only for its own internal mechanical inequality of motion, caused by

the action of the universal joint, barrel (see Figure 2-15). As noted

but also for the surges, or slightly unequal pumping, of the A-end pump when this is its source of hydraulic power. Therefore, in the

Figure 2-15. Separating shaft from barrel.

calibration of the B-end socket ring and cylinder barrel, an attempt is made to correct two errors at once:

1. The unequal spacing of the cylinders from each other compensates for the internal mechanical inequality motion arising from the action of the universal joint in the B-end motor itself.

2. The eccentricity or unequal spacing, of the cylinders from the center, compensates for the surge delivery of the A-end pump so that the B-end shaft will turn at exactly the same speed as does the A-end shaft when the A-end tilt-box is at maximum tilt. The A-end is calibrated for an angle of tilt 10 degrees either side of neutral; the B-end is calibrated for the full tilt of 20 degrees from vertical, corresponding to the permanent tilt of its angle-box.

in the description of the socket ring, the cylinders are spaced unequally from each other to compensate for the inequality of motion between the socket ring and the main shaft arising from the action of the universal joint. (For a fuller description of this feature, see Section 2C4b).

The cylinder barrel has keyways cut into it and is loosely attached to the main shaft by two keys (12, Figure 2-13), so that end play of the shaft will not be transmitted to the barrel. The looseness of this attachment of the cylinder barrel is intentional; its purpose is to allow a slight play, permitting. the pressure of the oil being pumped, or of the spring, when the pump is not pumping, to hold the barrel squarely against the valve plate.

The spring, which is backed by the main shaft yoke, maintains the barrel continuously against the valve plate when the pump is not running, or when the socket ring is in neutral. When the unit is pumping, the oil under pressure automatically maintains the barrel against the valve plate, since the cylinder ports are smaller than the cylinders of the barrel, so that the pistons, forcing oil out of the cylinder during the discharge stroke, will also cause the oil to exert a force against the walls formed by the ports, holding the barrel tight against the valve plate.

e. Piston assembly. Each cylinder in the cylinder barrel contains a piston which has been ground and fitted in the cylinder, and therefore requires no rings or packing. Figure 2-16 shows a cutaway view of a single piston. The shallow grooves cut around

d. The cylinder barrel. The cylinder barrel is in reality a cylinder block into which seven or nine separate cylinders are bored. The length of the cylinders is such that the pistons riding within each separate cylinder will, as a group, always be within the cylinder

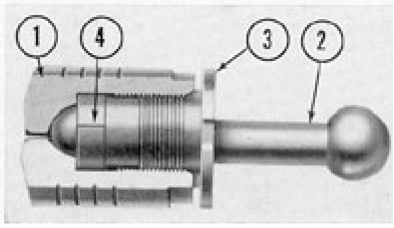

Figure 2-16. Cutaway of piston assembly. 1) Piston; 2) connecting rod; 3) cap nut; 4) socket cap.

the piston interrupt the streams of oil leakage, thereby tending to trap small particles of dirt or grit which otherwise might score the piston and cylinder surfaces.

Each piston (6, Figure 2-13) is connected to the socket ring (2) by a connecting rod (7). The rods have ball-ends, one larger than the other. The large end is secured into the socket ring, the small end into the piston.

1. Assembly of connecting rods to socket ring. The connecting rods are secured in the socket ring in the following manner. Into the face of the socket ring are bored and tapped seven or nine holes, one for each piston rod. Each hole is then provided with two hollow bronze half-bushings which, when fitted to each other, form a spherical, cuplike socket in which the large ball-end is held. The inner half, called the ring socket, is press-fitted into the bottom of the hole. The outer half, called the socket cap, fits against it, sliding into the hole with a rather free fit.

The socket cap is ring-shaped; its inside diameter is sufficient to allow it to be slipped over the end-play, in the rod. If end-play exists, the socket must be disassembled and the shim replaced by a thinner one. If, on the other hand, the fit is too tight, a thicker shim is needed.

2. Assembly of connecting rods to pistons. The manner in which the small ball-end of the connecting rod is secured into the piston is somewhat different from the manner of securing the large end into the socket ring (see Figure 2-16).

The piston itself (1) is of bronze, and the inner half of the socket is hollowed out of the metal of the piston.

Since the outer half, or socket cap (4), must serve to hold the small ball-end in place in the piston socket, it must necessarily have a smaller inside diameter than the diameter of the small ball. Therefore if it were formed as a single piece, it could not be slipped on or off the rod at all. Accordingly, it is made up as a split bushing, that is, split into two equal semicircular segments which are dropped into the piston after the ball of the connecting rod is placed in the inner hollow, or socket proper. Then the piston is

small end of the connecting rod, before that end has been secured into the piston.

To lock the two halves solidly together in the bottom of the hole, a threaded piece shaped like a short section of pipe, called the socket-cap nut, is then also slipped over the small end of the rod and screwed down on top of the socket cap.

In assembling the socket, the two halves are not actually fitted directly to each other. Instead, a thin metal ring, called a shim, or spacer, whose function is to maintain proper clearance for the contained ball-end, is inserted between them, thus correcting any misfit resulting from tolerances in manufacture of the different parts. Spacers for each assembly are individually selected to suit that particular assembly.

The fit between ball and socket, when assembled and locked in by the cap nut, should be free enough to allow the connecting rod, when standing upright, to fall over sideways by its own weight. It must never be loose enough to permit any axial motion, or carefully tapped or shaken until the two segments of the split bushing fall into place around the rod. The piston socket-cap nut (3) is flanged and slotted to provide a wrench grip. Like the ring socket-cap nut, it is threaded. After the split bushing is in place, the nut is screwed down through the tapped part of the piston interior to secure the socket assembly firmly into the bottom.

The fit between socket and ball should be the same in the piston socket as in the ring socket, that is, a free fit with no end-play. As in the socket ring assembly, spacers or shims of the required thickness are used between the inner edge of the split bushing and the shoulder cut in the piston against which they fit to form the socket cup.

As can be seen in Figure 2-16, a small hole is drilled through the crown of the piston. This furnishes passage to the oil for lubrication of the surfaces of the ball and socket. Another hole (not visible in the figure) is drilled lengthwise through the connecting rod, ending at the tip of each ball.

Thus both sockets are provided with continuous high pressure lubrication whenever the pump is running. The oil, thus pumped from the external, or high pressure, side of the piston, leaks into the case, or inactive system, and is a part of the oil loss which must be constantly fed back into channels (6) cast in the inner face of the valve plate. These communicate directly with the passage leading to the external ports on the valve plate's outer side. The two channels are divided at the top and bottom by flat faces called lands.

the active system through the replenishing valves.

f. The valve plate. The valve plate (16, Figure 2-13) serves as an end-plate, or cover plate, for one end of the speed gear. Into it are cast the oil passages which empty into the suction and discharge ports (14, Figure 2-13). It also holds the outer race of the roller bearing (11, Figure 2-13) in which the end of the main shaft revolves.

Figure 2-17 shows the inner face of the valve plate against which the cylinder barrel rotates. Oil is drawn into or discharged from the cylinder through crescent-shaped

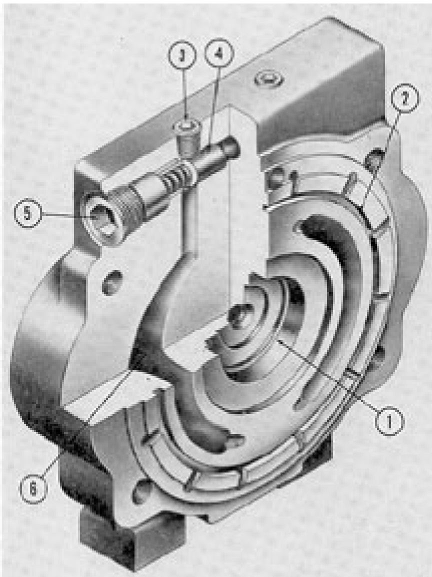

Figure 2-17. Cutaway of valve plate. 1) Main shaft bearing; 2) collector channel; 3) air vent; 4) replenishing valve; 5) replenishing valve retainer plug; 6) port.

As the cylinder barrel rotates, the cylinders pass in succession across these lands. For a brief moment, fluid is locked in each cylinder as it crosses the land.

The valve plate also contains two replenishing valves and four vent valves, which are described in Section 2C4h.

g. The tilt-box and the control shaft. The tilt-box provides the roller tracks against which the socket ring rotates, or, to put it another way, it provides the opposite races for the radial and axial thrust bearings described in Section 2C4c.

The socket ring may be tilted to any desired angle of tilt from 0 degrees to 20 degrees in either direction. This is accomplished by a tilt-box (3, Figure 2-18), which is suspended on two trunnions (10) formed on the box itself and which ride in bronze bearings (11) located in the sides of the case. An elongated hole is cut through the center of the tilt-box to give free passage to the main shaft at any degree of tilt of the tilt-box.

The tilt-box is retained in its bearings by two retaining trunnions (4, Figure 2-18) which are screwed through from the outer sides of the case and enter bushed holes in the tilt-box.

The angle of the tilt-box is determined by the control shaft (1, Figure 2-18) which tilts the tilt-box on its trunnions to obtain the desired amount of pumped fluid and to control the direction of pumping.

The end of the control shaft which protrudes from the case is

threaded. This end is connected to a control device either to the linkage of a control cylinder assembly (if it is functioning as a motor-driven pump), or to a pump-stroke setting lever (if it is functioning as a telemotor pump).

The control shaft fits into the case of the speed gear through the control shaft bearing

(2). External oil leakage is prevented by the packing (8), held in place by the packing gland cap (9).

The control trunnion pin (5) is secured to the control shaft, inside the pump case, by a dowel pin (12) which is peened over at both ends. The control trunnion pin is fitted with a pair of small square blocks, the outer guide block (6) and the inner guide block (7); one of these pairs can be seen in the illustration.

The vertical chamber in which the control shaft moves is drilled cylindrically, and then fitted with guides, or tracks, whose inner surfaces are cut into rectangular channels, thus giving the chamber a rectangular shape. The outer guide blocks are held within these rectangular vertical tracks, with which they make a smooth, sliding fit. The inner and outer guide blocks are free to move independently, having no connection with each other, except that they are both carried on the trunnion pin, riding with it as it moves up and down with the control shaft.

The fingers of the tilt-box (3) form a pair of square recesses within which the inner guide blocks (7) are held with a fit just tight enough to allow the block to be tapped into the recess by hand. This inner block is also free to turn smoothly on the trunnion pin. Therefore, as the control shaft is moved by the external linkage, the inner guide blocks, carrying with them the fingers of the tilt-box, will cause the tilt-box to rotate on its trunnions. Thus, the control shaft is fitted to the tilt-box through the inner blocks, and, as the shaft is moved by the external linkage to any given position, the tilt-box will assume a corresponding angle of tilt to follow it,

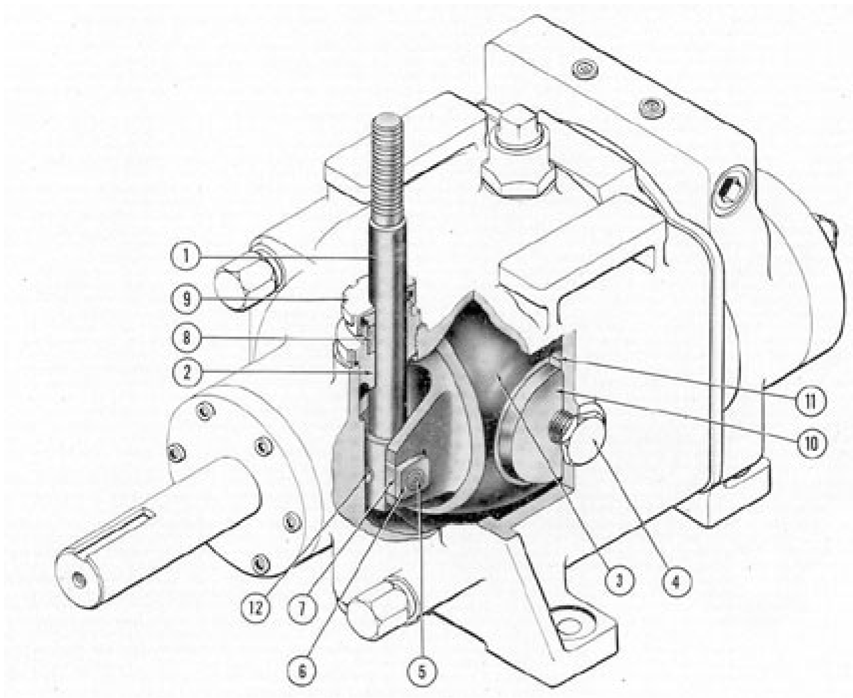

Figure 2-18. Cutaway of control shaft. 1) Control shaft; 2) control shaft bearing; 3) tilt-box; 4) tilt-box retaining trunnion; 5) control trunnion pin; 6) control guide block (outer); 7) control guide block (inner); 8) packing; 9) packing-gland cup; 10) trunnion; 11) trunnion bearing; 12) dowel pin for control trunnion pin.

within the limits of its angular rotation (20 degrees from vertical in each direction).

h. Minor parts. Any oil which has been lost from the active, or pressure, side of the system by leakage, is replenished in the active, or pressure, side from the case through two check valves, called replenishing valves (4, Figure 2-17) which are located in the valve plate. There is one for each port. The replenishing valves allow replenishment of oil from the case to the active, or pressure, side of the system on the suction side of the pump. When this side of the pump is the discharge side, the check valve will be seated by the oil pressure, thereby preventing oil from escaping from the active, or pressure, side of the system back to the case.

The shaft of the motor is direct-coupled to the main shaft of the A-end pump, driving it clockwise as viewed from the motor end of the pump. Since the direction and speed of rotation are fixed, the only variable factor in determining how much oil is pumped by the pistons, and in which direction it will be pumped, is determined by the positions of the tilt-box.

As this is one of the motor-driven pump installations, the control shaft, which determines the position of the tilt-box, is itself controlled, through bell-crank linkage, by the action of a control cylinder plunger.

Figures 2-19, 2-20, 2-21, and 2-22 illustrate the relationship between angle of tilt and pumping action. In Figure 2-19, the control shaft is centered, the tilt-box is at neutral,

The hole in the valve plate through which the valve is inserted is kept closed by a plug known as the replenishing valve retainer plug (5). Above each port is a needle valve (3, Figure 2-17) which provides the means for venting air out of the valve plate. Two additional needle valves are placed in corresponding positions at the underside of the ports, to be used as vents when the pump is mounted upside down.

At the point where the shaft passes through the case, oil leakage is prevented by an oil seal (13, Figure 2-13). The seal is made of a synthetic rubber ring protected by metal guards. (A steel ring, with a ground surface, is fitted into the metal guards which rotate directly against a ground surface on the pump end-plate.) The entire assembly of the oil seal rotates with the shaft.

2C5. Operation of the Waterbury A-end speed gear. a. As a motor-driven pump. Three motor-driven A-end speed gears are used in the submarine to furnish normal hydraulic power, one for the steering system, one for the stern plane tilting system, and one for the bow plane tilting system. Each speed gear is driven by an electric motor at 440 revolutions per minute. The motor used to drive the speed gear on the steering system is rated at 15 horsepower; the motors used for driving the speed gears in the bow and stern plane systems are rated at 7.1 horsepower each.

the socket ring is parallel to the cylinder barrel, and no pumping action will occur since each piston occupies the same amount of space in its cylinder throughout each cycle, or revolution. There is no suction and no

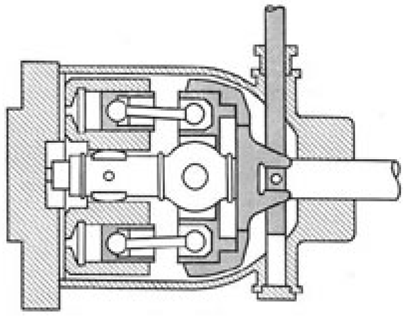

Figure 2-19. Tilt-box at neutral.

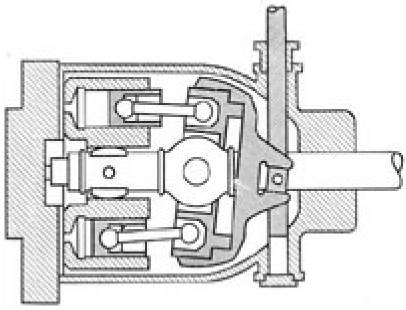

Figure 2-20. Tilt-box at slight tilt.

displacement. Note the position of the control shaft and inner guide block.

In Figure 2-20, the control shaft has been pushed down a short distance, tilting the tilt-box slightly away from vertical, inclining the upper part away from the cylinder barrel.

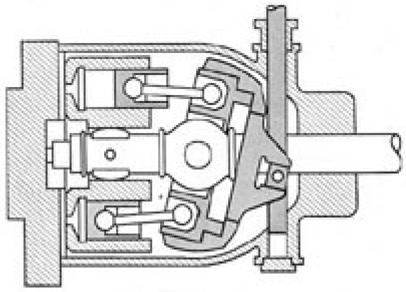

Figure 2-21. Tilt-box at maximum tilt.

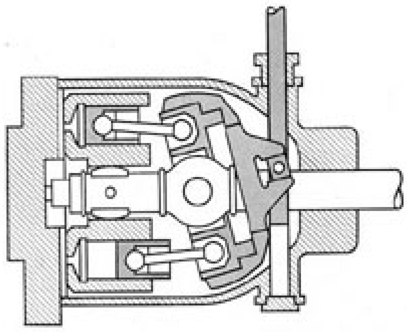

Figure 2-22. Tilt-box at reverse tilt.

Since the socket ring is now rotating in a different plane from that of the cylinder barrel, each piston will acquire a reciprocating motion, moving back and forth within its cylinder during each full revolution, as it alternately approaches and withdraws from the cylinder barrel. Therefore, as they rotate, each piston will alternately draw oil into its cylinder during that half of the revolution in which it is approaching the topmost position, and drive it out of the cylinder again during the other slightly from the vertical, and, consequently, the displacement within the cylinders is small.

In Figure 2-21, the control shaft has been pushed down to its maximum travel, tilting the tilt-box to its maximum angle of tilt, still in the same direction away from vertical as in Figure 2-20. The plane of rotation of the socket ring now makes an angle of 20 degrees with the plane of rotation of the cylinder barrel. The piston displacement inside the cylinders is at maximum, resulting in an increased amount of oil being pumped, in the same direction as in the preceding figure.

In Figure 2-22, the control shaft has been raised to its maximum travel, again tilting the tilt-box and socket ring to a maximum angle of 20 degrees' tilt away from the vertical, but in the opposite direction. Again there is maximum piston displacement, but since the direction of rotation is unchanged, the flow of oil through the pump is reversed.

Since the control shaft can tilt the tilt-box to any desired angle of tilt within the 20-degree range on either side of neutral, it is evident that the number of gradations in the quantity of oil pumped from zero to maximum is infinite. This factor makes possible the fineness of control which is an outstanding advantage of these pumps.

It should be made clear that, when the A-end pump is pumping the maximum quantity of oil, it is not necessarily delivering it at maximum pressure. The reason for

half of the revolution during which it is approaching the lowest position. Each of the seven or nine pistons, in turn, repeats this process during each revolution. The volume of oil pumped will be relatively small, as the socket ring is tilted only this is that the farther the socket ring is tilted away from the vertical and the greater the consequent piston displacement, the greater the quantity of oil pumped in a given length of time; on the other hand, the smaller the angle of tilt, and consequent piston displacement, the greater will be the mechanical advantage of leverage exerted against the oil being pumped. Therefore, if the angle of tilt is small, and the resistance encountered by the oil is sufficient to act as an effective obstacle to its flow, enormous pressure will be developed.

b. As a hand-driven telemotor pump. The output of the motor-driven Waterbury A-end pump is controlled by a hand-driven telemotor A-end pump. Three basic differences should

be noted between the operation of the motor-driven A-end pump and of the hand-driven telemotor A-end pump:

1. In the motor-driven A-end pump, the direction of rotation of the main shaft is fixed, while in the telemotor pump, the shaft may be rotated in either direction by the attached handwheel.

2. In the motor-driven A-end pump, the direction of tilt, as well as the angle of tilt of the tilt-box, are variable; in other words, it may be tilted up to 20 degrees in either direction away from the vertical.

3. In the motor-driven A-end pump, therefore, the direction in socket ring; in other words, in the A-end the sockets are unequally spaced but are concentric, while in the B-end, they are unequally spaced and eccentric.

2C7. Operation of the Waterbury B-end speed gear. a. Use of the Waterbury B-end speed gear in submarine hydraulic systems. The A-end speed gear is used primarily as a pump, converting mechanical torque into hydraulic fluid displacement, while the B-end speed gear is usually used as a hydraulic motor, converting hydraulic fluid displacement into mechanical torque. In practice, only two B-end motor installations are used on the submarine:

which fluid is pumped will be determined only by the direction in which the tilt-box is tilted. In the telemotor pump, the direction in which fluid is pumped will be determined only by the direction in which the main shaft is rotated.

Though the tilt-box in the telemotor pump can be tilted in only one direction, the angle of this tilt is variable, and may be set at anything from minimum to maximum. In the case of the telemotor pump, this angle is controlled by a pump-stroke setting lever, or pump control lever, which is placed by hand at any desired setting.

2C6. The Waterbury. B-end motor. a. Summary of structural differences. The basic differences in structure between the A-end pump and B-end motor have already been discussed (see Section 2C3c). They may be summarized as follows:

1. The A-end speed gear has a variable displacement feature consisting of a tilt-box whose position is determined by the vertical control shaft. In the B-end speed gear, this tilt-box is replaced by the angle-box, a casting secured to the inside of the case, which gives to the socket ring a fixed tilt of 20 degrees in one direction from the perpendicular (see Figure 2-14). The B-end motor has no control shaft.

2. Both the A-end and B-end speed gears have the sockets spaced at unequal distances from each other in the socket ring. In the B-end, however, the

1. A No. 10-B motor is used on all late classes of submarines, both of Portsmouth design and Electric Boat Company design, for operating the rigging gear of the bow diving planes, forward capstan, and anchor windlass. The hydraulic power to operate this installation comes from the main hydraulic system. The shaft of the No. 10-B motor, through a clutch and a series of gear trains, operates the bow plane rigging gear, forward capstan, and anchor windlass. This No. 10-B motor will be replaced by a No. 10-A unit to decrease the rigging-out time for the bow planes, since the A-end, by maintaining a small angle of tilt on the tilt-box, can rotate faster with a given amount of oil from the main system, assuming that the external loading is not excessive.

2. In some earlier classes of boats, a No. 5-B motor was used for the tilting of the bow diving planes. In this type of installation, the source of hydraulic power was a No. 5 A-end pump driven by an electric motor; fluid under pressure was delivered to the No. 5-B motor, whose shaft, through a gear train, rotated a large herringbone sector gear fixed to the tiller of the plane stocks.

b. Principles of operation of the B-end motor. When the Waterbury B-end speed gear is used as a hydraulic motor, the principles of its operation are the reverse of those of the Waterbury A-end pump. Instead of torque being applied to the main shaft from some external source to force the piston to displace oil, and thereby develop fluid

sockets are also placed at unequal distances from the center of the

pressure, here the fluid pressure is admitted to the cylinders in order to force them to reciprocate and rotate the shaft, developing in the shaft a torque which is then used to actuate some mechanism.

This will be made clearer by referring again to the diagram, Figure 2-14. The oil under pressure enters the channel in the valve plate. From the channel it flows into all the cylinders on that side whose ports are open to that channel. This oil will tend to push the pistons on this side of the cylinder barrel out of their cylinders, exerting a force against the socket ring. The socket ring, fitting squarely against the axial roller bearing of the angle-box, which is at an angle and is free to turn, will thereby receive the force exerted on it by the pistons and their connecting rods and convert it into rotary motion. The socket ring will therefore rotate against the inclined plane of the angle-box, transmitting its motion through the universal joint to the shaft. Thus, the impulses received by the pistons through the channel on the pressure side of the valve plate tend to apply a torque to the entire revolving group, consisting of the cylinder barrel, socket ring, and shaft.

As each cylinder in the cylinder barrel is carried around toward its topmost position (see Figure port of this cylinder is passing across the opposite land of the valve plate, at which time its piston has reached its maximum discharge stroke.

If the oil under pressure, called pressure oil, is continuously delivered to the side of the motor, each piston in turn, as it receives the impact of the oil against it, will go through this cycle, receiving oil from one channel on the ascending half of its cycle and discharging it through the other on the descending half of its cycle, transmitting to the socket ring, and thus to the shaft, a smooth, virtually nonpulsating torque which, as long as the shaft is free to turn, will be translated into continuous rotation in one direction.

The port on that side of the motor which receives pressure oil from the outside line is termed the supply port; the other port, through which the oil is expelled when the pistons have completed their discharge stroke, becomes the return port.

Since the direction of tilt of the angle-box is fixed, the direction in which torque is applied to the shaft will be determined by which port the motor receives the pressure oil. In other words, if oil were delivered under pressure to the opposite port, in the example we have just considered, all the movement described would be

2-14), the space in that cylinder continues to increase as the oil under pressure forces the piston farther out of the cylinder, to its maximum intake stroke. At this moment, the port of this cylinder is passing across the land on the valve plate, between the two crescent-shaped channels, and the oil in the cylinder remains trapped in it as long as the cylinder port remains in contact with the land.

As this cylinder begins its descent on the other side of the motor, its piston, whose socket in the socket ring is now riding down the other side of the inclined plane on the angle-box, is once again pushed down into the cylinder, expelling the trapped oil through the cylinder port into the opposite crescent-shaped channel. Consequently, the space within the cylinder continues to decrease during this half of the cycle until it once again reaches its lowest position, where again the reversed. The pistons would push the socket ring in the opposite direction, and as a result, the shaft would turn in the opposite direction.

In other words, since the direction of tilt of the angle-box is fixed, it is clear that the direction in which the shaft of a B-end motor rotates is determined exclusively by the direction in which fluid is pumped to it. And since the angle of tilt is fixed, it is clear that the speed with which the pistons are pushed out of their cylinders by the pressure oil, and the consequent speed of shaft rotation, will depend exclusively on the quantity of oil delivered to the motor in a given length of time.

If the shaft were free to turn, and carrying no load, it is clear that to keep it turning just enough force would be needed at the supply port to overcome the inertia and internal friction of the moving parts. However, when a load is applied to the shaft, an

additional force proportional to the load must be exerted against the pistons on the pressure side of the motor. Since the piston area remains constant, this increase of force can be made available only by an increase in the pressure of the oil delivered to the motor. Therefore, it is obvious that the amount of torque available at the shaft will depend exclusively on the amount of pressure, in pounds per square inch, of the oil being delivered to the motor.

few minutes without load and with the vent valves closed, then stopped and the vents again opened as before until all air is removed. The hydraulic system should be vented periodically until all air has been removed.

NOTE. The presence of air in the hydraulic system may be detected by noisy operation and by speed variations in the B-end, especially slowing down under load.

b. Handling controls. The life of the Waterbury speed gear can be

The operational principles of a B-end motor may now be summarized as follows:

1. The function of the B-end motor is to receive hydraulic power from an outside source in the form of continuous fluid displacement and convert it into a rotary motion of its shaft.

2. The direction in which its shaft rotates is determined by which of its two ports receives the supply of pressure oil.

3. The speed of rotation of its shaft depends on the quantity of pressure oil delivered to it per unit of time.

4. The amount of working torque available at its shaft is determined by the amount of hydraulic pressure available at its supply port. In practice, the normal working pressure of the oil from the main hydraulic system received at the supply port of the No. 10 B-end motor to operate the bow plane rigging gear, windlass, and capstan runs between 600 and 700 pounds per square inch.

2C8. Service instructions. a. Air in the system. Air in the hydraulic system hinders its efficient operation, and great care must be taken to prevent the entrance of air into the lines, and to get rid of any air which may have accumulated there. This applies also to the Waterbury speed gear, whose case must be kept filled with oil and free of air bubbles. To vent off any accumulated air in the valve plate, open the two air vent valves (3, Figure 2-17) on top of the valve plate. Turn the shaft materially prolonged by observing proper precautions. Avoid unnecessary sustained overloads. Even though the gear is protected by relief valves, it is well to slow down when excessive pressure is indicated or when obvious shocks are expected. For example, when securing an anchor, the windlass should be operated slowly during the last few feet of chain travel. Do not keep the A-end operating unnecessarily.

c. Opening for inspection. As long as the equipment operates satisfactorily, it should not be opened. The units give the best service when they are not disturbed.

2C9. Overhaul. Waterbury speed gears are carefully assembled machines. Therefore, when repairs are necessary, it is always best to return them to a tender or base where trained personnel and special tools are available. Unexpected circumstances, however, sometimes make it necessary to restore the units to immediate service, regardless of whether the repairs may endure.

The following overhaul procedure is intended for such an emergency. It describes primarily the B-end with variations for the A-end procedure.

a. Disassembly. 1. Removing the oil. Close all cut-out valves on the piping connected to the pump. Remove the drain plug on the bottom of the case and drain the oil. Disconnect the piping from the unit. Remove pump from mounting.

2. Removing valve plate. Remove the nuts and the bolts which

over a few times while the vent valves are still open, to relieve any air which may be trapped in the oil. Despite these precautions, there may still be air in the system. The Waterbury speed gear should be run for a attach the valve plate to the ease. Tap the end of the shaft to free the valve plate from the case. Take off the valve plate, being careful not to bring the

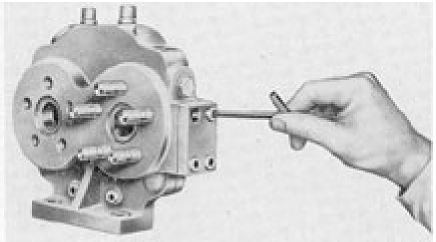

Figure 2-23. Removing replenishing valve block cover.

machined surfaces in contact with hard objects.

3. Removing valves from valve plate. The block containing the valves is mounted on the side of the valve plate. Remove the four bolts as in Figure 2-23. In some installations there is only a plug to be removed. Take off the cover, and the replenishing valve parts can then be removed as in Figure 2-24.

4. Removing oil seal. To do this, remove the six bolts around the circular cover plate. Remove the cover plate, and the oil seal elements can then be pulled out (see Figure 2-25).

5. Separating case from rotating group. Rest the open end of the case, through which the cylinder barrel is visible on a pair of wooden blocks. Remove the angle-box screws from the end of the case. Lift the case straight

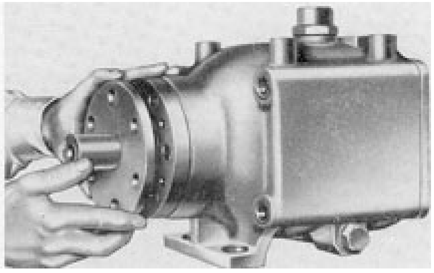

Figure 2-25. Taking off end cover.

up as in Figure 2-26. The angle-box should remain with the revolving group. If it does not, reinsert two of the angle-box screws part way and loosen by tapping lightly. On the A-end, the revolving group is removed without its tilt-box. The tilt-box may be freed by removing the trunnion retainers on the side of the case. With the control in its neutral position, lift the tilt-box straight out from its bearings.

6. Removing shaft from barrel. The end of the shaft beyond the barrel contains the inner race for the valve plate roller bearing (11, Figure 2-13). This must be taken off with a bearing puller which is furnished as a special repair tool. Pry off the barrel lock ring with a screwdriver. Rest the barrel on

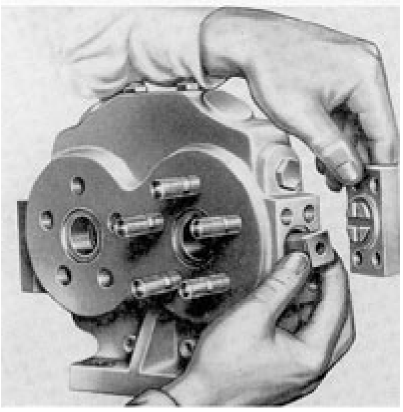

Figure 2-24. Taking out replenishing valve.

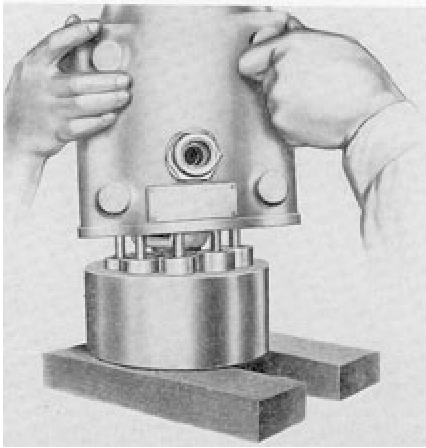

Figure 2-26. Lifting case.

the two wood blocks mentioned earlier. Lift up the shaft, socket ring assembly, and pistons as in Figure 2-15, being careful not to mar the surfaces of the pistons.

7. Separating socket ring from shaft. Remove the screws which hold the bronze trunnion shaft bearing blocks in the socket ring as in Figure 2-27. With the socket ring carefully held, drive the bearing blocks out by tapping gently with a wooden drift. Figure 2-28 shows this operation. Push the shaft through the socket ring as in Figure 2-29.

8. Separating piston assembly from socket ring. It is seldom necessary to dismantle the entire socket ring assembly. Disassemble only the pistons which require obvious repairs. Since the parts of each group, such as pistons, rods, caps, and trunnion blocks are hand-fitted at original assembly, care should be taken to reassemble them so that individual parts are returned to their original location. Corresponding fitted parts are usually numbered or punched as

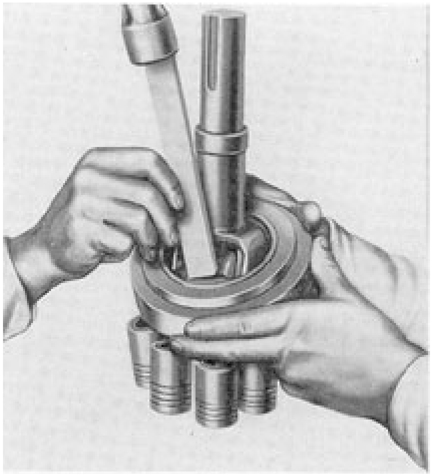

Figure 2-28. Driving-out trunnion bearing blocks.

prick punched for identification. Connecting rods are not marked and should be tagged with the numbers corresponding to their pistons.

Remove lock springs or split pins. Loosen the cap nuts which secure the ball-ends of the connecting rods (2, Figure 2-16) in the socket ring. Pull the caps and rods out of the socket ring, being careful not to wedge the edges of the caps into the threads of the socket ring.

a relocation guide. For example, ring socket caps and nuts are numbered to correspond with hole numbers in the socket ring. If the parts are not marked, they should be marked by numbers or punch marks as they are removed. The slot on the cap nuts and the corresponding locking hole on the socket ring are

Figure 2-27. Removing trunnion bearing block screws.

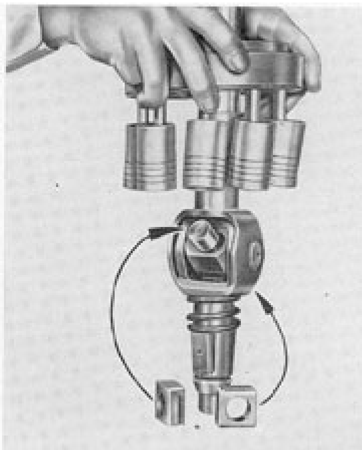

Figure 2-29. Separating shaft from socket ring.

Use a wooden clamp to prevent injury to a piston when separating it from a rod. Make the clamp by boring a hole of the same diameter as the piston. Split the wood at the center of the hole. Place the piston between the two jaws just formed, in a vise. The piston should be clamped at its solid end only, to avoid crushing the hollow part. Unscrew the piston cap nut (3). Pull the connecting rod (2) out with the two halves of the split bushing (4). Keep the two together for reinstallation in the same piston (1).

9. Removing shaft trunnion block. Drive the main shaft pin retainer out of the trunnioned block. Drive the main shaft pin

boxes are left empty. This is suggested only as an emergency repair. If spare bearings are available, they should be used.

The socket thrust race is secured to the socket ring by a shrink fit. It may be removed by driving it off with a pin inserted into the driving holes in the socket ring. This race is reversible. When its bearing surfaces become worn, it can be turned over.

The box thrust race fits snugly in either the tilt-box or angle-box and can be lifted out. This race is also reversible and can be turned over if one side is worn.

The radial race is attached by a tap fit and should be removed from

out of the block and shaft. If it should be necessary to replace the main shaft pin bushings, it can be done by driving the main shaft pin bushing out of the shaft.

10. Overhauling radial and thrust roller bearings. The thrust and radial bearings fit loosely into the angle-box or tilt-box, which ever the case may be, and may be lifted out as illustrated in Figure 2-30. If any of the rollers shows a defect, it should be removed. This can be accomplished by removing the rivets that hold the parts of the cage together. A cage may be assembled with three or four rollers missing, provided no two adjacent

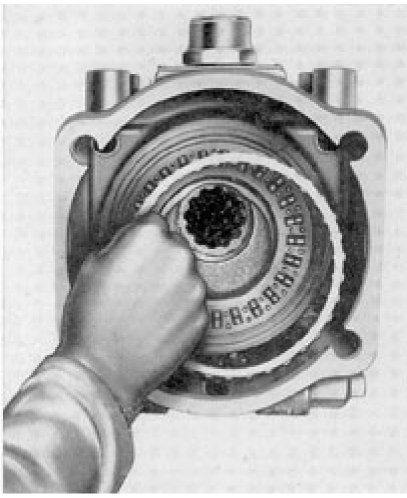

Figure 2-30. Removing bearings.

the box by gently jacking it out with a hook-shaped bar.

Reassembly of the thrust race to the socket ring requires a shrink fit. It will therefore be necessary to heat the race in an oil bath to a temperature of about 270 degrees Fahrenheit.

b. Reassembly. 1. Fitting connecting rods to socket ring. If replacement parts are used in the socket ring assembly, it will first be necessary to fit the connecting rods into the sockets. Assemble and tighten the cap nut until the rod is held firmly in the socket, just tight enough to allow it to be moved backward and forward and from side to side without difficulty. Repeat this motion several times until a bearing surface is established. This surface should be a band about 1/32-inch in width around the ring socket and socket cap.

When a satisfactory bearing surface has been obtained, the fitting for proper freedom of movement without end-play should be made in the following way. Assemble connecting rods in the ring sockets with the ring socket caps and cap nuts. The rod should fit freely but without perceptible end-play. If the fit is so loose that the connecting rod shakes endwise after the nut has been tightened, it is necessary to dress down the end of the socket cap slightly to obtain a tighter fit. When dressing down the cap, draw it carefully over a fine file or emery cloth, and be sure to check the end for squareness.

If, however, the rod fits too tightly, place a shim between the socket

cap and the socket.

To complete the installation of the replacement rod, mark the lock hole location in the lock groove of the socket ring with a prick-punch. Carefully align the marks so that the resulting hole will line up with a notch in the cap nut. Drill a hole which will come through the center of the notch. The nut must be kept from turning during the drilling operation. Remove burrs.

After all the replacement rods have been fitted into the sockets, disconnect them for further reassembly later. Each rod must be tagged for proper relocation.

2. Fitting connecting rods to pistons. The method of fitting the connecting rods in the pistons differs somewhat from that of fitting them in the socket because of the split bushing. The following procedure is recommended for the rod and piston adjustments where there is a split socket cap (4, Figure 2-16) which must be seated firmly against the socket of the piston in addition to bearing properly on the ball-end of the connecting rod. If possible, secure a set of circular laminated shims. If this is not possible, prepare a set of circular shims in thicknesses ranging from 0.001-inch to 0.020-inch which will fit between the piston socket cap (3, Figure 2-16) and its seat in the piston. Laminated or prepared shims should be of smooth, flat brass and without burrs. Place shims 0.015-inch

through the socket ring, observing that the socket which is radially in line with the trunnion bearing block is in line with the shaft keyway. Secure the blocks with screws.

4. Reassembling shaft, barrel, and socket ring. Place the barrel spring (19, Figure 2-13) and keys (12, Figure 2-13) on the shaft. The barrel key marked "V" is to be in line with the keyway at the end of the shaft. Stand the shaft on end with the socket ring down. Keep it in that position in a properly padded vise. Lower the cylinder barrel (4, Figure 2-13) with its pistons over the shaft and keys so as to bring the corresponding connecting rods and their sockets in the socket ring together. In this operation, the pistons must be retained in their cylinders to prevent their sliding out of the barrel.

NOTE. The barrel must slide freely over the keys. The barrel lock ring is then slipped over the end of the shaft and snapped into the shaft groove. Assemble the connecting rod ends into the sockets of the socket ring with the ring socket caps and cap nuts. Screw the nuts down to the locking position as determined by the earlier fitting process. Insert cotter pins into the nuts. Press the inner race of the valve plate roller bearing (11, Figure 2-13) on the end of the shaft. The revolving group is now ready for assembly with the case.

thick in the piston and reassemble the rod, cap, and nut, screwing the nut down tight. Check the rod for end-play. If it is too tight, select a thicker shim. When the end-play has become imperceptible, lock the piston cap nuts in place. Reassemble the pistons and connecting rods in the socket ring and insert the pistons in their respective cylinders in the cylinder barrel.

3. Reassembling shaft and socket ring. Press the main shaft bushings, into the holes in the shaft yoke and secure them with the bushing pins. With the shaft trunnion block in the yoke, press the main shaft pin (9, Figure 2-13) through the block, passing it through the bushings in the yoke, and secure it in the block with the shaft pin retainer. Place the trunnion bearing blocks on the trunnions of the shaft pin and pass the shaft

5. Assembling B-end shaft group and angle-box to case. Carefully place the revolving group on a flat surface with the barrel down. Place the rollers in position on the rotating group. Place the angle-box and races on top of the rollers. Work the box back and forth until it is properly seated.

Press the angle-box dowels into place in the case. Lower the case over the revolving group so that the dowels slip into the holes in the angle-box and the box seats in the recess of the case.

6. Assembling A-end control shaft and tilt-box. If the parts of the control have been disassembled, restore them in the control housing. Replace the washer and screw the control shaft bearing (2, Figure 2-18) down tight. Insert the packing (8, Figure 2-18) and the gland and secure it with the gland cap

(9, Figure 2-18). Prepare the tilt-box for installation by pressing down the radial race. Insert the thrust race and put the rollers in place. Press the retaining trunnion bushings into their sockets in the tilt-box. For the installation, set the case open-end up. Place the case trunnion bushings which are half segments, in the openings in the sides of the case so that the tilt-box forks engage the outer control guide blocks. Replace the washers and screws in the tilt-box retaining trunnion.

7. Assembling A-end revolving group to case. Support the case

9. Overhaul tools. A few special tools are provided for the overhaul of Waterbury speed gears. They consist of:

- 1 piston cap nut wrench, size 5
- 1 ring socket cap nut, size 5
- 1 socket cap nut wrench, size 10
- 2 angle-box guide rods, size 10
- 1 spanner wrench
- 1 race puller

with the open end up, leaving enough space underneath for the full projecting length of the shaft and for inserting the case bolts from the bottom. Suspend the revolving group by an eyebolt screwed into the end of the shaft and lower the group into the case so that the lower end of the shaft goes through its bearing and the socket ring rests properly on the rollers in the tilt-box. The group will rotate freely if it is properly seated. This seating should be checked carefully to make sure the socket ring is not riding the shoulders of the roller bearings.

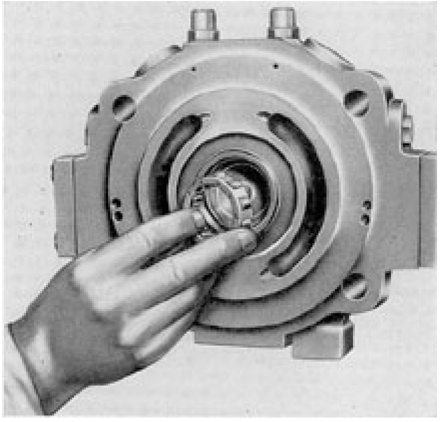
Figure 2-31. Inserting valve plate bearing.

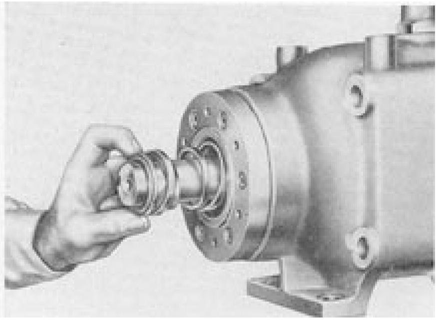
Figure 2-32. Installing oil seal.

8. Assembling valve plate. Press the outer races of the valve plate roller bearing into place. Set the rollers on the race as shown in Figure 2-31. Make a gasket out of the same thickness of fibrous paper that was previously installed to act as a seal between the valve plate and case. Clean the valve plate surfaces thoroughly. Stick the gasket to the inner face with a thin layer of grease. Then oil the side of the gasket which comes into contact with the case. Place the intershaft disk into the recess of the valve plate. If this was removed, it should be restored with heavy grease so that it will not fall out when the valve plate is inverted. Cover the surfaces of the cylinder barrel and the valve plate with a film of oil. Lower the valve plate onto the case and secure with the case bolt nuts. Replace the oil seal elements as in Figure 2-3 and bolt the end cover in place.

3
THE MAIN HYDRAULIC SYSTEM

A. INTRODUCTION

3A1. Functions. The main hydraulic system performs the bulk of the hydraulic work aboard a submarine. Lines from the central power source radiate throughout the ship to convey fluid under pressure for the operation of a large variety of services. The vent valves of the main ballast, fuel oil ballast, bow buoyancy and safety tanks, and the flood valves of the negative and safety tanks are hydraulically opened and closed by power from the main system. It also operates the air induction valves, the outer doors of the torpedo tubes, the bow plane rigging gear, the forward windlass-and-capstan, the echo-ranging and detecting apparatus (sound heads), and the main engine exhaust valves on earlier classes of boats. (In some of the latest installations the main engine exhaust valves are operated by pneumatic-hydraulic, or air cushion, units.) In an emergency the main hydraulic system is also called upon to supply power for the steering system and for the tilting of the bow and stern diving planes, although these systems normally have their own independent power supply units.

On the latest classes of boats, the periscopes and antenna masts are also hydraulically operated as units of the main hydraulic system. In earlier classes, they are electrically operated.

3A2. Component parts. In order to perform these numerous tasks, a variety of valves,

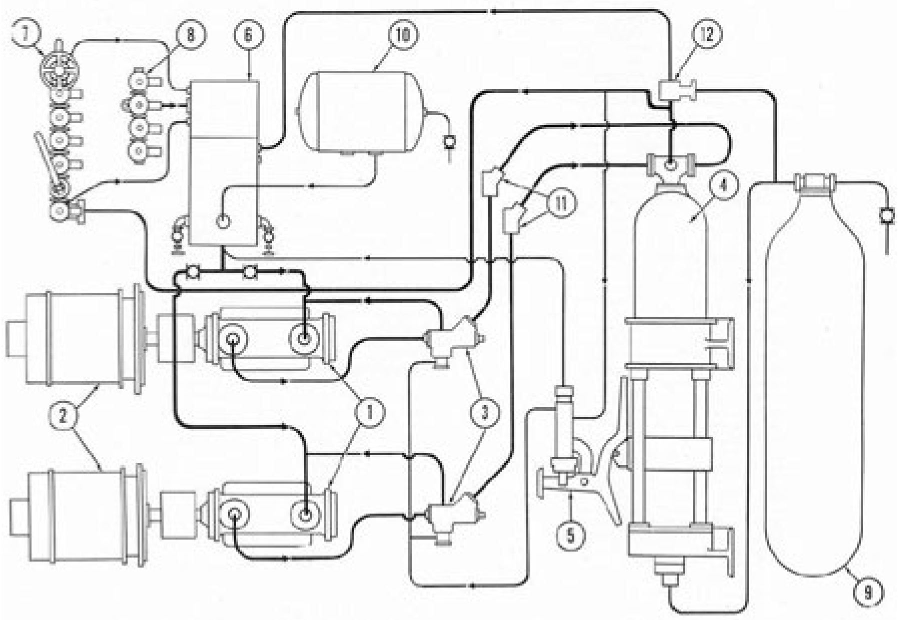

Figure 3-1. Schematic piping diagram of power generating system. 1) IMO pumps; 2) 18-horsepower motors; 3) automatic bypass and non-return valves; 4) accumulator; 5) pilot valve; 6) main supply tank; 7) main supply manifold; 8) main return manifold; 9) accumulator air flask; 10) back-pressure air, or volume, tank; 11) non-return valves; 12) air-loaded relief valve.

actuating cylinders, tanks, and manifolds is required, as well as the pumps for building up the required power. The units of the main hydraulic system fall conveniently into five groups:

a. Power generating system.
b. Floods and vents.
c. Periscope and radio mast hoists.
d. Forward and after service lines.
e. Emergency systems.

A schematic view of the main hydraulic system in the submarine may be seen in Figure 7-1 at the back of the book.

B. POWER GENERATING SYSTEM

3B1. General arrangement. The power generating system consists of a group of units whose coordinated action provides the hydraulic power necessary for the operation of the main hydraulic system. It consists of the following principal parts (see Figure 3-1):

a. The IMO pumps (1) supply hydraulic power to the system.

b. The main supply tank (6) contains the oil needed to keep the system filled.

c. The accumulator (4), as the name implies, accumulates the oil from the pump and creates pressure oil which is maintained at a static head for instant use anywhere in the system.

d. The main supply and return manifolds (7 and 8) act as distribution and receiving points for the oil used throughout the system.

e. The pilot valve (5) is a two-port, lap-fitted trunk, cam-operated slide valve, which directs the flow of oil that causes the automatic bypass valve to open or close.

f. The automatic bypass and nonreturn valves (3). The automatic bypass valve directs the flow of pressure oil in response to the action of the pilot valve. The nonreturn valve prevents the oil from escaping through the open automatic bypass.

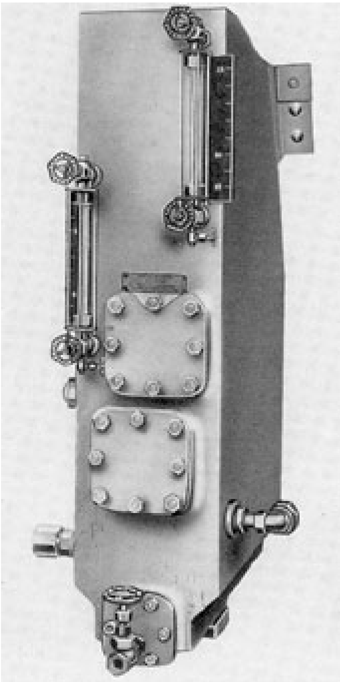

Figure 3-2. Main supply tank.

g. Cut-out valves, serving various purposes throughout the system and nonreturn valves to permit one-way flow.

h. The back-pressure tank, or volume tank (10), contains compressed air at a pressure of 10 to 25 pounds per square inch, which provides the air pressure on top of the oil in the main supply tank and maintains the entire system full of oil.

i. The accumulator air flask (9) serves as a volume tank for the accumulator, allowing the air to pass to and from it when the accumulator is loading or unloading.

3B2. Detailed description. a. Pumps. Power is developed for the system by means of two IMO pumps. The power rotor of each pump is direct-coupled to an 18-horsepower electric motor which drives it at about 1750 revolutions per minute. The two IMO pumps were described in Sections 2B1 to 2B3. They may be operated either singly or both at once, depending upon the volume of oil required by the system at a given moment. Ordinarily a single IMO pump is sufficient to supply the

required volume of oil. However, when operation of the hydraulic units creates a heavy enough demand, the driving motor of the second IMO pump is switched on. The switch can be set on either manual or automatic control.

b. The main supply tank. Fluid is supplied to the pumps from the

accumulator serves the same purpose as a storage battery in an electric system which retains an electrical charge until it is used. Then the charge must be replaced or the battery becomes discharged, or exhausted.

2. Principal parts. The accumulator has three principal working parts: the oil cylinder, the air cylinder,

main supply tank (see Figure 3-2). The shape of this tank varies in different installations. Its total capacity is 50 gallons, but the normal supply maintained there is only 35 gallons; the 15-gallon difference is an allowance made for discharge from the accumulator and thermal expansion of the oil.

When the system is operating, the fluid circulates through the power system, returning to the supply tank. However, the fluid will not remain in the supply tank for any length of time, but will be strained and again pumped under pressure to the accumulator and the manifolds.

Figure 3-3 shows another view of a main supply tank with some sections partly cut away to show the internal structure.

Glass-tube sight gages (1) mounted on the side of the reservoir give minimum and maximum readings of the amount of oil in the tank. A drain line and vale (5) near the bottom of the tank provide a means for draining water which may have accumulated there.

The back-pressure tank is connected by a length of pipe to the top of the supply tank (air inlet [2]), It maintains an air pressure of 10 to 25 pounds per square inch on the oil in the supply tank. This forms an air cushion between the top of the tank and the body of the fluid and maintains the system in a full condition. An air relief valve set to lift at 48 pounds per square inch prevents the and the plunger. The cutaway view (Figure 3-5) shows the internal structure of the unit.

The oil cylinder (1) receives oil from the IMO pumps through the passage (8) at the top of the cylinder.

Air is admitted into the lower end of the air cylinder (3) through the inlet (9), from the accumulator air flask.

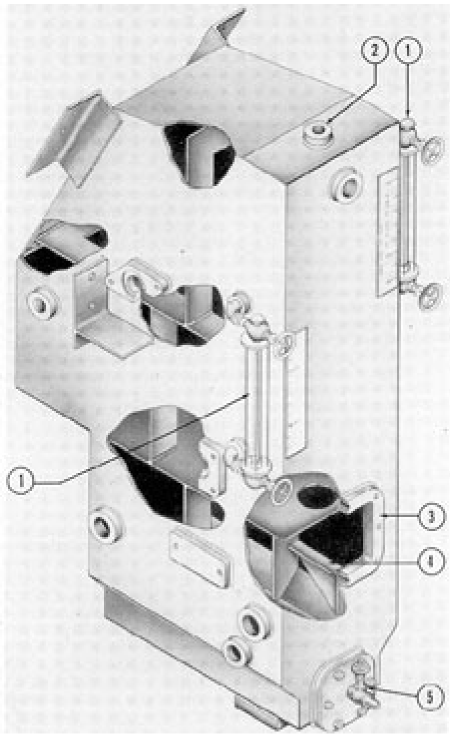

Figure 3-3. Cutaway of main supply tank.
1) Gage; 2) air inlet; 3) hand hole for strainer; 4) strainer mounting base; 5) valve.

building up of excessive air pressures in the supply tank.

c. Accumulator. (See Figure 3-4.)
1. Basic principles of operation. Oil which is discharged by the IMO pumps is directed to the accumulator until the required quantity is obtained. The accumulator receives and stores fluid under pressure and transmits it to the system as it is needed. Actually, the

Air pressure is exerted against the inner surface of the plunger (2) while oil pressure acts on its outer surface. Therefore, its position in the accumulator varies in relation to the differences between the air pressure on the inner surface and the volume and pressure of the oil acting on the outer surface.

Leakage past the inner and outer surfaces of the plunger is prevented by chevron, or C-type ring packing (4 and 6). These packing rings nest together and are held in place by the packing glands (5 and 7). Note that both the air cylinder and the oil cylinder are equipped with drain valves. The oil packing is shown assembled in Figure 3-6. The air packing is illustrated in Figure 3-7.

A gage connected to the oil line leading to the accumulator indicates the oil pressure on the pressure side. The air system is also

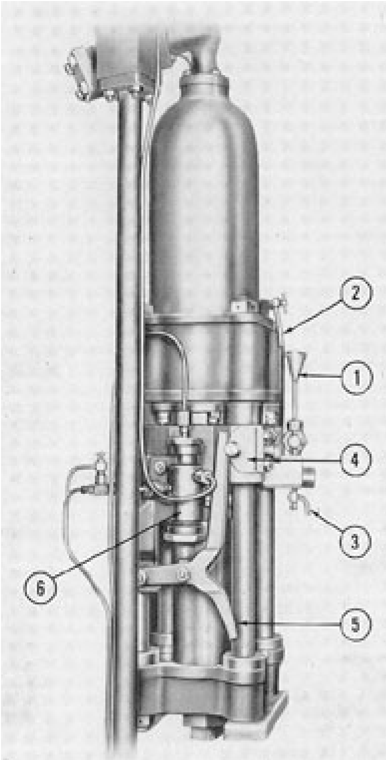

Figure 3-4. Accumulator shown with pilot valve.
1) Oil seal fill; 2) oil cylinder drain; 3) oil seal drain; 4) cam roller; 5) pilot valve operating arm; 6) pilot valve.

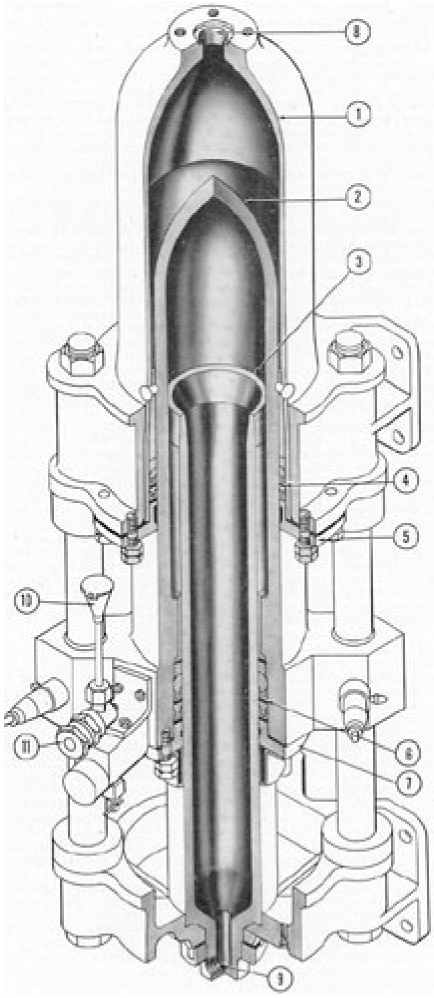

Figure 3-5. Cutaway of accumulator.
1) Oil cylinder; 2) plunger; 3) air cylinder; 4) oil cylinder packing; 5) packing gland; 6) air cylinder packing; 7) packing gland; 8) oil inlet; 9) air inlet; 10) oil seal fill; 11) oil seal valve.

equipped with a gage for indicating the air pressure in the air side of the accumulator. In order to prevent leakage from the air side of the accumulator, an oil seal is provided. The oil filler connection (10, Figure 3-5) attached to the plunger supplies oil to a narrow space between the air cylinder and plunger, above the packing. Since the packing will not retain high pressure air, the oil seal is placed on top of the packing. Therefore however, can slide up or down inside the oil cylinder and over the air cylinder. Before the IMO pumps are started, the accumulator air flask and the air cylinder are charged with compressed air to a pressure of 1750 pounds per square inch from a connection to the high-pressure air system. The cut-out valve for opening the high pressure service line is shown at the extreme right of the piping diagram, Figure 3-1, on the line

the high-pressure air acts against the oil seal instead

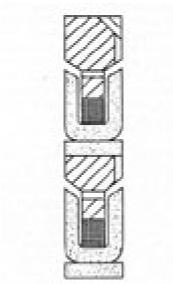

Figure 3-6. Accumulator packing (oil).

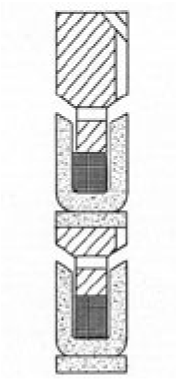

Figure 3-7. Accumulator packing (air).

of the packing. Oil is poured through a pipe and funnel in the oil filler until its level reaches the mid-position of the funnel. The oil filler pipe is mounted in a trap which catches water. A stop valve is fitted to the oil filler to retain the oil seal within the accumulator; also, a needle-type drain valve (3, Figure 3-4) is provided to empty the trap and the oil seal from the air cylinder packing gland.

3. Operation. The oil cylinder and the air cylinder are stationary. The plunger, leading off from the accumulator air flask (9, Figure 3-1).

When the pumps are stopped, air pressure holds the plunger at the top of its travel, ready to receive the charge of pressure oil from the pumps. Since it is the charge of pressure oil that determines the load conditions of the oil cylinder, the cylinder will, therefore, be under no-load when the pumps are not running. In starting the system, it is desirable but not necessary to maintain the no-load condition until normal operating speeds have been attained. Therefore, the hand bypass valve on the main supply manifold is opened, and one of the IMO pumps is switched on. The opened hand bypass valve allows the oil from the discharge side of the pump to flow back to the supply tank, relieving the pump of any load, until it has attained normal operating speed.

The hand bypass valve is then closed, and the oil from the discharge side of the pump begins, to fill the oil cylinder in the accumulator.

When the hand bypass valve is open, the plunger is held at the top of the cylinder by air pressure. Therefore, closing the hand bypass valve forces sufficient pressure oil from the pump into the oil cylinder, on the outer surface of the plunger, to meet and overcome the force exerted by the air upon the inside of the plunger, thus pushing the plunger down in the oil cylinder. The oil pressure in the line between the discharge side of the pump and the accumulator will rise immediately to a value sufficient to overcome

the air pressure that tends to force the plunger up.

The two operating diagrams, Figures 3-8 and 3-9, illustrate the action which takes place.

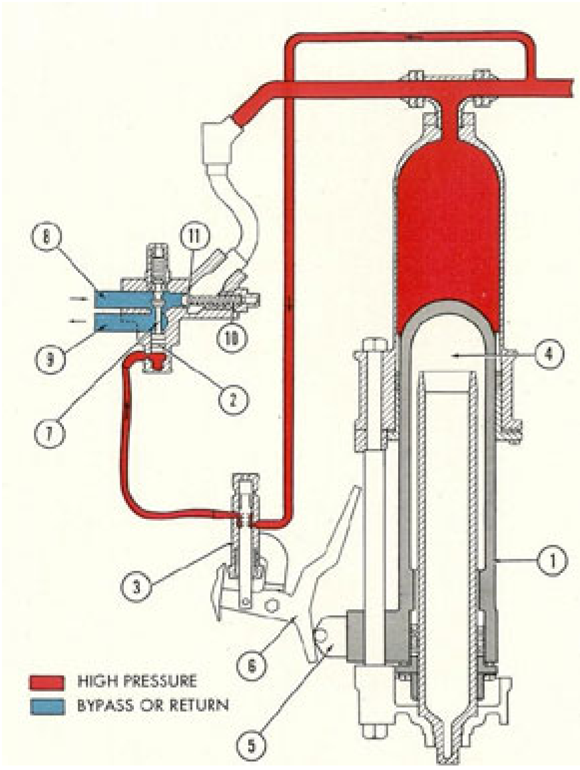

Figure 3-8. Accumulator In fully loaded position.
1) Plunger; 2) automatic bypass valve piston; 3) pilot valve; 4) air chamber; 5) cam roller; 6) pilot valve operating arm; 7) automatic bypass valve; 8) from pump; 9) bypass to pump suction; 10) nonreturn valve spring; 11) nonreturn valve.

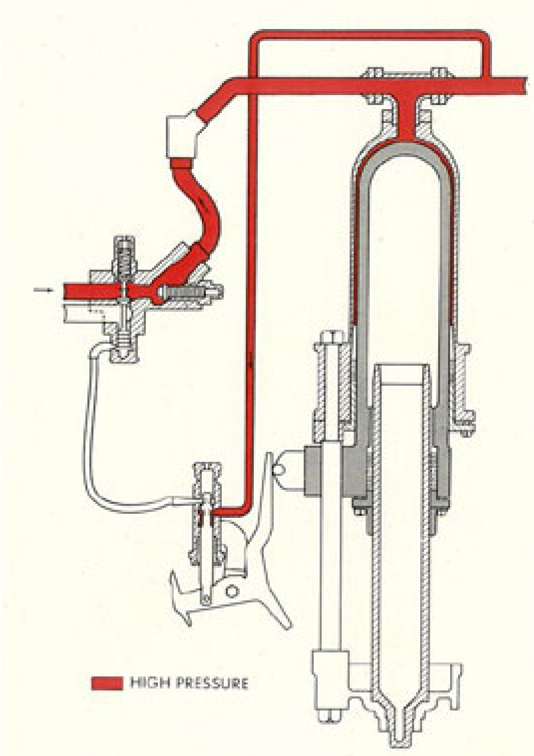

Figure 3-9. Accumulator In unloaded position.

The force of 600 to 700 pounds exerted by this oil upon the outer surface of the plunger (1, Figure 3-8) will force it to travel downward until it has reached the limit of its downward stroke, tripping-the pilot valve operating arm, as shown in Figure 3-8.

The pilot valve (3) which hydraulically operates the automatic bypass valve will cause the automatic bypass valve to open when a column of oil is sent from the pressure side of the system to the underside of the automatic bypass valve piston (2). The oil coming from the discharge side of the pump through the line (8) is now bypassed directly back through the line (9) to the pump's suction side. This allows the nonreturn valve (11) to close, shutting off the line between the pump and the accumulator so that the pressure oil in the accumulator

4. Automatic switches and contact makers. The cam roller on the plunger actuates the pilot valve operating arm, which not only operates the pilot valve, but also at different intervals throws two electrical contact makers which switch on the IMO pumps as the plunger is traveling upward and switch them off again as the plunger travels downward.

Figure 3-10 shows schematically how the contact makers, switches, and electrical wiring are arranged. The cam roller (2, Figure 3-10) is shown in a position intermediate between the highest and lowest limits of its travel. As it moves in either direction from

will not returns through the open bypass valve.

In practice, the pump can either be run continuously or switched off automatically by the use of a toggle switch as the plunger approaches the bottom of its stroke. However, the automatic bypass valve serves as a further precaution to guarantee that no more pressure oil will be forced into the accumulator line after the accumulator is fully charged. In this condition, the full charge of oil will be maintained under pressure in the accumulator. However, this is only theoretically true. In practice, the accumulator will not remain fully charged indefinitely, even when no hydraulic mechanisms are being operated, since there is always a slight oil leakage at various points in the system.

If a control valve were opened at some point in the system, utilizing some of this stored oil to operate a hydraulic mechanism, the force exerted by the compressed air at 1750 pounds per square inch upon the inner surface of the plunger would immediately cause the plunger to travel upward.

When enough of the oil charge has been used, the plunger cam roller, as in Figure 3-9, will trip the pilot valve, closing the automatic bypass valve, and again directing the oil from the discharge side of the IMO pump through the nonreturn valve to the accumulator. The pressure oil will again begin to charge the accumulator, forcing the plunger downward.

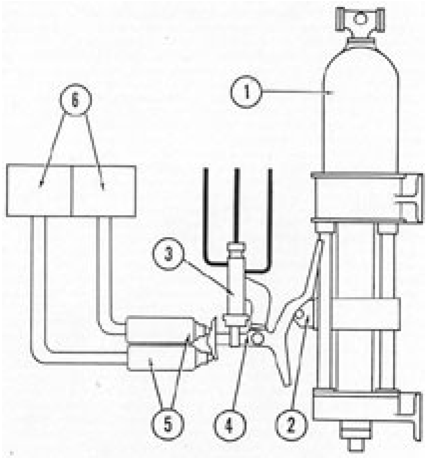

Figure 3-10. Contact makers for pump controls.
1) Accumulator; 2) cam and cam roller; 3) pilot valve; 4) pilot valve control arm; 5) contact makers; 6) motor switches.

this intermediate point, it actuates the pilot valve operating arm, which throws the contact makers (5) connected to the motor switches (6). The wiring is so arranged between the contact makers and the manual push-buttons that, when required, either or both pumps can be automatically switched on or off by the motion of the cam roller. This arrangement permits each pump to be used in turn at continuous service, so that both pumps will receive equal wear.

5. Explanation of pressure differential. The oil pressure on top of the plunger varies

between 600 and 700 pounds per square inch, while the air pressure underneath it is maintained at 1750 pounds per square inch. Since the air pressure is so much greater than the oil pressure, the oil, to be able to exert a force sufficient to overcome that of the air beneath it, allowing the plunger to travel downward, must be acting over a greater area than the air.

This is in fact true. The area on the oil side of the plunger is much larger than the area on the air side, the ratio between the two areas, being approximately 3 to 1. Since the total force exerted by a fluid at a given pressure is proportional to the area over which it is exerted (see Section 1B3b), it follows that an oil pressure of 600 pounds per square inch exerted on the larger area of the oil side of the plunger will be sufficient to overcome an air pressure of 1750 pounds per square inch exerted against the smaller air side of the plunger, which is only about one-third as large as the oil side.

6. Function of the air-loaded relief valve. In Figure 3-1, an air-loaded relief valve (12) is seen just beyond the top of the accumulator. This valve contains a double-ended piston, one end of which is air-loaded by a small secondary line running from the accumulator air flask. The other end of the piston is in contact with the high pressure oil from the oil cylinder in the accumulator.

The ratio between the area of one surface of the piston and the area of the other surface is approximately 3 to 1, or about the same as the ratio between the area of the oil side of the plunger to the area of the air side.

This ratio will not allow for an oil pressure overload of more than 10 percent. In other words, if the oil pressure increases to a value which is more than 10 percent over one-third of the air pressure, the valve piston will lift, allowing oil to escape from the accumulator back to the return side of the system until the 3:1 ratio between air pressure

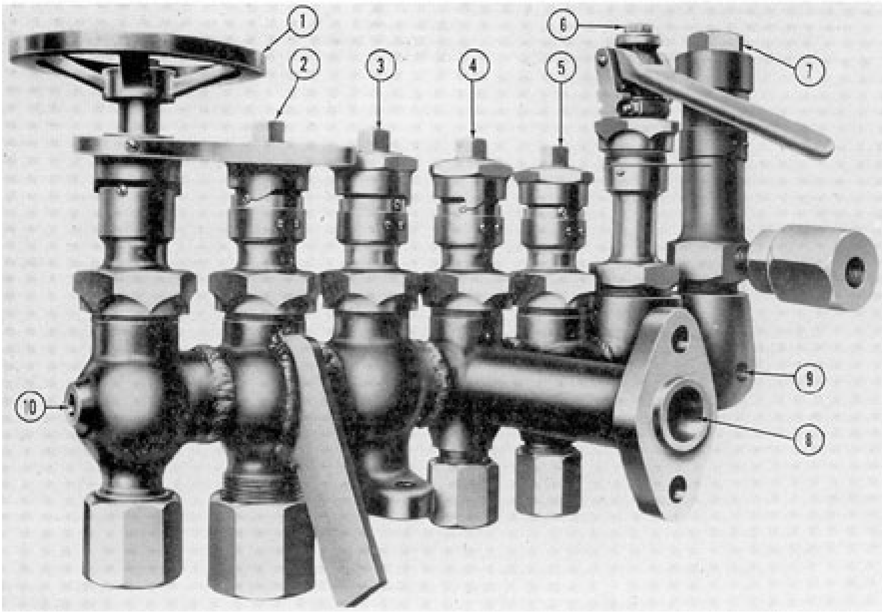

Figure 3-11. Main supply manifold.
1) Bypass; 2) service aft; 3) service fore; 4) emergency planes; 5) emergency steering; 6) quick-throw cutout; 7) relief valve; 8) to control manifolds; 9) to pilot valve supply; 10) to gage and vent.

and oil pressure is restored. For example, if the air pressure, because of leakage, fell off to 1500 pounds, the oil pressure to maintain the correct ratio would be about 500 pounds. If now the oil pressure were to exceed 550 pounds per square inch (one-third of the air pressure plus 10 percent), the valve would lift, allowing the oil to escape from the accumulator back to the return side of the system.

The valve will function correctly regardless of variations in the value of the air pressure.

This air-loaded type of relief valve is currently installed only on Portsmouth built boats. It is intended to furnish additional protection since the existing relief valves in the high pressure side of the system are not adequate to handle an overload when both IMO pumps are running.

(7). The four supply valves are connected to the forward and after service lines and to the emergency systems for steering and plane tilting.

A flanged port (8) connects with the flood and vent control manifolds. A small opening under the relief valve at the end of the fluid channel (9) provides a connection to the pilot valve. A small opening (10) in the hand bypass valve body provides for a gage and vent connection. Both the pilot valve and the gage and vent connections are always open to the common oil passage in the manifold.

3. The bypass handwheel (1, Figure 3-12) is attached to the collar (2). The upper end of the stem (3) is square, to fit into the collar inside the squared hub of the handwheel (1). The lower end, passing through the packing (4), is attached to the short stem which

On submarines of Electric Boat Company design, the line from each IMO pump is provided with its own relief valve, making unnecessary the inclusion of an air-loaded relief valve in the high pressure side of the system.

d. The main supply and return manifolds. 1. Hydraulic fluid discharged by the accumulator is conveyed to the main supply manifold (see Figure 3-11) where its flow is distributed to the supply lines and also to the control valve manifolds. The returning fluid flows through lines to the main return manifolds which then deliver it back to the oil supply tank.

The supply manifold consists of a series of valves combined into a single unit. The opening or closing of any of the valves either permits or interrupts the flow of hydraulic fluid controlled by that valve without affecting the other valves in the manifold. The valves are all connected into a common fluid channel, but distribution of the oil is made through pipe lines attached to those valves which supply a group of hydraulic units. The return manifold is similar in design to the supply manifold.

2. The main supply manifold has seven valves, a bypass valve (1, Figure 3-11), four supply valves (2, 3, 4, and 5, Figure 3-11), a quick-throw cut-out (6), and a relief valve

is attached to the disk (5). When the handwheel is turned to the left, the disk (5) is raised off its seat, opening a passage between the central fluid channel and the port at the bottom. At the time the IMO pumps are started, the bypass is opened so that the oil will flow freely from the pump back to the supply tank until the pumps attain their maximum speed. Then the bypass is closed so that hydraulic pressure will build up.

4. Starting from left to right in Figure 3-12, the bypass valve appears first. The next four valves supply hydraulic fluid to:

a) After service line.
b) Forward service line.
c) Emergency bow and stern planes system.
d) Emergency steering system.

The internal mechanism of these valves is identical with that of the bypass valve. The valve is operated by a double-ended wrench. The small end fits over the turn-nut (8) to rotate the inner mechanism. Before the turn-nut can be moved, the locking cap (7) must be backed off slightly with the large end of the wrench. After each operation, the lock cap is tightened to prevent accidental turning of the valve stem.

5. A quick-throw cut-out valve is provided on the supply manifold. This is a

tapered plug-type valve. Its method of operation is

6. A relief valve of conventional type is installed on the manifold

somewhat different from that of the disk valves. The plug valve has an elliptical hole cut through its center. It can be turned by the lever (9) through the stem (10) so that the hole is in line with the fluid passage in the manifold, or turned in the opposite direction, thereby cutting off the flow of oil to supply valves and manifolds. The valve is spring-loaded and must be lifted off its seat by the handle before it can be turned. The plug valve is provided as a means for rapidly blanking off the oil lines from the power group to the rest of the units in the main hydraulic system.

for relief of excessive pressure. The normal operating oil pressure for the main hydraulic system is 600 to 700 pounds per square inch. The relief valve, however, is adjusted to open when the pressure reaches 750 pounds per square inch, since pressures in excess of 750 pounds per square inch may cause damage to the equipment. The valve (15) is held on its seat by spring (14) until oil pressure overcomes tension on the spring. When this occurs, the valve is lifted off and passes through port (16) to the supply tank. The tension on the spring is regulated by the

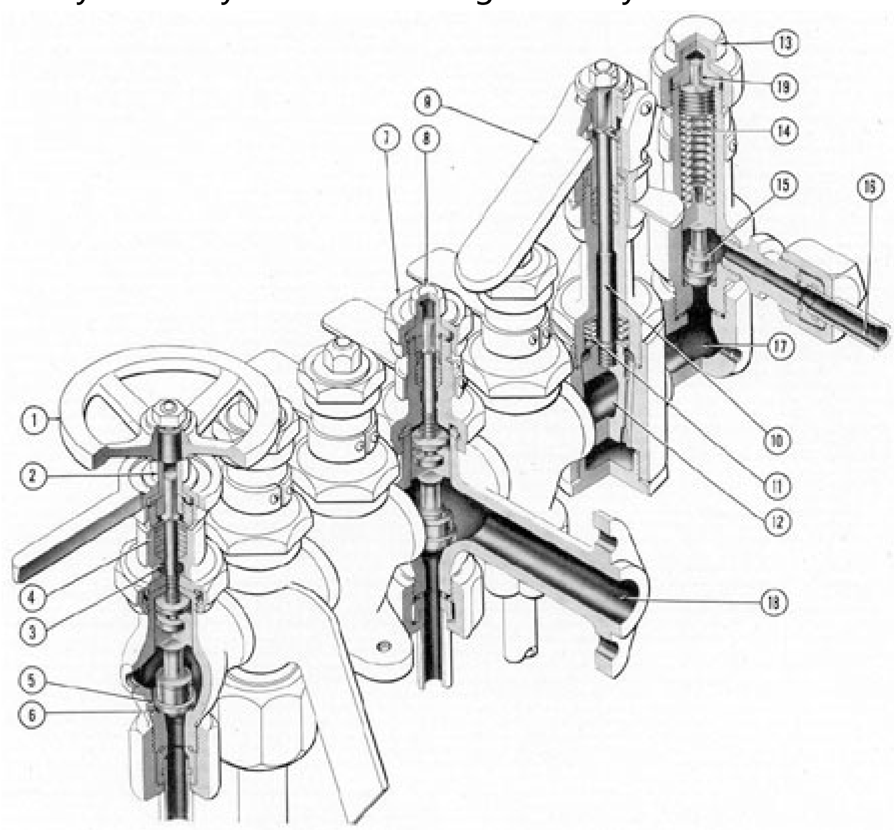

Figure 3-12. Cutaway main manifold.
1) handwheel; 2) collar; 3) stem; 4) packing; 5) disk; 6) seat; 7) locking cap; 8) turn-nut; 9) handle; 10) 11) spring; 12) plug valve; 13) cap; 14) relief valve spring; 15) valve; 16) connection to supply tank; 17) main fluid passage; 18) flood vent manifold; 19) adjustment nut.

adjusting nut (19). The retaining cap (13) prevents leakage from valve.

valves may be welded to the units when required.

7. The main return manifold, illustrated in Figure 3-13, has four valves which are connected to the following lines:

a) After service line.

b) Forward service line.

c) Emergency bow stern planes system.

d) Emergency steering system.

Each valve is identical with disk-type valves contained in the main supply manifold, and operates in the same way. Oil returned to this manifold is directed back to the oil supply tank.

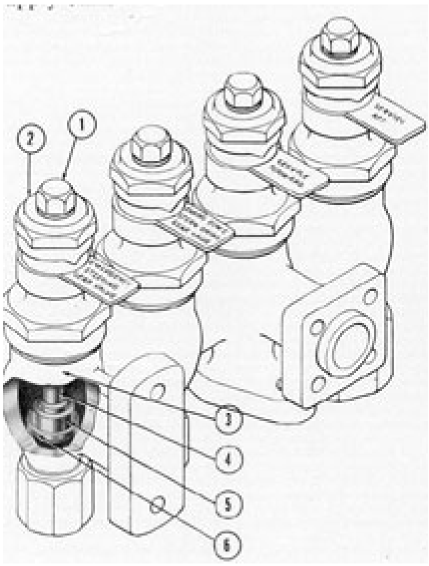

Figure 3-13. Cutaway of main return manifold.
1) Turn-nut; 2) lock cap; 3) valve body; 4) stem; 5) valve; 6) seat.

In submarines which have hydraulically operated radio mast and periscope hoists, the return manifold has six valves, instead of only four. On this installation, however, the two necessary additional supply valves are not attached directly to the main supply manifold, but adjacent it.

The quick-throw cut-out at the main supply tank suction lines and main supply tank suction lines and main supply manifold are normally kept open. They are closed only when it is desired to isolate these units from the rest of the system.

All supply and return valves on both manifolds are normally open, making power instantly available in any part of the main hydraulic system.

e. Pilot valve. The pilot valve (see Figure 3-14) is used in the main hydraulic system to operate the automatic bypass valve by directing oil under pressure to the automatic bypass valve piston when the accumulator is fully charged, thereby opening the bypass and then venting off this oil when the accumulator is discharged, allowing the bypass to close again.

3-14. Pilot valve.

Figure 3-15 shows a cutaway view of this valve. It is mounted on or near the accumulator in such a way that the operating arm (6) is actuated by a cam roller mounted on the accumulator plunger. Hydraulic fluid from the accumulator under pressure enters the valve at the supply port (7). As the accumulator is charged, the plunger moves downward, carrying with it the cam roller. As the plunger approaches the bottom of its stroke, the cam will bear against lower end of the pilot

8. Both the supply and return manifolds are flexible in size, in the sense that additional

valve operating arm, pushing the piston (2) up within cylinder (1). In this position, the flat-milled surface (2) cut along side of the piston will allow a column of oil to pass from the supply port (7) through the

port (8) leading to the automatic bypass valve.

This will open the automatic bypass valve, bypassing the pressure oil from the discharge side of the IMO pump back to the suction side of the pump and allowing the nonreturn valve to close. No more oil will be delivered to the accumulator as long as the pilot valve remains in this position.

When the oil charge in the accumulator is depleted either by the use of oil required for operation of various units in the system, or by leakage, the plunger rises. This causes the cam roller to bear against the upper end of the pilot valve operating arm, thus depressing the pilot valve piston until the land between the two flat-milled surfaces on the piston blocks off the supply port (7) from the port (8) leading to the automatic bypass valve. At the same time, the upper flat surface (10) now aligns the port (8) with the escape

port (9), and the oil trapped under pressure in the line leading to the automatic bypass piston is vented out through the port (9) to a vent line which bleeds into the main supply tank.

This removes the pressure from under the valve piston of the automatic bypass, permitting the loading spring to reseat the automatic bypass valve and thus shut off the bypass line.

Immediately pressure oil from the IMO pump, once more directed against the underside of the nonreturn valve, opens this valve, allowing the oil to flow to the accumulator.

A packing gland with chevron packing (3) prevents oil leakage past the pilot valve piston at its point of entry into the valve body.

The foregoing description applies only to the latest types of pilot valves, since earlier pilot valves are different both in design and installation. The earlier type valve, while serving the same purpose and designed on the same general principle as the later type, has two structural differences. (1) it uses a spool piston and has its accumulator and automatic bypass line reversed from the later pilot valve installation; and (2) the drilled passage in the center of the

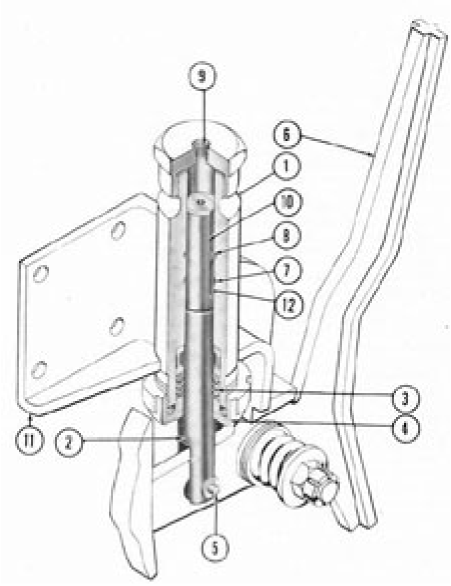

Figure 3-15. Cutaway of pilot valve.
1) Body; 2) piston; 3) packing; 4) gland nut; 5) pin; 6) pilot valve operating arm; 7) port from high pressure line; 8) port to automatic bypass; 9) to oil supply tank; 10) flat-milled passage; 11) Mounting bracket; 12) flat-milled passage.

piston actually allows the venting and releasing of the oil pressure from the automatic bypass valve. This reversal of lines uses the automatic bypass line to be blanked off as the piston rises rather than when the piston descends as in the later type. The purpose of this change in the later pilot valve is to have the toggle switch, that automatically starts and stops the pumps, operated by the cam attached to the pilot valve bracket arm. This change also provides for more positive action of the pilot valve.

f. Automatic bypass and nonreturn valves. 1. The automatic bypass and nonreturn valves (see Figure 3-16) are installed between the IMO pumps and the accumulator. There is one on each pump pressure line. The automatic bypass valve bypasses hydraulic oil when the accumulator is fully charged. The nonreturn valve prevents back-flow of the oil to the pump.

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2. As seen in Figure 3-17, the valve body (1) contains two valve parts. One is the bypass valve (2) which is held on its seat by the valve spring (3). The other valve is of the disk-type (4) which is also seated by a spring (5).

1. Sound isolation: supplementary nonreturn valves. If the noise of the IMO pumps in operation were transmitted to the hull of the submarine, it would greatly increase the danger of detection by enemy listening devices. The pumps are therefore mounted on rubber. This precaution, however, would be of comparatively little value if rigid pipelines connected the pumps with the rest of the system, since then the piping would carry the vibration to the framework and thence to the hull.

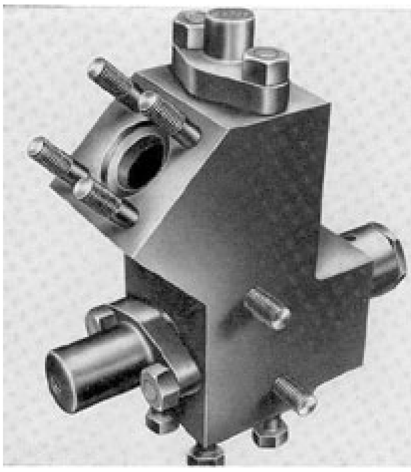

Figure 3-16. Automatic bypass and nonreturn valve.

3. During the intervals when the accumulator is being charged, hydraulic oil is delivered by the pump into the pressure line (8). The oil pressure unseats the spring-held nonreturn valve disk (4) and oil under pressure goes into the line (7) to the accumulator. When the accumulator is fully loaded, the pilot valve is tripped and oil enters the bypass valve at port (9). The force of this pressure opens the bypass valve (2) and the oil from the pumps is bypassed back to the suction side of the pumps through port (6). When this occurs, there is not enough pressure to keep the nonreturn valve (4) off its seat, so the disk valve spring (5) returns the disk to its seated position, thus blocking the back-flow of oil from the accumulator. Oil pressure from the accumulator also assists in the seating of the valve.

g. Miscellaneous valves. Brief mention should be made of a group of cut-out and check valves found in the main hydraulic system as well as in the steering and planes systems.

Accordingly, the pump noise is isolated by inserting short lengths of flexible rubber tubing in the hydraulic pipelines between the automatic bypass and nonreturn valves and the accumulator.

Rubber hose is, of course, subject to deterioration and lacks the strength of the rigid parts of the system. Hence, the flexible connection represents a weak point in the piping. An examination of the schematic piping diagram (Figure 3-1) will show that if either of those connections were to give way, and no

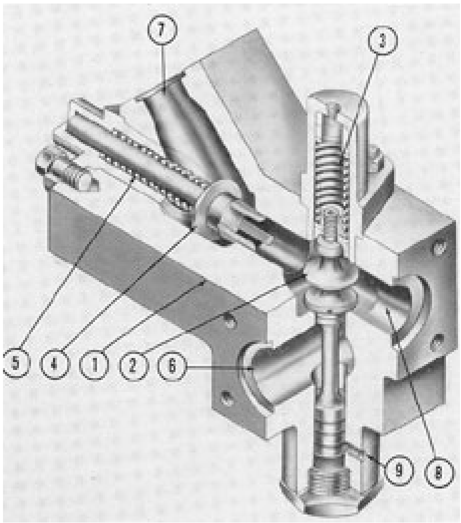

Figure 3-17. Cutaway of automatic bypass and nonreturn valve.
1) Body; 2) bypass valve; 3) bypass valve spring; 4) nonreturn valve disk; 5) nonreturn valve spring; 6) to pump suction; 7) to accumulator; 8) from pump; 9) from pilot valve.

provisions were made for shutting off the lines between the accumulator and the automatic bypass and nonreturn valves, oil stored in the accumulator would instantly be discharged into the pump room with accompanying hazard and inconvenience. To prevent backing up of oil from the accumulator in this eventuality, an additional nonreturn valve is placed in each of these lines. The schematic piping diagram shows the location of these valves (11, Figure 3-1).

Figure 3-18, the internal structure of a nonreturn valve, shows that this valve is practically identical with the nonreturn valve which forms part of the automatic bypass and nonreturn valve assembly (see Figure 3-17), except that it has no return spring. The pressure oil coming from the automatic bypass and nonreturn valve enters these nonreturn valves at the intake port (2), pushing the valve disk (1) off its seat and allowing the oil to flow out through the outlet port (3),

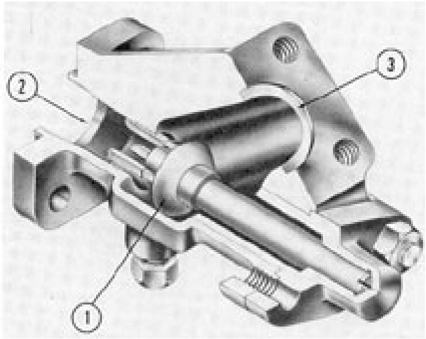

Figure 3-18. Cutaway of nonreturn valve.
1) Valve disk; 2) inlet port; 3) discharge port.

valve plug (5), either to line up the port in the plug with the fluid flow or to turn the plug to prevent flow. The plug is tightly held on its seat by a spring (4). The handle must be raised to allow the plug to lift far enough to be rotated and then released so it can be reseated. This type of quick-throw cut-out valve is located in the pump supply lines from the supply tank.

3. Hydraulic cut-out valves. A smaller type of cut-out valve is illustrated in Figure 3-20. The nonrising stem (2) is rotated by a wheel fitted with finger knobs (1). Both ends of the stem are square, the top end fitting into the finger wheel from which the knobs extend and the bottom end fitting into a threaded piece which bears against the valve disk (4).

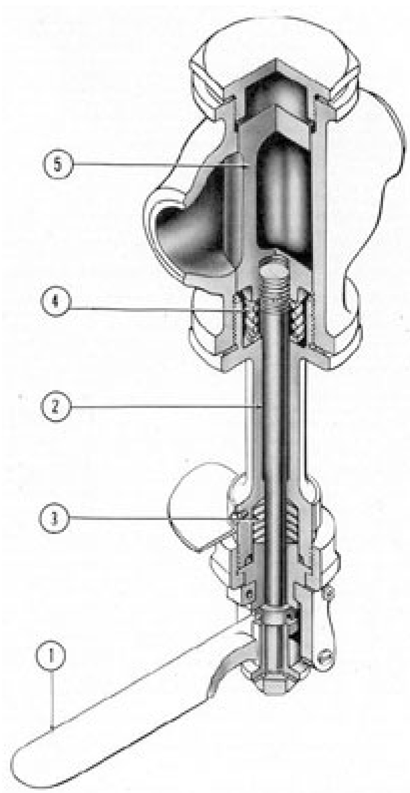

Figure 3-19. Cutaway of quick-throw cut-out valve.
1) Handle; 2) stem; 3) packing; 4) spring; 5) valve plug.

into the line leading to the accumulator. The instant that the pressure through this valve is reversed, oil flowing in through the outlet port (3) would immediately force the disk (1) back against its seat, shutting off the line.

2. Quick-throw cut-out valve. This valve (see Figure 3-19) is similar in operation to the cut-out valve in the main supply manifold described in Section 3B2d. The handle (1) rotates a stem (2) which is attached to a

The top of this disk forms a collar, which fits into a groove cut in the interior of the male threaded piece. As this piece screws

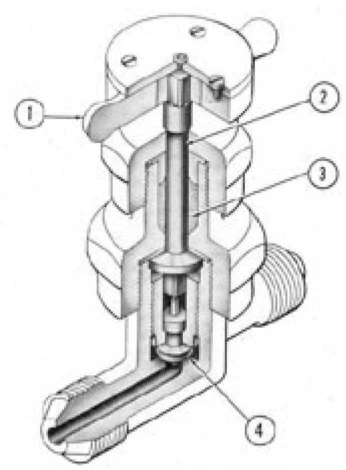

Figure 3-20. Cutaway of hydraulic cut-out valve.
1) Handle; 2) stem; 3) packing; 4) valve disk.

up or down as a result of being turned left or right by the squared lower end of the stem, the disk will ride with it. Therefore, rotating this stem by means of the finger wheel will cause the male threaded piece to be screwed downward, seating

consists essentially of a valve body, or bonnet, containing an upper and lower chamber which can be opened to each other by raising the valve disk (5, Figure 3-21), or closed by lowering the disk down into its seat. The disk is moved up and down by a traveling stem (4), the top end of which is squared, and the lower end threaded. The square top of the stem fits loosely inside the turn-nut (1). The lower end of the stem is formed into a double collar to hold the valve disk (5), within which it can turn freely. Turning the stem left or right, therefore, will cause it to travel up or down, thus raising or lowering the valve disk, which rides on its lower end.

The turn-nut is secured in any required position by screwing the locking cap (2) down tightly to it, using for this purpose the large-end hex-wrench. Therefore, before the turn-nut can be moved, the locking cap must be backed off a little, until the turn-nut is freed. The small end of the hex-wrench is

the valve disk and shutting off the flow of oil.

The valve disk has a hole drilled partially through its center into which fits a small cylindrical rod, extending downward from the squared lower end of the stem. This rod serves as a guide upon which the valve disk slides up or down with the rotation of the threaded piece.

Oil leakage past the stem is prevented by packing (3), held in place by a gland.

An indicator plate at the top of the valve (not shown in the illustration) shows which way to turn the wheel in order to open or close the valve.

4. Hydraulic Silbraz valves. Several of these valves (see Figure 3-21) are located throughout the hydraulic system. They range in size from 1/8-inch to 1/4-inch. This valve is of the on-and-off type in which the valve position is secured by a lock cap. It then applied to the turn-nut. Turning the turn-nut all the way to the right will screw-the stem down to its lowest position,

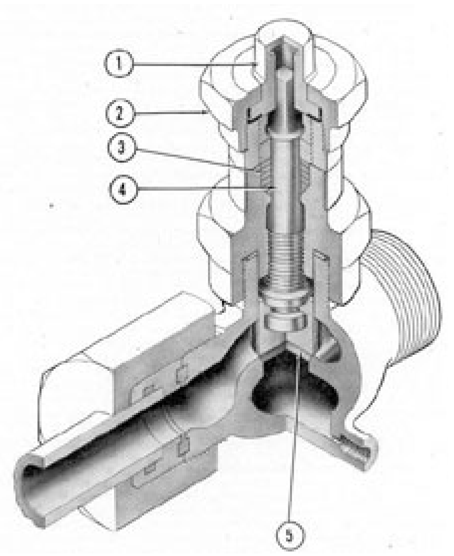

Figure 3-21. Cutaway of hydraulic Silbraz valve.
1) Turn-nut; 2) locking cap; 3) packing; 4) stem; 5) valve disk.

seating the valve disk and blocking off the upper and lower chambers from each other, thereby shutting off the line through the valve. Turning the turn-nut to the left will raise the disk, opening the valve.

Oil leakage is prevented by packing (3), held in place by the packing gland.

It should be noted that though it is the turn-nut to which the wrench is applied, the turn-nut occurs, the plunger (1) is forced down until it reaches the fully loaded position shown in this illustration. The cam roller (5) moves downward with the plunger and changes the position of the pilot valve operating arm (6). The piston of the pilot valve (3) moves up so that the port which allows oil to flow to the automatic bypass valve is uncovered. This oil acts upon the automatic bypass valve (7), forcing it upward off its seat. Hydraulic oil which enters the automatic bypass and nonreturn

itself does not travel up or down, it merely turns left or right, while the stem rides up or down within it.

3B3. Operation. a. Preliminary steps. With all units arranged in place as shown in Figure 3-1, the following steps must be taken before the power generating system is started.

1. The entire system must be filled with oil and the accumulator fully charged. An additional 35 gallons, over and above the amount necessary to fill the entire system, must be placed in the main supply tank.

2. The back-pressure, or volume, tank must be charged with compressed air at a pressure of from 10 to 25 pounds per square inch, from the 200-pound air service line. (Not all classes of submarines have this unit.)

3. All hand levers on the control manifolds must be placed in the HAND position.

4. The quick-throw cut-out valves at the main supply tank and main supply manifold must be opened.

5. The air cylinder in the accumulator and the air bottle must be charged with compressed air to a pressure of 1750 pounds per square inch from its high pressure service line, raising the plunger in the accumulator to its top position.

6. The hand bypass valve on the main system manifold may be opened if required.

valve from the pump pressure line (8) is bypassed to the suction side of the pump through the port (9). In the meantime, the nonreturn valve (11) is seated because of the reduction in pump pressure caused by bypassing the oil, and the flow of oil from the IMO pumps to the accumulator is shut off.

d. When the accumulator is discharged, nearly all its contents being used in the operation of the hydraulic system, the plunger again rises to the position shown in Figure 3-9. The cam roller, acting upon the arm of the pilot valve, lowers the piston so that oil no longer flows to the bypass valve (7), while the small quantity of oil under pressure trapped in the line between the bypass and

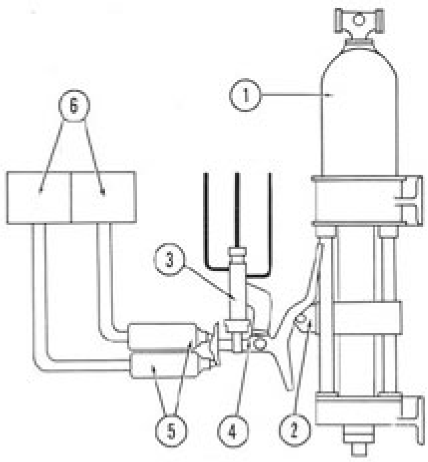

Figure 3-22. Contact makers for pump controls.
1) Accumulator; 2) cam and cam roller; 3) pilot valve; 4) pilot valve control arm; 5) contact makers; 6) motor switches.

b. Starting pumps. Turn on the motor switches which start the pumps. In a few seconds, the pumps should be operating at full speed and the hand bypass valve (if opened) can be closed, making possible full development of oil pressure.

c. The accumulator (see Figure 3-8) is charged with oil under pressure. As this

the pilot valve vents off through the pilot valve vent line back to the main supply tank. The spring will then reseat the automatic bypass valve. Oil from the pressure side of the pump unseats the-nonreturn valve (11) and once more charges the accumulator.

e. During the periods when pressure is being built up in the accumulator, the two IMO pumps can be operated jointly, if required. In more recent classes of boats, this is accomplished automatically. Figure 3-22 shows a typical installation. A pair of contact makers, one for each pump, is mounted so that they are in contact with the bracket arm of the pilot valve. When the accumulator is in the unloaded position, the cam on the pilot valve operating arm releases both contact makers, and both pump motors are switched on at proper intervals. In the fully loaded position, the cam presses in both of the contact makers, shutting off both pumps at proper intervals.

C. FLOOD AND VENT CONTROL SYSTEM

3C1. General. The ability of a submarine to attain neutral buoyancy, so that by suitable manipulation of its diving planes it can submerge, surface, or maintain a given depth, is effected by a series of tanks built around the pressure hull. These tanks are divided into separate compartments, which can be filled with sea water to submerge the vessel, and emptied by compressed air to restore water equal to the quantity which would flood the conning tower as a result of enemy action. In such case, the amount of positive buoyancy supplied by blowing the safety tank would just compensate for the amount lost by the flooding of the conning tower.

A special feature of both tanks is that they are constructed as strongly as the pressure hull itself, and hence can withstand full sea pressure at any working depth.

positive buoyancy. The tanks are classified and named according to their normal functions as follows:

a. Main ballast tanks. The main ballast tanks (M.B.T.) comprise e principal group. They contain air when the vessel is surfaced, sea water when it is submerged.

b. Fuel ballast tanks. The fuel ballast (F.B.) tanks normally carry fuel for the Diesel engines. When the fuel has been consumed, they can be converted for use as normal ballast tanks.

c. Negative and safety tanks. 1. The negative tank. The negative tank is a special-purpose tank located under the control room, just forward of amidships. When opened to the sea, it fills up with water. It is used to get the vessel under rapidly, or if the vessel is already submerged, to make a quick descent to greater depth. It is called the negative tank because its purpose is to, provide negative buoyancy.

2. The safety tank. The safety tank is another special-purpose tank, located amidships. Its function is the opposite of that of the negative tank; that is, it provides positive buoyancy in an emergency situation. Specifically, it is designed to hold a quantity of

Therefore, whenever it is necessary either to surface or to attain a shallower depth, the full working pressure of the high pressure air line can be let into these tanks, rapidly expelling the water.

d. The bow buoyancy tank. The bow buoyancy tank, as its name implies, is located in the bow of the vessel, and controls-its buoyancy. When the ship dives, this tank is flooded first to make the ship nose-heavy; when surfacing, it is blown out first, to make the ship rise by the bow.

3C2. Detailed description. a. Flood valves and vent valves. All main ballast tanks have flood ports; the fuel ballast tanks have hand-operated flood valves. All have hydraulically operated vent valves.

The vent valve on the safety tank and the flood valves on the safety and negative tanks normally are hydraulically operated, but if necessary, can also be operated by hand.

The vent valve on the negative tank is hand-operated and is vented inboard.

When the submarine is surfaced, the vents are closed, and the water is kept out of the tanks by keeping them filled with air at about 10 pounds pressure. Since the flood

ports of the main ballast tanks are always below the waterline, the sea exerts a constant upward pressure, but is prevented from entering because the imprisoned air cannot escape. To submerge

1. The main vent control manifold. a. Portsmouth installation. Figure 3-24 shows the main vent control manifold, commonly called the six-valve manifold, as installed on boats of Portsmouth design. It is a

the vessel, therefore, it is necessary only to open the vents, allowing the imprisoned air to escape, and the sea water will enter the tanks.

To surface again, the vents are closed, and air is forced into the tanks from the top, blowing the water out through the flood ports in the bottom.

b. Flood and vent control manifolds. The main ballast, fuel ballast, and safety tank vent valves, and the bow buoyancy and the two hydraulically operated flood valves (safety and negative tanks) are controlled from two flood and vent control manifolds, the six-valve manifold and the three-valve manifold, both located in the control room. housing containing six identical control valves, each one of which is separately operated by individual hand levers.

Reading from right to left (Figure 3-24), these six levers operate the following vent valves:

1) Bow buoyancy tank
2) Main ballast tanks No. 1 and No. 2
3) Fuel ballast tanks No. 3 and No. 5
4) Main ballast tank No. 4
5) Main ballast tanks No. 6 and No. 7
6) Safety tank

b. Electric Boat Company installations. The main vent control manifold on boats

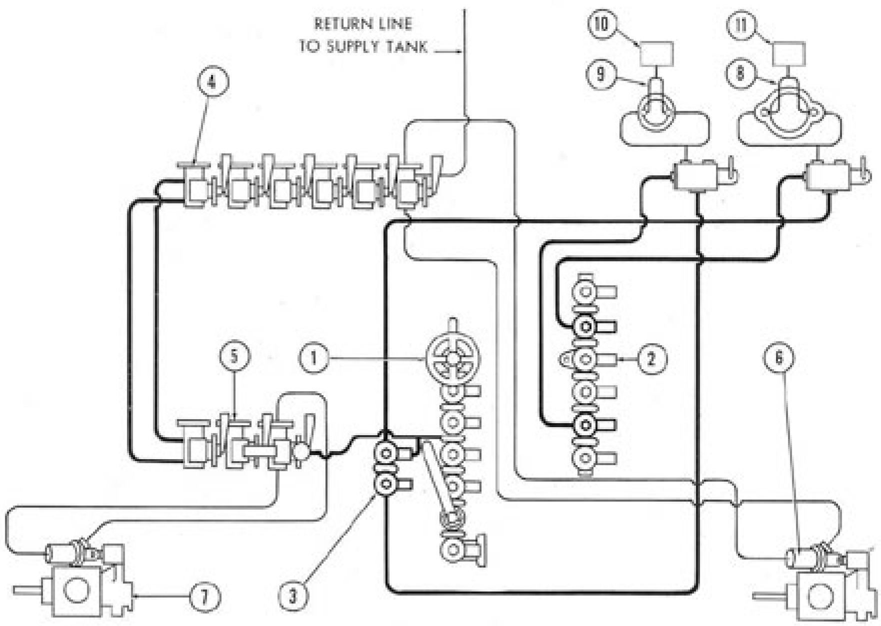

Figure 3-23. Piping diagram of flood and vent system and periscope and antenna mast hoists.
1) Main supply manifold; 2) main return manifold; 3) two-valve addition to main supply manifold, for periscope hoist and antenna hoist (in practice welded to lower end of main manifold); 4) main vent control, or six-valve, manifold; 5) flood and hull ventilation control, or three-valve, manifold; 6) vent valve operating gear, bow buoyancy tank; 7) main engine air induction and hull ventilation; 8) periscope vent line; 9) antenna vent line; 10) settling tank; 11) settling tank.

built by the Electric Boat Company houses seven control valves instead of the six found in the Portsmouth installation.

Reading from right to left, these seven valves operate the following vent valves:

1) Bow buoyancy tank
2) Main ballast tanks No. 1 and No. 2
3) Fuel ballast tanks No. 3 and No. 5
4) Main ballast tank No. 4
5) Safety tank
6) Main ballast tank No. 6
7) Main ballast tank No. 7

c. Operation of the valves. Each valve has four positions, which are shown on indicator plates next to the hand levers:

1) CLOSE, which closes the vent.

2) OPEN, which opens it.

3) HAND, which bypasses the oil allowing hand operation.

4) EMERGENCY, which shuts off the lines to the hydraulic unit cylinder, so that if there is a break in the local circuit, oil will not leak out of it from the main system, and only the oil in the local circuit will be lost.

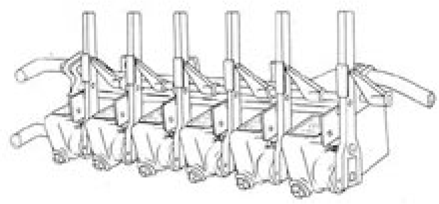

Figure 3-24. Main vent control manifold (six-valve manifold).

The frame mounted on the manifold has notches cut into it for each valve position. The hand lever is firmly latched into these through suitable linkage, to the valve operating mechanism.

Figure 3-25 shows the internal construction of one of these valves, as it would look from the left end of the manifold. (The illustration shows the three-valve manifold, but the internal structure of its valves is identical with those in the six-valve manifold.) It is a spool-type valve, so called because of the spool (11) which, when moved by the hand lever (2), shaft (15), arm (14), and connecting link (13), opens and closes the required combinations of ports and channels in the body (1) of the valve. The pressure line (7) and the return line (8) form channels which run lengthwise through the whole manifold; the threaded port (9) on the bottom of the manifold goes to the upper end of the hydraulic unit cylinder; a similar port just behind it (not shown) goes to the lower end of the cylinder. The latching spring (10) holds the hand lever firmly in place. The individual locking arms (5) swing freely on the pivot rod, making a sliding fit against the side of the hand lever, just tight enough to prevent the lever from being pulled out of the notch. Therefore, the hand lever cannot be moved from any of the four notched positions while its locking arm is down, that is, horizontal. The lock hole (6) is just above the top of the locking arm when it is horizontal so that, to secure a valve in any position, it is necessary only to place the hand lever in the desired notch, drop the locking arm, and slip a padlock through the locking hole. In this view, Figure 3-25, the three locking arms are viewed from the left end of the manifold and

notches by a lateral spring. Once placed in any position the lever remains there until moved by the operator.

Each of these control valves operates a flood or vent valve, at some point remote from the manifolds, by directing a column of pressure oil to one side or the other of a hydraulic unit cylinder whose piston is connected,

shown in the dropped position. Reference to Figure 3-24, in which they are shown partly raised, and viewed from the right end, will make the arrangement more easily understood.

2. The flood and hull ventilation manifold. Figure 3-26 shows the flood and hull ventilation manifold, usually called the three valve manifold. Its three control valves are identical in structure and operating principles with those on the six-valve manifold just described (see Figure 3-25). Its hand levers are all shaped differently, however, and its functions differ in important ways from those of the six-valve manifold.

Reading from right to left (Figure 3-26), its three hand levers operate the following units:

a) Main engine. Engine air induction and hull ventilation supply and exhaust. (Ball-shaped handle; name plate V.)

b) Negative tank flood valve. (T-shaped handle; name plate N.)

c) Safety tank flood valve. (Straight handle; name plate S.)

As on the six-valve manifold, each valve

has four positions, shown on indicator plates next to the hand levers:

a) CLOSE, which closes the hydraulically operated unit.

b) OPEN, which opens it.

c) HAND, allowing hand operation.

d) EMERGENCY, which shuts off the lines to the hydraulic unit cylinder in case of a break in them, so that the oil in that circuit only will be lost.

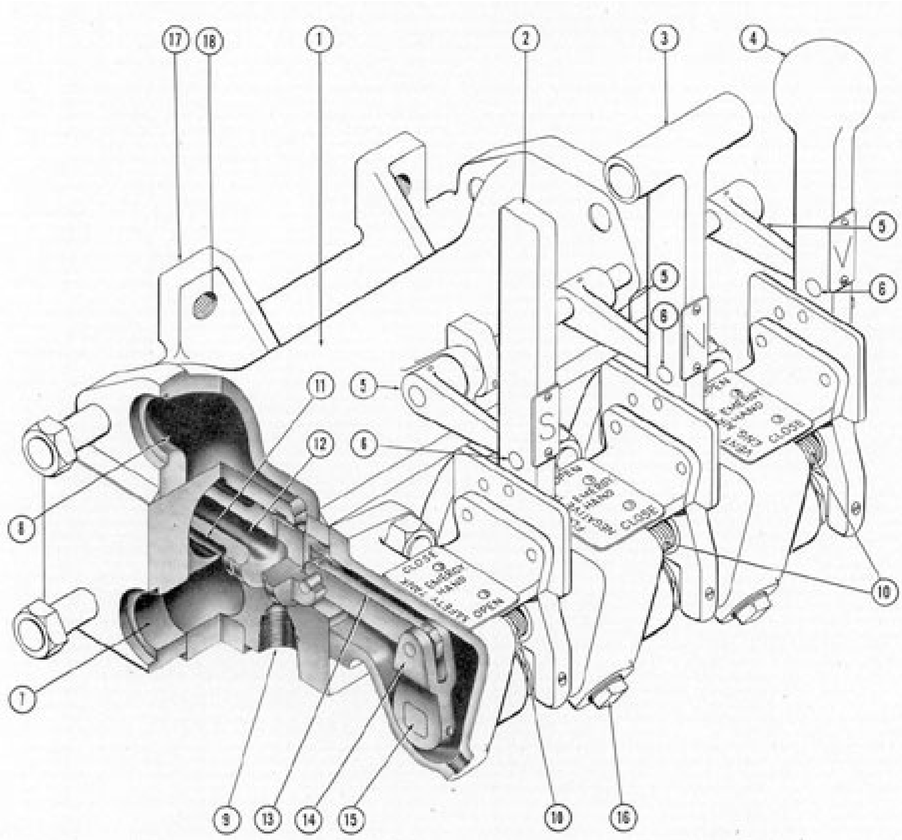

Figure 3-25. Cutaway of safety and negative flood, engine air induction and hull ventilation control manifold (three-valve manifold).
1) Valve manifold body; 2) hand lever for flood valve of safety tank; 3) hand lever for flood valve of negative tank; 4) hand lever for hull ventilation valve and engine air induction valve; 5) locking arms; 6) hole for padlock; 7) hydraulic port from supply line, main hydraulic system; 8) hydraulic port to return line; 9) hydraulic port to hydraulic cylinder of operating gear; 10) latching spring; 11) spool; 12) bypass channel in valve; 13) link; 14) arm; 15) shaft; 16) drain plug; 17) bracket; 18) mounting hole.

The units operated by this manifold are extremely important to the safety of the vessel and the following precautions have been taken to prevent errors in its operation:

a) As already shown, its handles are so shaped as to be instantly identifiable, even in the dark.

b) The safety and negative tank flood valve levers throw in opposite directions from each other for CLOSE or OPEN (see name plates in Figure 3-25).

The operating gear is shown in Figure 3-27. It consists essentially of a hydraulic unit cylinder and suitable linkage connecting it to a vertical operating shaft which opens and closes the vent. It can also be operated by the hand lever (shown projecting downward in the illustration).

c) The main engine air induction and hull ventilation valve lever (with ball-shaped handle) is fitted with a spring-loaded pin which will lock it when placed in the CLOSE position (see Figure 3-26). In order to move this lever to OPEN, this pin must be pulled out and held out while the lever is being moved. In other words, it takes both hands to move this lever out of either position.

In addition, the three-valve manifold has the regular latching and locking devices described in connection with the six-valve manifold.

c. The vent valve operating gear. All vent valves on the main ballast tank system and the valve on the safety tank and bow buoyancy tank are hydraulically operated.

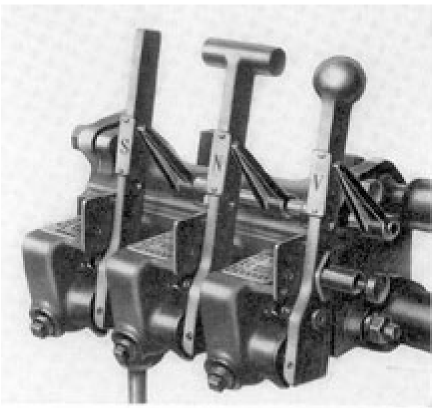

Figure 3-26. Safety and negative flood, engine air induction and hull ventilation control manifold (three-valve manifold).

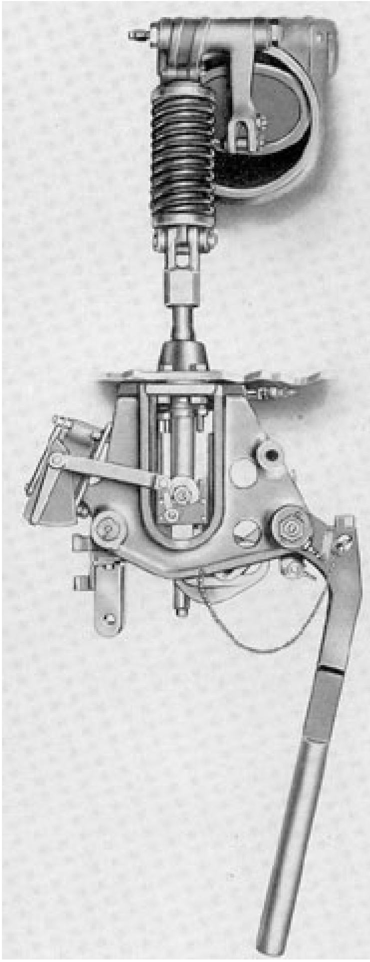

Figure 3-27. Vent valve operating gear and hydraulic unit cylinder.

A cutaway view of the same mechanism is shown in Figure 3-28. Fluid under pressure is admitted from the control valve into the hydraulic unit cylinder (1) through the ports (4). As the piston head (2) moves, it the top of the crosshead is screwed the lower end of the operating shaft (11). This shaft goes up through a packing gland in the pressure hull, to the superstructure, where the mechanism which opens and

actuates the crankshaft (6). This moves the cam, which, bearing against the groove in the slotted link (8), causes that link to push up or pull down on the flat link (9), thereby moving the crosshead (10) up or down. Into closes the vent is located. Figure 3-28 shows the mechanism as it would look with the vent closed.

The mechanism is furnished with a locking pin (15), attached to the framework by a chain. This pin is placed in one of three holes,

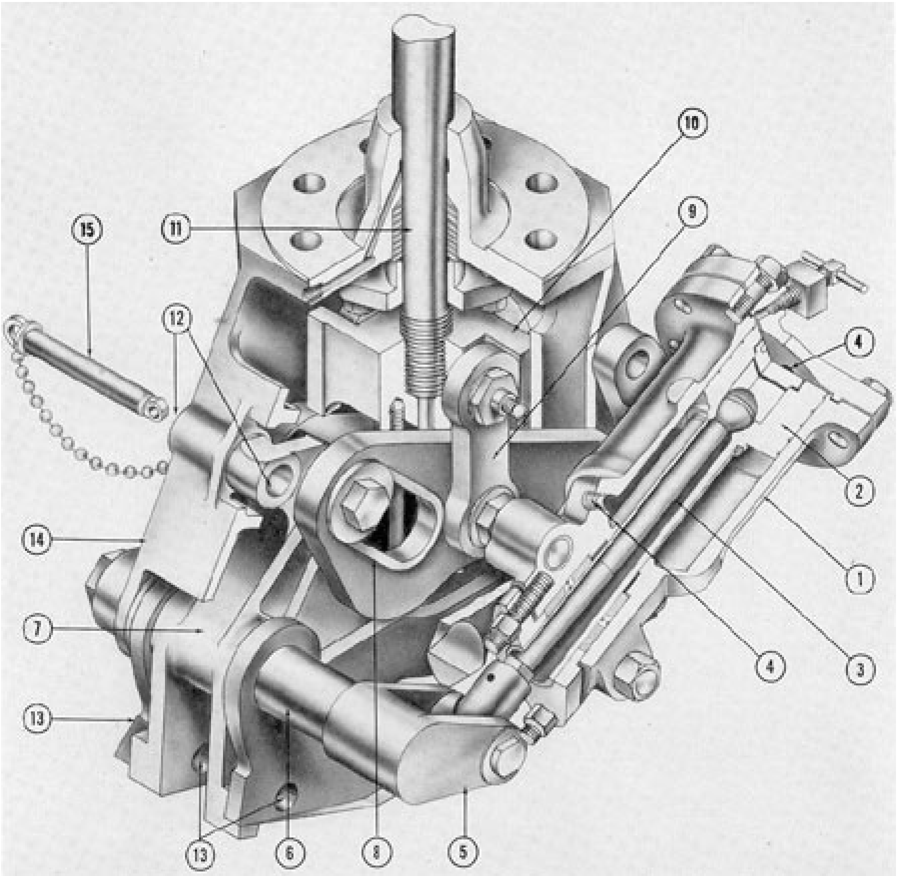

Figure 3-28. Cutaway of vent valve hydraulic unit cylinder and operating gear. 1) Hydraulic unit cylinder, 2) piston; 3) connecting rod; 4) hydraulic pressure ports; 5) double crank; 6) crankshaft; 7) crank arm; 8) slotted link; 9) connecting link; 10) crosshead; 11) operating shaft; 12) locking holes, LOCK position; 13) locking holes, HAND position; 14) frame; 15) locking pin.

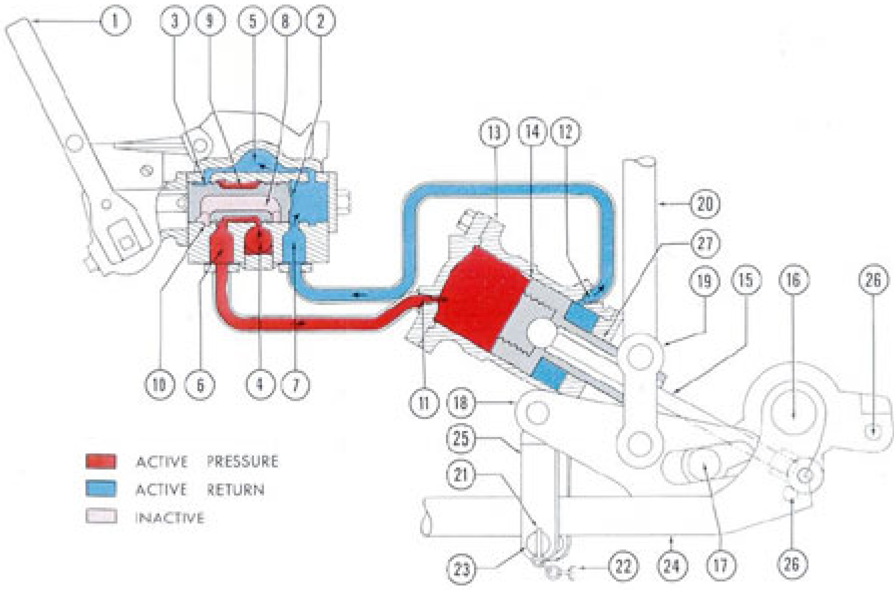

Figure 3-29. Diagram of vent control valve and cylinder, OPEN.
1) Hand lever; 2) control valve; 3) return port; 4) supply port; 5) return channel; 6) port to upper end of cylinder; 7) port to lower end of cylinder; 8) bypass channel of control valve; 9) spool; 10) equalizing bypass; 11) upper port in cylinder; 12) lower port in cylinder; 13) hydraulic unit cylinder; 14) piston; 15) piston rod; 16) crankshaft; 17) cam; 18) slotted link; 19) connecting link; 20) operating shaft; 21) locking pin; 22) chain for locking pin; 23) locking hole for POWER position; 24) hand-operating lever; 25) handle locking bracket; 26) locking hole for HAND position; 27) piston guide sleeve.

labeled respectively POWER, HAND (13), and LOCK (12), and identified by adjacent indicator plates.

When the pin (21, Figure 3-29) is placed in the POWER hole (23), the hand-operating lever (24) is locked in the stowed position, and the vent is operated by the hydraulic unit cylinder.

When placed in the lock holes for the HAND position (26, Figure 3-29), the pin bolts the hand-operating lever solidly to the linkage, so that moving the lever (24) will actuate the mechanism and operate the vent.

When placed in the lock hole for the LOCK position-which can be done only when the valve is closed and the hand lever stowed-the pin locks the

negative tanks are hydraulically operated by the mechanism shown in Figure 3-30. The crossarm and hand grips shown are for hand operation in case of failure of the hydraulic power.

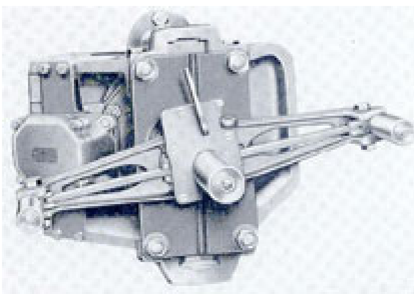

Figure 3-30. Flood valve operating gear and hydraulic cylinder.

operating shaft so that it cannot be moved.

d. The hydraulic flood valve operating gear. The flood valves on the safety and

Figure 3-31 is a diagram of this mechanism. It is essential to understand that the main piston rod (3) and the tie rods (6) are yoked rigidly together through the crosshead (4). Impelled by the hydraulic pressure against the piston head (2), all three rods move inward or outward as a unit.

Two positions, OPEN and CLOSE, are shown in the diagram. Oil under pressure from the control manifold is shown in red, return oil in blue; direction of flow is indicated by arrows.

1. To open the valve, hydraulic fluid from the control valve is admitted through the port (13), moving the piston head (2) outward (up in the diagram). The motion is communicated through the crosshead (4). The tie rods (6), screwed rigidly into this crosshead, are

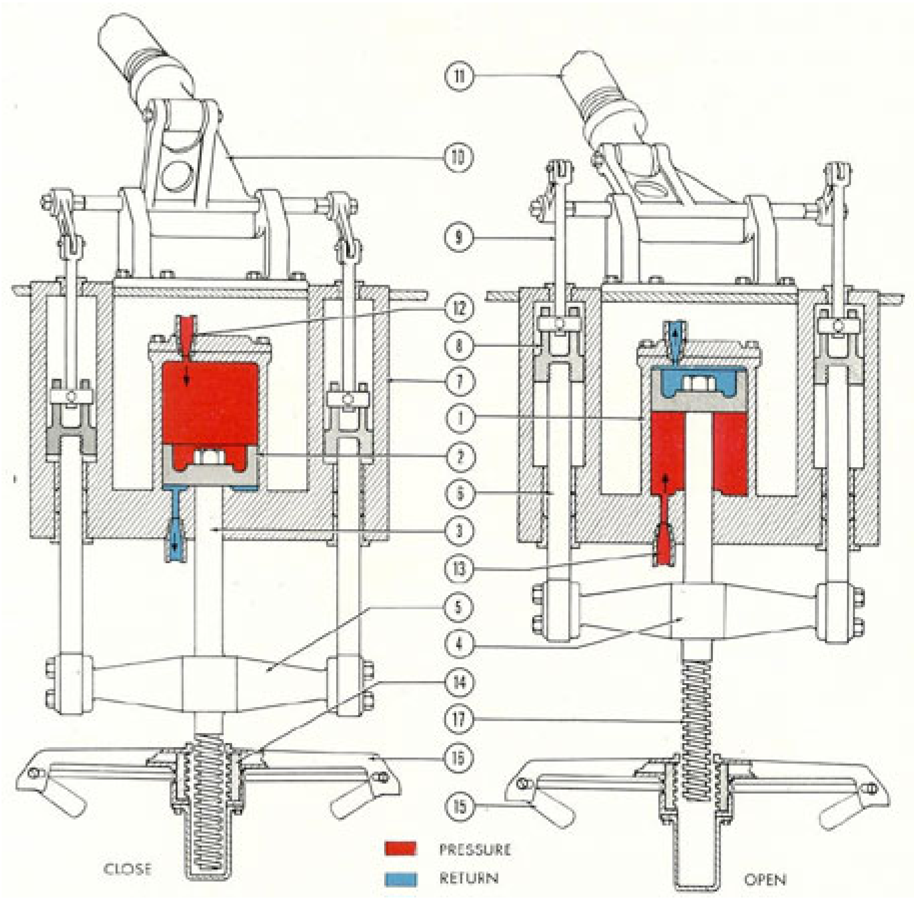

Figure 3-31. Diagram of flood valve operating gear and hydraulic cylinder in OPEN and CLOSE positions.
1) Hydraulic unit cylinder; 2) piston; 3) main piston rod; 4) crosshead; 5) yoke; 6) tie rod; 7) guide cylinder; 8) guide piston; 9) outboard connecting rods; 10) crank; 11)

operating shaft; 12) hydraulic port, pressure to close flood valve; 13) hydraulic port, pressure to open flood valve; 14) half-nut; 15) hand grips; 16) crossarm; 17) threaded shaft.

pushed outward; the outboard connecting rods (9), through the crank (10), push the operating shaft (11) out, opening the flood valve (not shown). Return oil meanwhile flows out through the other port and back to the control valve.

2. To close the valve, the flow of hydraulic fluid is reversed, pushing the piston inward (down in the diagram).

3. To operate the mechanism by hand, the hand grips (15) are pulled outward (to the position shown in Figure 3-30). This meshes the half-nut (14) with the threaded shaft (17). Turning the crossarm (16) will then cause the shaft to travel.

4. The guide cylinders (7) are watertight. The guide pistons (8) slide through greased packing into the tank.

e. Operation of vent valves. Figures 3-29, 3-32, 3-33, and 3-34 illustrate the operation of a vent by any valve on the six-valve manifold (see Figure 3-24). In all cases, oil from the supply line of the main hydraulic system is shown in red, oil to the return line in blue, and inactive oil in lighter red. Direction of flow is indicated by arrows.

Figure 3-29 shows the hand lever (1) of the control valve (2) in the OPEN position. The spool (9) directs oil from the supply port (4) to the port (6) into the line leading to the upper port (11) of the unit cylinder

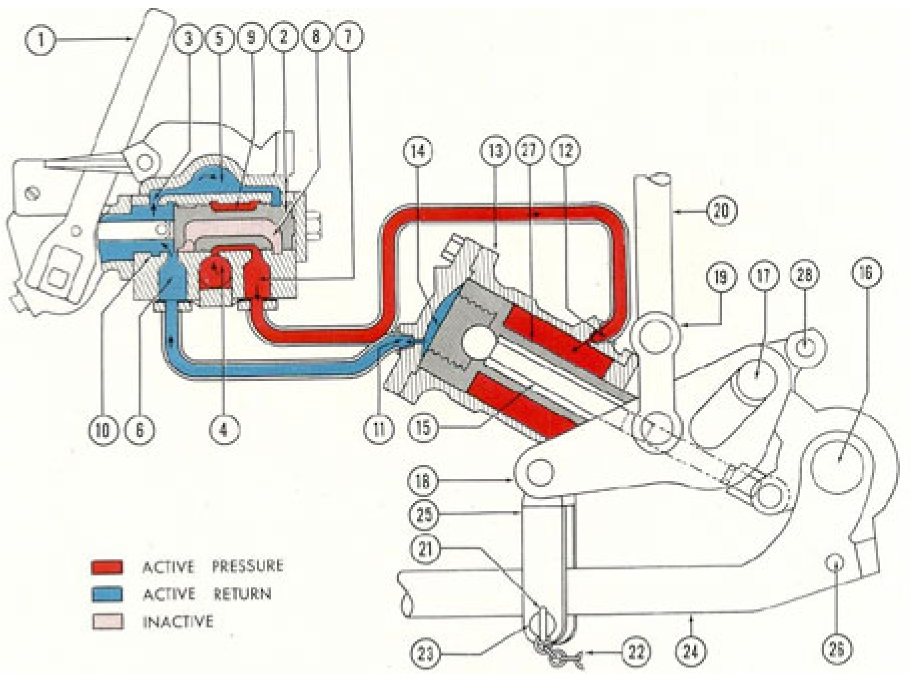

Figure 3-32. Diagram of vent control valve and cylinder, CLOSE.
1) Hand lever; 2) control valve; 3) return port; 4) supply port; 5) return channel; 6) port to upper end of unit cylinder; 7) port to lower end of unit cylinder; 8) bypass

channel of control valve; 9) spool; 10) equalizing bypass; 11) upper port in cylinder; 12) lower port in cylinder; 13) hydraulic unit cylinder; 14) piston; 15) piston rod; 16) crankshaft; 17) cam; 18) slotted link; 19) connecting shaft; 20) operating shaft; 21) locking pin; 22) chain for locking pin; 23) locking hole for POWER position; 24) hand-operating lever; 25) hand lever locking bracket; 26) locking hole for HAND position; 27) piston guide sleeve; 28) locking hole for LOCK position.

(13). The pressure lowers the piston head (14) turning the crank (16), which actuates the cam (17). The cam rides down in the slot of the slotted link (18), pulling the flat link (19) downward. This in turn pulls down the operating shaft (20), opening the vent. Return oil, forced from the lower port (12) in the unit cylinder, flows through the port (7) to the return channel (5) in the control manifold body. Note that for power operation, the hand-operating lever (24) is in the stowed position, locked into the bracket (25) by the locking pin (21).

Figure 3-32 shows the control valve in the CLOSE position. The spool (9) directs oil from the supply port (4) to the port (7) into the line leading to the lower port (12) of the hydraulic unit cylinder, pushing the piston up and pulling the cam (17) up through the slotted link (18). This raises the operating shaft (20), closing the vent. Return oil, forced through the upper port (11) of the unit cylinder, flows through the port (6) back into the return channel (5) of the manifold. Note that the hand-operating lever (24) is again in the stowed position, and the locking pin (21) is placed in the POWER hole (23) in the bracket (25). In this position, with the vent closed and the hand-operating lever stowed, the locking pin can be placed, if required, in the locking hole for the LOCK position (28), thus preventing accidental opening.

Figure 3-33 shows the lever in the HAND position. Here the bypass channel (8) in the control valve connects the two ports (6 and 7) leading to the unit cylinder. This allows bypassing of the oil between the upper and the

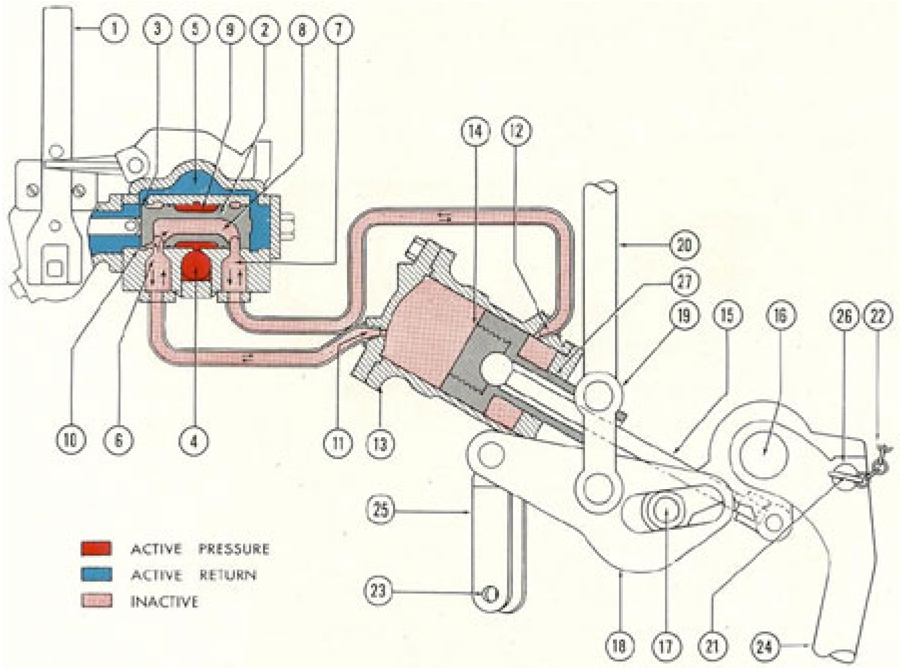

Figure. 3-33. Diagram of vent control valve and cylinder, HAND.
1) Hand lever; 2) control valve; 3) return port; 4) supply port; 5) return channel; 6) port to upper end of unit cylinder; 7) port to lower end of unit cylinder; 8) bypass channel of control valve; 9) spool; 10) equalizing bypass; 11) upper port in cylinder; 12) lower port in cylinder; 13) hydraulic unit cylinder; 14) piston; 15) piston rod; 16) crankshaft; 17) cam; 18) slotted link; 19) connecting link; 20) operating shaft; 21) locking pin; 22) chain for locking pin; 23) locking hole for POWER position; 24) hand-operating lever; 25) hand lever locking bracket; 26) locking hole for HAND position; 27) piston guide sleeve.

lower sides of the unit cylinder (13) permitting hand operation. At the same time, the lands on the control valve (2) have cut off the pressure port. A special feature of the HAND position is the small extra channel, 3/16-inch in diameter, called the equalizing bypass (10). This permits a very small flow of oil from the bypass channel (8) back into the return line when the valve is operated at CLOSE. It also permits replenishment of oil when the valve is in the OPEN position to compensate for the unequal areas of the two sides of the piston. Without this compensation, opening and closing the valve by hand would meet with considerable piston guide sleeve (27) cast integral with the piston. Note that for hand operation the locking pin (21) is placed in the HAND locking hole (26), so that when the hand-operating lever (24) is moved, the linkage also moves.

Figure 3-34 shows the lever in the EMERGENCY position. The control valve lands completely blank off the supply port (4) and the return channel (5) from the ports (6 and 7) which lead to the hydraulic unit cylinder. These lands also close the 3/16-inch equalizing bypass (10). Thus the oil to the hydraulic unit is completely isolated from the rest of the system. In case of a broken line, hand operation is possible, since the cylinder ports are bypassed to each other. However,

resistance, because the top of the hydraulic unit cylinder's piston (14) presents a greater effective area to the contained oil than does the bottom side, whose effective area is practically negligible because of the some resistance will be encountered because of the difference in area between the lower and upper sides of the piston, which was explained in the preceding paragraph.

The locking pin (21) is shown here in the lock hole (26) for HAND operation.

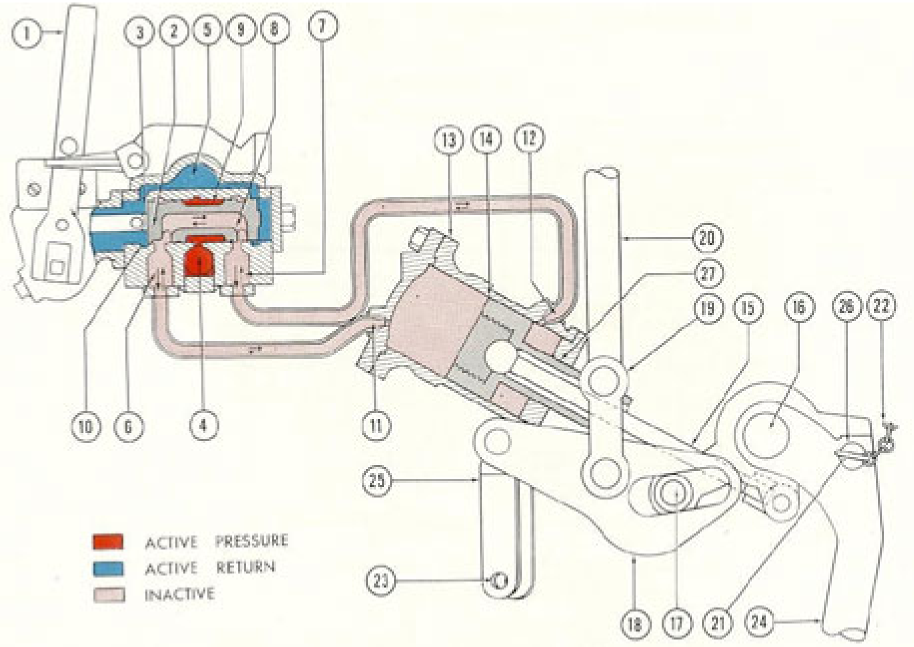

Figure 3-34. Diagram of vent control valve and cylinder, EMERGENCY.
1) Hand lever; 2) control valve; 3) return port; 4) supply port; 5) return channel; 6) port to upper end of unit cylinder; 7) port to lower end at unit cylinder; 8) bypass channel of control valve; 9) spool; 10) equalizing bypass; 11) upper port, in cylinder; 12) lower part in cylinder; 13) hydraulic unit cylinder; 14) piston; 15) piston rod; 16) crankshaft; 17) cam; 18) slotted link; 19) connecting link; 20) operating shaft; 21) locking pin; 22) chain for locking pin; 23) locking hole for POWER position; 24) hand-operating lever; 25) hand lever locking bracket; 26) locking hole for HAND position; 27) piston guide sleeve.

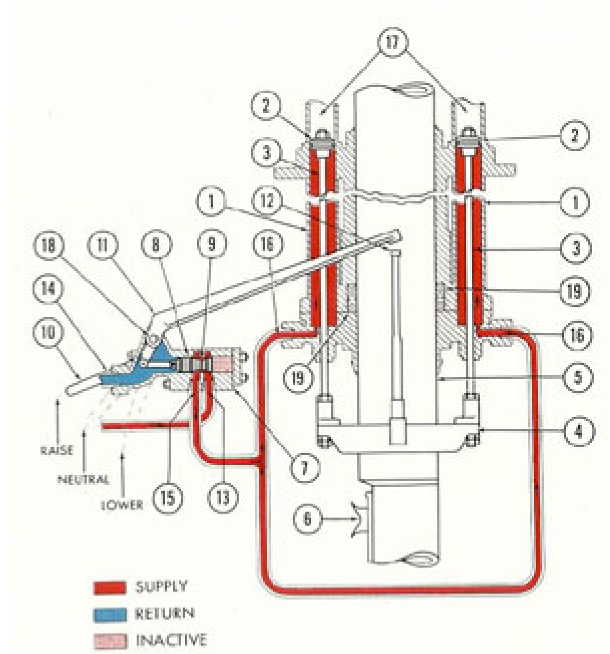

Figure 3-35. Diagram of periscope hoist approaching fully raised position.
1) Hydraulic cylinders; 2) piston; 3) piston rods; 4) yoke for periscope; 5) periscope; 6) eyepiece; 7) control valve; 8) control valve spool; 9) tapered center of spool; 10) control valve hand lever; 11) automatic trip; 12) actuating spindle for automatic trip; 13) supply port, from main supply manifold; 14) return port, to main return manifold; 15) port to hydraulic cylinders; 16) cylinder ports; 17) upper section of hydraulic cylinders (no oil in upper section); 18) shaft; 19) packing.

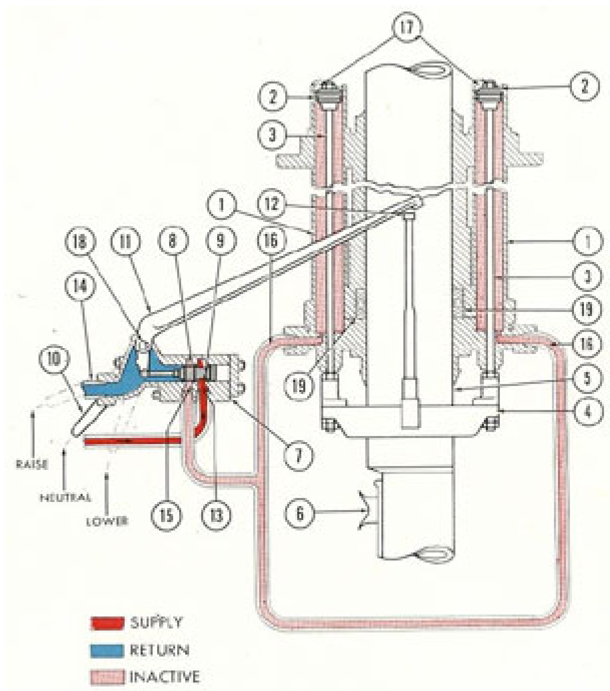

Figure 3-36. Diagram of periscope hoist in fully raised (tripped) position.
1) Hydraulic cylinders; 2) piston; 3) piston rods; 4) yoke for periscope; 5) periscope; 6) eyepiece; 7) control valve; 8) control valve spool; 9) tapered center of spool; 10) control valve hand lever; 11) automatic trip; 12) actuating spindle for automatic trip; 13) supply port from main supply manifold; 14) return port, to main return manifold, 15) port to hydraulic cylinders; 16) cylinder line; 17) upper section of hydraulic cylinders (no oil in upper section; 18) shaft; 19) packing.

D. PERISCOPE AND VERTICAL ANTENNA HOISTS

3D1. General arrangement. On some later classes of submarines, the periscope and the vertical antenna are hydraulically operated, as units of the main hydraulic system. Their location is shown schematically in Figure 3-23.

Each is raised and lowered by a hydraulic hoist. This consists essentially of a pair of long, vertically mounted hydraulic cylinders of small diameter, bracketed in the fairwater above the conning tower. Two piston rods emerge from the lower ends of the cylinders are yoked together and carry between them, in the yoke, the periscope or vertical antenna. Control valves for each are located in the conning tower. Since these units are raised by hydraulic power and lowered by gravity, an automatic trip arrangement reduces the hydraulic pressure before the unit reaches the mechanical stop at the top of its travel, while a spring bumper at the bottom cushions its descent.

3D2. Detailed description. a. The periscope. 1. Arrangement of hoist mechanism and distribution of pressure. The general arrangement of the periscope hoist and hydraulic lines is illustrated schematically in Figure 3-35.

A pair hydraulic-cylinders (1) is bracketed into the periscope fairwater, at the top of the conning tower. The piston heads (2) and piston rods (3) are bolted to a yoke (4) which carries the the conning tower, are provided to catch any oil that may leak up past the piston heads.

To lower the periscope, the lines from the ports (16) at the lower ends of the cylinders are opened to the return line (14) and the periscope and pistons are allowed to descend by their own weight, forcing the oil out of the cylinders into the return line.

2. The control valve. The control valve (7) is a three-position spool-type valve. The spool itself (8) has a center channel (9) with a very fine taper (40-30), and hence the lands do not rise at a sharp angle from the center channel.

This tapered cut-off has the effect of opening and closing the valve ports gradually, preventing sudden shocks and so-called hydraulic hammer which might affect the delicate optical instruments in the periscope.

The position of the spool is controlled by the hand lever (10). As shown in Figure 3-35, this lever has three positions, RAISE, LOWER, and NEUTRAL. At RAISE, the spool is pulled toward the left, admitting pressure from the supply port (13) into the discharge port (15) leading to the cylinder ports (16). The return line (14) is blanked off.

At NEUTRAL, the spool is in the intermediate position, blanking off all the ports and hydraulically locking the periscope at any given height.

periscope (5). In other words, the pistons and periscope are rigidly connected and travel as a unit. As the pistons are raised by hydraulic pressure admitted to the undersides of the piston heads, the periscope extending through the center of the fairwater rises from its well and is projected upward.

A distinctive feature of this type of hoist is the fact that the control valve (7) admits hydraulic fluid only to the lower ends of the cylinders. No oil is present on top of the piston heads except that which leaks past the piston from the pressure side. Overflow lines and a settling tank (not shown), located in

At LOWER, the spool is pushed to the right, blanking off the supply port (13) and opening the cylinder line (16) to the return port (14). This allows the oil to escape from the cylinders into the return line by the weight of the periscope assembly. Note that, because of the lack of a hydraulic line to the upper end of the cylinder, this valve needs only three ports instead of the usual four.

3. The automatic trip. To prevent the periscope from jolting against the mechanical stop when it reaches the top of its travel, an automatic trip (11) is attached to the same shaft (18) as the hand lever (10).

This automatic trip is operated by the spindle (12) bolted onto the yoke (4). The

height of the spindle and the angle of the trip are so adjusted that, as the periscope approaches the fully raised position, the spindle pushes up the trip, automatically moving the tapered spool (8) toward the intermediate, or NEUTRAL, position. This gradually cuts off the flow of oil to the cylinders, bringing the periscope to an easy stop.

The trip and the hand lever are solidly connected to the same shaft (18) so that if the operator should try to hold the lever at the RAISE position after the spindle has reached the trip, the trip, mechanically impelled by the upward movement of the periscope, will pull the hand

In Figure 3-36, the periscope is fully raised and the spindle has pushed the trip and hand lever, moving the valve to the NEUTRAL position, blanking all ports, cutting off the flow of oil, and locking the periscope in that position. Oil under pump pressure is shown in red; return oil in blue; inactive oil in lighter red. Direction of flow is indicated by arrows.

b. The vertical antenna. The vertical antenna hoist need not be discussed in detail, as it is almost identical to the periscope hoist in arrangement, structure, and operating principles.

In addition to the automatic trip arrangement for preventing a sudden stop at the top of its travel, the vertical antenna hoist

lever out of his grasp. This simple arrangement therefore acts as a quick, sure, automatic cut-out.

4. Explanation of Figures 3-35 and 3-36. In Figure 3-35, the control valve is at RAISE and the periscope has almost reached the top of its travel. The spindle (12) is almost at the automatic trip.

also has a dash-pot arrangement and a piston head with tapered grooves cut toward its underside, which help to bring it to an easy stop at the bottom.

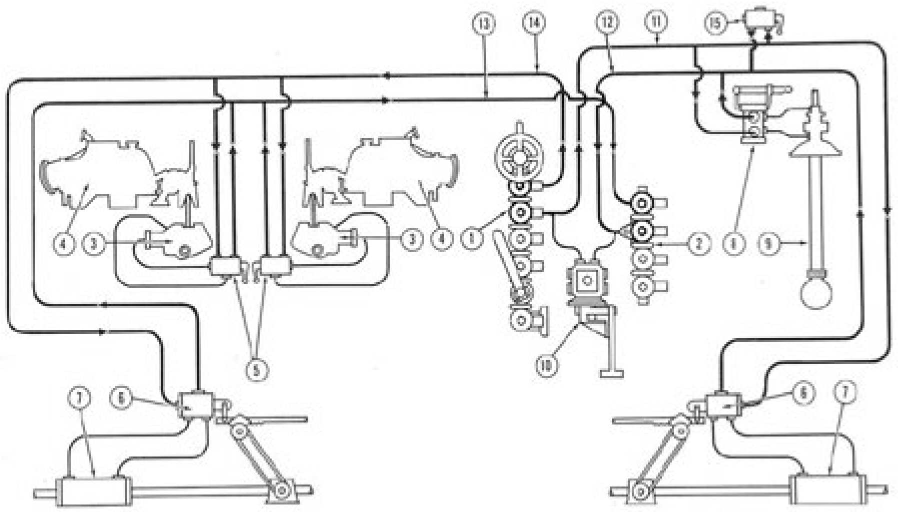

Figure 3-37. Piping diagram of forward and after service lines.
1) Main supply manifold; 2) main return manifold; 3) main engine exhaust actuating cylinder; 4) main engine exhaust gear and exhaust valve; 5) main engine exhaust control valve; 6) torpedo tube outer door control valve; 7) torpedo tube outer door actuating cylinder; 8) echo-ranging control valve; 9) echo-ranging cylinder; 10) bow plane rigging control valve; 11) forward service line, supply; 12) forward service line, return; 13) after service line, return; 14) offer service line, supply; 15) control valve for forward windlass-and-capstan.

E. FORWARD AND AFTER SERVICE LINES

3E1. General arrangement. There are two sets of hydraulic lines extending from the main supply manifold and the main return manifold to both ends of the submarine. These lines, known as the forward and after service lines, furnish power to a miscellaneous group of hydraulically operated submarine necessary power to the following apparatus:

a. The after service lines supply power for the operation of:

1. Main engine drowned-type exhaust valves.

equipment; specifically, these hydraulic lines supply

2. Outer doors of the four after torpedo tubes.

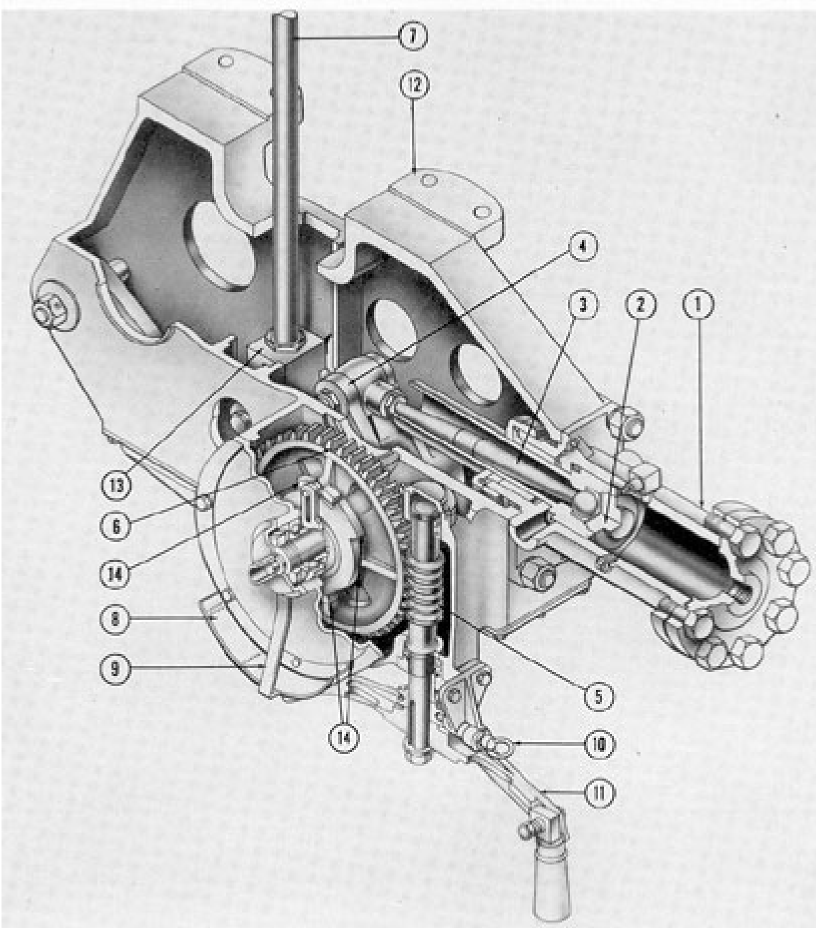

Figure 3-38. Cutaway of main engine drowned-type exhaust valve operating gear and hydraulic cylinder.
1) Cylinder; 2) piston; 3) connecting rod; 4) crank, 5) worm gear; 6) drive gear; 7) power shaft; 8) indicator dial; 9) pointer; 10) locking pin; 11) hand gear; 12) frame; 13) crosshead; 14) operating lugs.

b. The forward service lines supply power for the operation of:

1. Bow rigging.

2. Forward windlass-and-capstan.

3. Two echo-ranging and sound detection devices, known as the sound heads.

4. Outer doors of the six forward torpedo tubes.

Each of the above items of equipment is operated by a

up or down to open or close the main engine exhaust valve through a set of linkage arms and cranks.

In the event of hydraulic power failure, the hand gear (11) can be used to rotate the drive gear through a worm (5). A locking pin (10) holds the hand gear in place when it is not being used.

The motion of the drive gear is indicated by the pointer (9) which moves with it and shows on the indicator dial (8) whether the

hydraulic cylinder to which oil under pressure is directed by a control valve. The remainder of this section is devoted to a description of the hydraulic cylinders and control valves for the equipment listed above.

Hydraulic pressure is distributed to the service lines at the main supply manifold by two valves. One line is marked SERVICE FORWARD, the other, SERVICE AFT. The return lines terminate in two similarly named valves of the main return manifold.

A schematic diagram of the forward and after service lines is shown in Figure 3-37. The diagram shows the rigging control valve but not the equipment which operates the bow rigging and the forward windlass-and-capstan. Although that equipment receives its power from the forward service lines, its description has been included in Section C of Chapter 5.

3E2. Main engine drowned-type exhaust valve. a. General arrangement. When the submarine is surfaced and the main engines are running, the engine exhaust is vented outboard. Each main engine has an exhaust which must be opened before the engines start and closed when the engines are stopped. These valves are hydraulically operated as units on the after service lines.

b. Detailed description. The control valve is of the conventional spool type, having three positions: OPEN, CLOSE, and HAND. A control valve is exhaust valve is in the OPEN or in the CLOSE position.

c. Operation. The installation and arrangement of the hydraulic equipment for operating the main engine drowned-type exhaust valves vary with different classes of submarines.

Some earlier classes of submarines have five exhaust valves: four main engine outboard exhaust valves and one outboard exhaust valve for the auxiliary engine. The control valves are arranged in two manifolds. The after engine room has a manifold of three control valves, and the forward engine room, a manifold of two valves.

The more recent type of submarine, however, has only four main engine outboard exhaust valves. There is no separate exhaust valve for the auxiliary engine, its exhaust being expelled through one of the main engine exhaust valves-main engine No. 4 on the Electric Boat Company submarine and main engine No. 3 on the Portsmouth submarine. The control valve for both main engine outboard exhaust valves in each engine room is located near the throttle, on the port side of that engine room, so that the engine operator can manipulate both exhaust valve controls simultaneously.

Figures 3-39 and 3-40 show a main engine drowned-type exhaust valve in the CLOSE and OPEN positions, as well as the connecting linkage between it and the hydraulic cylinder.

When the control valve handle is brought to the CLOSE position, the exhaust valve and actuating

provided for each hydraulic cylinder. As the piston (2, Figure 3-38), is moved backward or forward in the cylinder (1) by hydraulic pressure, the connecting rod (3) which is attached to a crank (4) rotates the operating lug (14). The operating lug, in turn, moves the power shaft (7)

cylinder are in the condition shown in Figure 3-39. Hydraulic pressure pushes

the piston (1) to the left, rotating the crank (3) so that it pulls down the cam lever (4). This action moves the power shaft (5) and shaft linkage (6) downward, and forces the exhaust valve (8) upward by means of the connecting linkage (7).

Moving the control valve handle to OPEN admits fluid into the hydraulic cylinder to move the piston to the right as shown in Figure 3-40, the OPEN position. This rotates the crank (3) so that the cam lever (4) is raised, lifting the power shaft (5) and the shaft linkage (6) which pulls the exhaust valve (8) downward by means of the valve linkage (7), thus opening it.

The valve operating gear just described will be found in all later classes of Portsmouth submarines. On the Electric Boat Company submarines, the main engine exhaust valves are operated by a hydropneumatic system, consisting of a small independent hydraulic system for each valve, to which pressure is provided by compressed air.

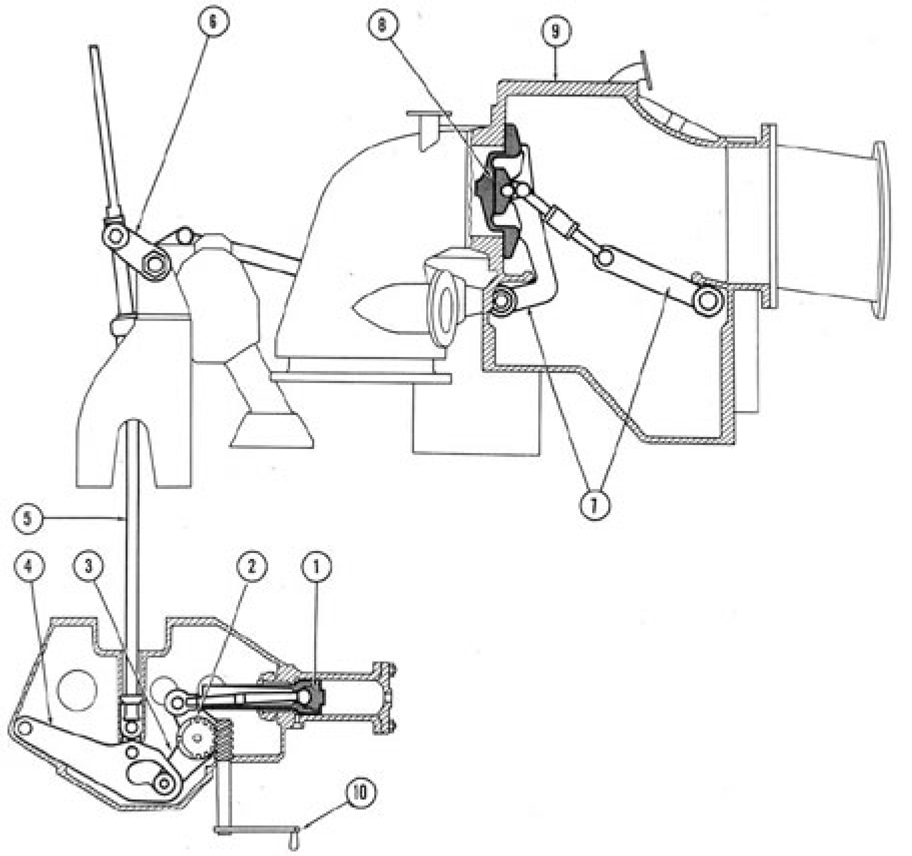

Figure 3-39. Diagram of main engine drowned-type exhaust valve operating gear and hydraulic cylinder, CLOSE.
1) Piston; 2) drive gear; 3) crank; 4) cam lever; 5) power shaft; 6) shaft linkage; 7) valve linkage; 8) exhaust valve; 9) exhaust valve housing; 10) hand gear.

To operate the valve, the air is admitted on top of an oil reservoir, which in turn is connected to the hydraulic cylinder.

The air, acting upon the oil, forces it into the cylinder where it moves the piston to open or close the exhaust valve.

3E3. Torpedo tube outer door mechanism. a. General. The torpedo tube outer doors are hydraulically operated as separate units from the fore and aft service lines. There are ten torpedo tubes in all, six forward and four aft. Their location is shown schematically in the fore and aft service line piping diagram, Figure 3-37.

The outer door operating mechanism consists essentially of the hydraulic cylinder, piston, and power shaft; the control valve and operating handle; and a jackscrew for hand operation. All parts are mounted on the torpedo tube itself and controlled from its breech.

1. The control valve. The control valve is a three-position spool-type valve. Figure 3-41 shows its internal structure. The operating lug (7) is moved back and forth when

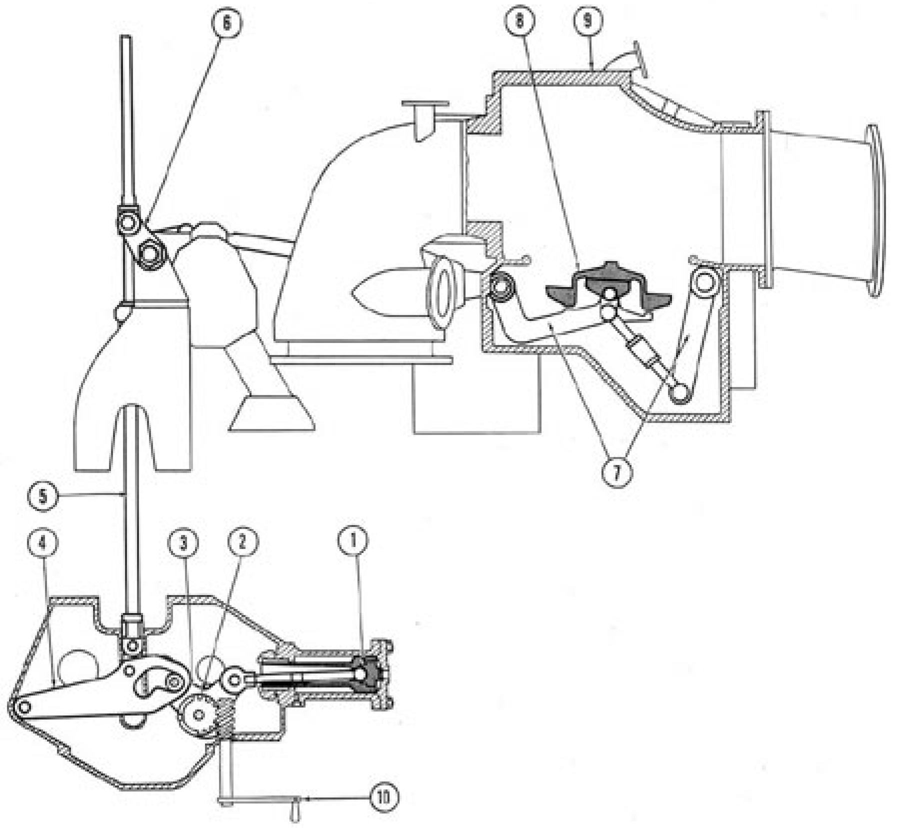

Figure 3-40. Diagram of main engine drowned-type exhaust valve operating gear and hydraulic cylinder, OPEN.
1) Piston; 2) drive gear; 3) crank; 4) cam lever; 5) power shaft; 6) shaft linkage; 7) valve linkage; 8) exhaust valve; 9) exhaust valve housing; 10) hand gear.

the handle is pushed in or out. This in turn moves the slotted link (6), rotating the shaft (5) and the arm (4). The arm moves the connecting link (3) which moves the valve (2) inside the valve body (1), opening and closing the required combination of ports. The ports (9) lead to opposite ends of the hydraulic cylinder; the return port (10) leads to the fore and aft service lines. The supply port is not shown in this view.

2. General arrangement. The considerably simplified general arrangement of the mechanism as a whole is shown in Figure 3-43. The hydraulic cylinder (1) contains a piston (2) which is moved by hydraulic power. It is connected rigidly to the power operating shaft (3) whose motion opens or closes the outer door. The hydraulic power is directed to one side or the other of the hydraulic cylinder by the control valve (18). This allows flow of hydraulic power from the supply side (20) of the forward or after service lines

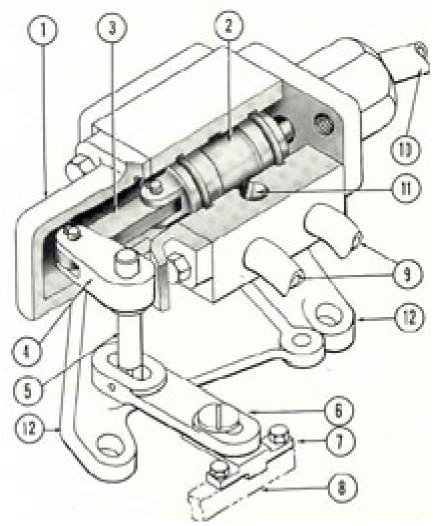

Figure 3-41. Cutaway of outer door control valve.
1) Valve body; 2) valve; 3) connecting link; 4) arm; 5) shaft; 6) slotted link; 7) operating lug; 8) connecting rod (to handle); 9) cylinder ports; 10) return port (to main hydraulic system); 11) channel from supply port (from main hydraulic system; port not shown in this illustration); 12) mounting bracket.

Figure 3-42 shows the control valve in each of its three positions: OPEN, in which the pressure line (7) is opened to the inner, or breech, end of the hydraulic cylinder, and the return line (8) is opened to the outer end; CLOSE, in which these connections (pressure and return) are reversed; and HAND, in which the pressure ports leading to the cylinder (9) are connected to each other, bypassing the oil in the cylinder. The pressure side is shown in red, the return side in blue; inactive oil is shown in lighter red. The direction of flow in each position is shown by arrows.

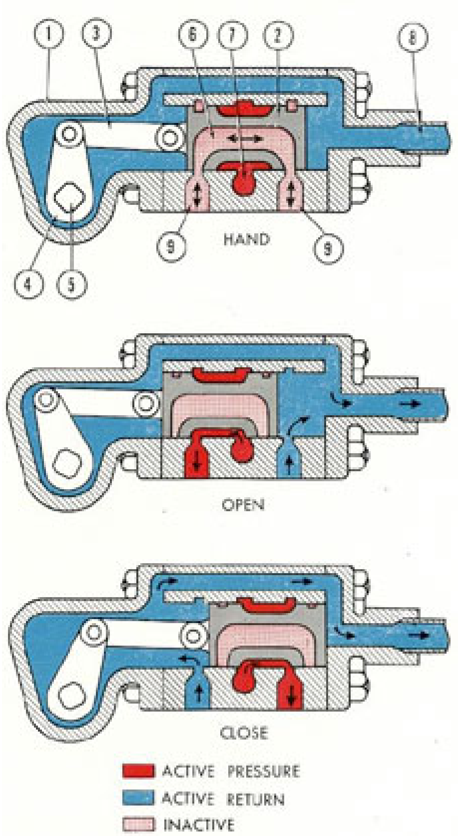

Figure 3-42. Diagram of outer door control valve in three positions.
1) Valve body; 2) valve; 3) link; 4) arm; 5) shaft; 6) bypass channel in valve; 7) channel to supply port from main hydraulic system; 8) return port (to main hydraulic system); 9) cylinder ports (to actuating cylinder).

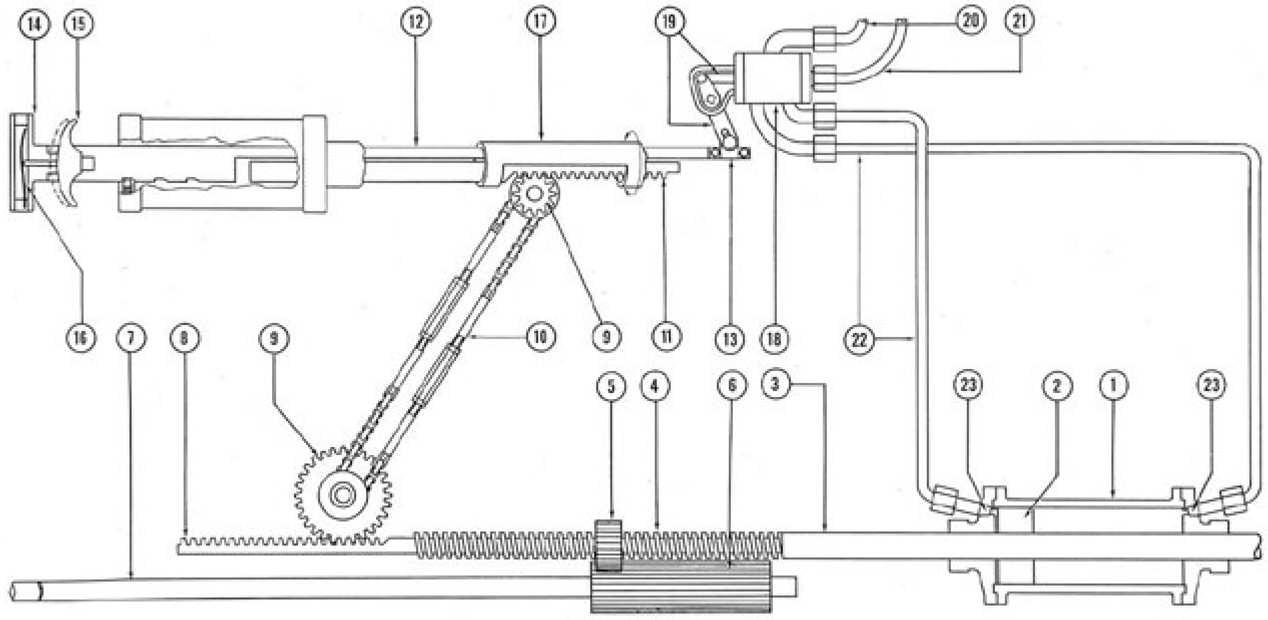

Figure 3-43. Schematic diagram of outer door operating mechanism.
1) Hydraulic cylinder; 2) piston; 3) power operating shaft; 4) jackscrew or threaded portion of shaft; 5) jack-nut; 6) hand shaft driving gear; 7) hand-operated shaft; 8) rack on power operating shaft; 9) spur gear; 10) sprocket chain; 11) rack on outer slide (breech and outer door interlock); 12) inner slide; 13) operating lug; 14) operating handle; 15) trigger; 16) spring; 17) ready-to-fire interlock tube; 18) control valve; 19) linkage on control valve; 20) supply from forward or after service line; 21) return to forward or after service line; 22) lines to hydraulic cylinder; 23) ports in hydraulic cylinder.

and feeds it back to the return side (21). The control valve is operated by the operating handle (14), a push-pull arrangement which slides in and out lengthwise through the ready-to-fire interlock tube, a section of which (17) is shown. The operating handle is connected to the control valve by the inner slide (12) which is attached to the control valve linkage (19) by the operating lug (13).

3. The interlocks. Safe operation of a torpedo tube is a delicate and complicated process. It involves several different conditions which cannot be allowed to occur simultaneously. For example, it is obvious that

b) CLOSE (handle pushed in all the way away from the operator), in which the power operating shaft will close the outer door.

c) HAND (handle in intermediate position), in which the lines from the hydraulic cylinder are bypassed through the control valve.

3E4. Echo-ranging and detecting apparatus. a. General arrangement. The echo-ranging and detecting apparatus is contained in a metal sphere, called the sound head, fixed to a cylindrical tube. This tube is extended downward through an opening in the underside of the vessel in much the same way that the periscope is extended upward

when the outer door is opened to the sea, the inner door must be locked shut, and vice versa. The tube must not be made READY-TO-FIRE unless different interlocks, not shown in full detail in the schematic diagram, are properly engaged. At the end of the power operating shaft (3) is a spur tooth rack (8) which, through a pair of spur gears (9), sprocket chain (10), and a similar spur tooth rack (11) on the outer slide, operates the ready-to-fire interlock (not shown). The ready-to-fire interlock is connected to the tube (17) which rotates around the inner and outer slides and also serves as a guide tube.

4. Hand operation of outer doors. For hand operation of the outer doors, a hand-operating shaft (7) is provided, with a squared end over which fits an operating crank. This turns the hand shaft driving gear (6). This gear is meshed with the jack-nut (5), which in turn is threaded into the threaded portion (4) of the power operating shaft. Therefore, as the jack-nut is turned, the power operating shaft will travel through it, opening or closing the outer door. In order to operate this by hand, the control valve (18) must be in the HAND position, so that the fluid trapped in the hydraulic cylinder (1) will not act as a hydraulic lock against the motion of the piton (2).

The operating handle (14), therefore, has three positions:

a) OPEN (handle pulled all the way out toward the operator), in which the power operating shaft through the top and is hydraulically operated by power from the forward service line of the main hydraulic system.

The hydraulic part of the apparatus consists essentially of three hollow tubes one within the other, so arranged that the two inside tubes act as a stationary piston fixed to the frame of the vessel. The outer tube, actuated by hydraulic pressure, acts as a movable cylinder which slides up and down over it, raising and lowering the sound head. A control valve directs the oil pressure to one side or the other of the piston head to raise or lower the cylinder.

A hand pump is installed in the lines for hand operation.

b. Detailed description. Figure 3-44 shows two views of the apparatus. A is a schematic diagram of the echo-ranging and detecting apparatus showing its operation; B is a cutaway view of the tube in its correct proportions. Wherever the same part is shown in both views, it has been given the same index number. The control valve appears only in the cutaway view, where its location with respect to the rest of the apparatus has been schematically indicated.

1. Stationary piston and traveling cylinder. The traveling hydraulic cylinder (1) is free to slide up and down in the bracket bearing (7). This bearing is bracketed solidly to the deck plate (8).

The outer tube (3) of the piston rod assembly (20) is the stationary member and is bracketed solidly to the overhead frame (14)

moved by hydraulic power will open the outer door.

through the trunnion yoke (12) and trunnion bearing (13).

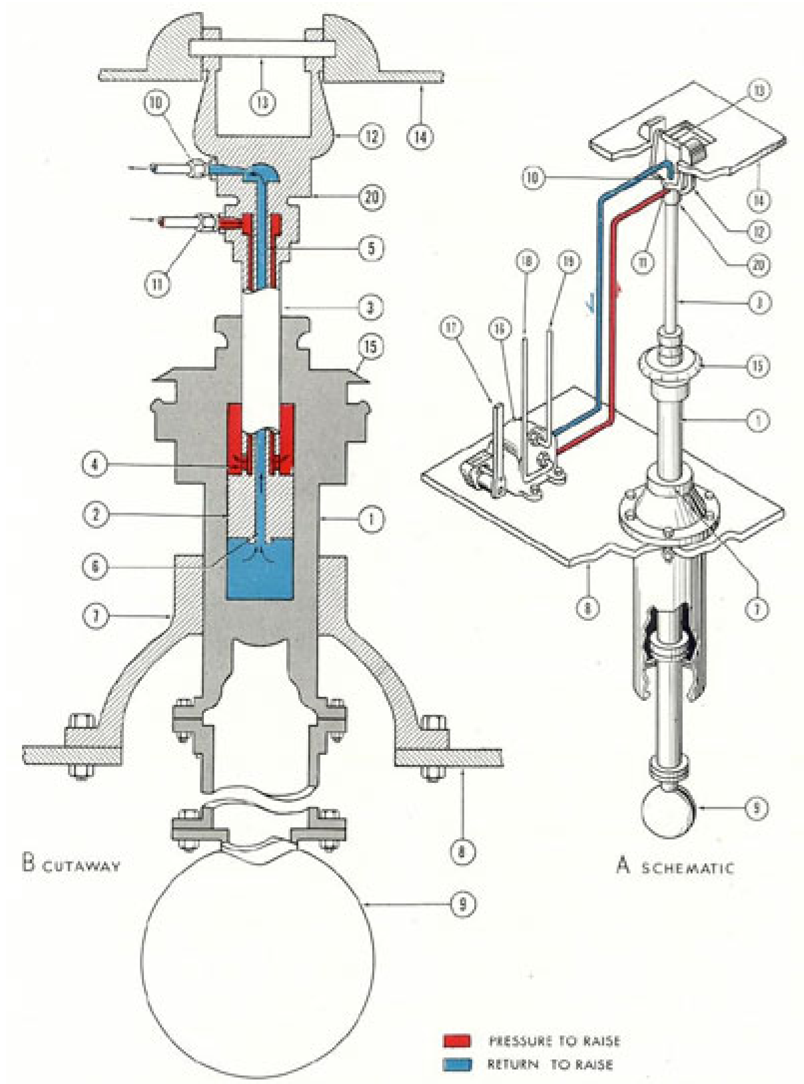

Figure 3-44. Cutaway and diagram of echo-ranging and detecting apparatus. 1) Hydraulic cylinder; 2) piston; 3) outer piston tube; 4) oil ports in outer piston tube, to top of piston head; 5) inner piston tube; 6) oil port, to underside of piston head; 7) bracket bearing; 8) deck plate; 9) sound head; 10) upper port of piston rod assembly, to inner piston tube; 11) lower port of piston rod assembly, to outer piston tube; 12) trunnion yoke; 13) trunnion bearing; 14) overhead frame; 15) indicator dial; 16) control valve; 17) control valve hand lever; 18) supply line, from main supply manifold; 19) return line, to main return manifold; 20) piston rod assembly.

2. Distribution of oil pressure. The piston rod assembly itself actually consists of two hollow tubes one inside the other. Both of these tubes are rigidly connected to the piston head (2).

metal sphere bolted to the lower end of the tube where it emerges from the watertight hull and extends downward into the sea. A cable (not shown) connects the electrical equipment in the sound

The inner piston tube (5) runs from the top of the piston rod assembly down through a hole in the center of the piston head itself to a port (6) which opens to the underside of the piston head. The outer piston tube (3) runs down from the top of the piston rod assembly only as far as the top end of the piston head, where two oil ports (4) open out of it just above the point at which it attaches to the top of the piston head. Thus, as can be seen in the schematic diagram, the inner and outer piston tubes form a pair of oil passages from the top of the piston rod assembly to the piston head, the inner tube opening underneath the piston head, the outer tube opening on top of it.

Since the hydraulic cylinder is free to slide up and down over the stationary piston head, admitting oil under pressure to the underside of the piston head will cause the cylinder to move downward, while admitting the pressure to the top of the piston head will force the cylinder upward.

3. The control valve. The control valve (16) is a three-position, spool-type valve fitted with a straight hand lever (17). The supply line (18) of the valve is connected to the main supply manifold of the main hydraulic system; the return line (19) is connected to the main return manifold. The location of the control valve with respect to the rest of the sound head hydraulic apparatus is shown schematically in Figure 3-44A. Its actual location varies to suit installation head with the electrical controlling and detecting devices.

c. Operation. Oil is admitted under pressure from the main hydraulic system through the control valve to the upper port (10) or the lower port (11), depending upon whether the operator desires to lower or raise the sound head. The upper port leads into the innermost tube and to the underside of the piston; the lower port leads into the outer tube and to the top of the piston.

In Figures 3-44A and 3-44B, the hand lever of the control valve is pulled all the way out, toward the operator, in the position to RAISE the sound head. Oil under pressure from the main hydraulic system enters the supply line (18) of the valve, goes through the valve body, and into the lower port (11) of the piston rod. Here it enters the outer piston tube (3) and flows out on top of the piston (2), through ports (4), forcing the hydraulic cylinder to slide upward through the bearing (7).

Meanwhile, as the cylinder space above the piston (the red area) is increased by the upward movement of the cylinder, the space under the piston (the blue area in the diagram) decreases, forcing the oil in through the port (6) upward through the innermost piston tube (5), and out through the upper port (10) in the top of the piston rod assembly. To LOWER the sound head, the hand lever (17) is pushed all the way in, away from the operator and the flow of oil is the reverse of that just described for raising.

requirements in the various classes of submarines.

4. Location of electrical equipment. The echo-ranging and detecting apparatus itself is contained in the sound head (9), a large

Placing the hand lever at NEUTRAL (intermediate position) will blank off all ports in the valve, and hydraulically lock the sound head in any given position.

F. EMERGENCY STEERING AND PLANE TILTING SYSTEMS

The steering and plane tilting operations are usually performed by their own individual hydraulic systems. To provide assurance against failure, it is possible to use the pressure in the main hydraulic system to power the gear which actuates the rudder and the planes. In the main hydraulic system, this is provided for by connecting lines to both systems from the main supply manifold and the main return manifold.

A group of valves located in the steering and the plane systems directs the flow of emergency power to whichever service requires it. A full description of utilization of emergency power is given in Chapters 4 and 5.

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4
THE STEERING SYSTEM

A. INTRODUCTION

4A1. General description. The rudder of the submarine is moved by hydraulic power. Under normal conditions of operation the steering system has its own source of power, a motor-driven No. 5 Waterbury A-end pump, and is therefore, except in emergencies,completely independent of the main hydraulic system described in Chapter 3.

The principal control units are assembled in the steering stand, located in the control room. However, since there is an auxiliary steering wheel in the conning tower connected to the steering stand controls by a shaft, the submarine can be steered either from the control room or from the conning tower. To allow for every contingency, the steering system is so planned that three different methods of steering, based on three different sources of hydraulic power, are available. They are designated as follows:

1. POWER, in which the hydraulic power is independently developed by a motor driven pump belonging to the system itself.

2. HAND, in which the hydraulic power is developed in the telemotor pump by the direct manual efforts of the steersman.

3. EMERGENCY, in which the hydraulic power is supplied by the main hydraulic system.

It should be emphasized that the rudder itself is moved by hydraulic power in all three cases; the only difference between these methods is in the manner in which the power is developed.

EMERGENCY power is used only when the normal power (called simply POWER) fails. HAND power is used only when silent operation of the submarine is necessary to prevent detection by enemy craft, or when both the normal POWER and the EMERGENCY power from the main hydraulic system have failed.

The submarine can be steered by all three methods from either the control room or the conning tower.

B. DESCRIPTION

4B1. General arrangement. A schematic diagram of the steering system as a whole is shown in Figure 4-1. The system may be conveniently thought of as divided into four principal parts:

a. The normal power supply system, which consists of a Waterbury No. 5 A-end pump, the motor which drives it, the control cylinder, and the main manifold.

b. The steering stand, which consists of the main steering wheel, emergency hand wheel, telemotor pump, pump control lever, change valve, emergency control valve, conning tower connecting shaft, and a clutch.

c. The main cylinder assemblies, which consist of the cylinders and plungers and the mechanical rudder-angle indicator.

d. The rudder assembly, which consists of the connecting rods and guides, the crosshead, and the rudder itself.

Other units or features are considered in Section 4B2e.

4B2. Detailed description. a. The normal power supply system. 1. The Waterbury pump. In normal operation, the hydraulic power used by the steering system is developed by a Waterbury No. 5 A-end pump, described in Section 2C. It is driven by a 15 horsepower electric motor at a constant speed of about 440 revolutions per minute. The pump turns in a clockwise direction as viewed from the motor end of the shaft. Its speed is constant, but the direction and angle of the tilt-box change. These factors determine the amount of oil pumped into the system to move the rudder, and the direction in which it is pumped.

2. The control cylinder. The function of the control cylinder is to translate the movement of the main steering wheel, as the

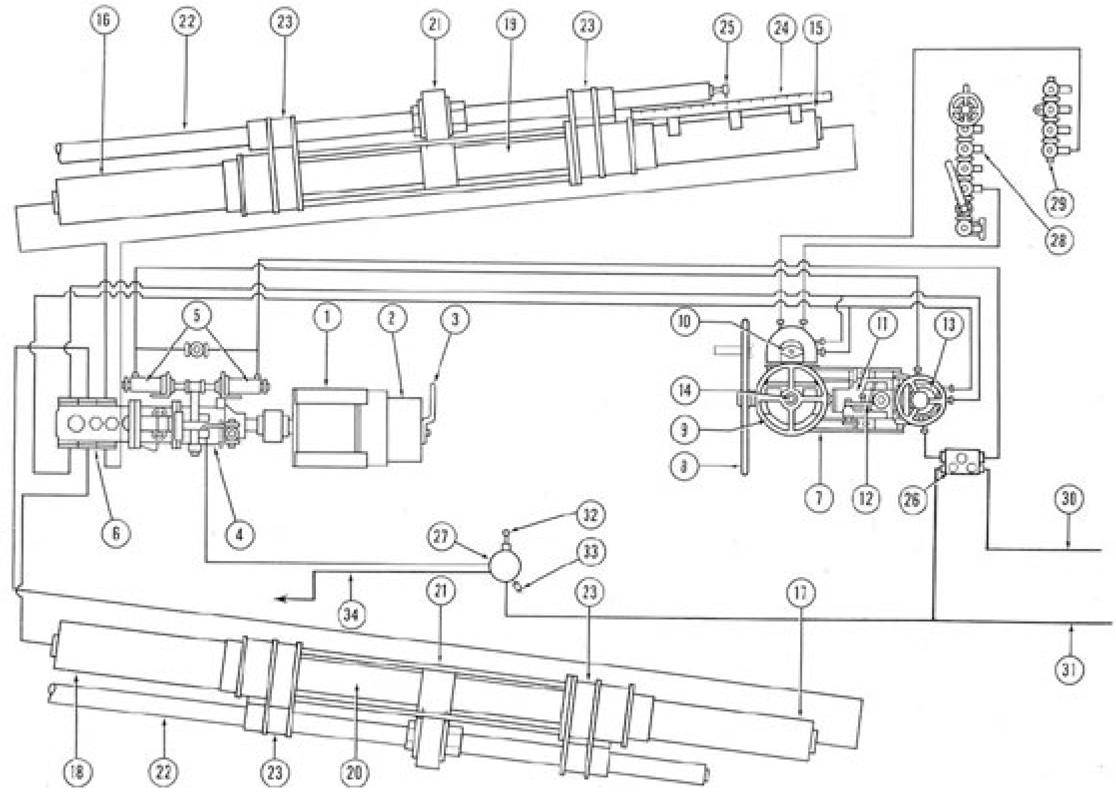

Figure 4-1. Schematic view of steering system.
1) Fifteen-horsepower electric motor, speed 440 revolutions per minute; 2) magnetic brake; 3) brake release lever; 4) motor-driven Waterbury A-end pump; 5) control cylinder; 6) steering system main manifold; 7) steering stand; 8) main steering wheel; 9) emergency steering wheel; 10) emergency control valve; 11) telemotor pump; 12) pump control lever; 13) change valve; 14) conning tower connecting shaft; 15) port main cylinder, forward end; 16) Port main cylinder after end; 17) starboard main cylinder, forward end; 18) starboard main cylinder, after end; 19) port plunger; 20) starboard plunger; 21) yokes for inboard connecting rods; 22) inboard connecting rods; 23) connecting rod bearings; 24) mechanical rudder-angle indicator dial; 25) mechanical rudder-angle indicator pointer; 26) vent and replenishing manifold; 27) vent and surge tank; 28) main hydraulic system supply manifold; 29) main hydraulic system return manifold; 30) line to main supply tank; 31) vent and replenishing line to supply tank; 32) gage; 33) relief valve (48 pounds); 34) vent and replenishing line to stern plane Waterbury A-end pump.

steersman turns it left or right, into a corresponding upward or downward motion of the control shaft, thereby changing the position of the tilt-box in the motor-driven Waterbury pump. This in turn varies the stroke of the pistons inside the motor-driven pump. It also determines the quantity and direction of flow of the oil which is pumped to the main rams. In this manner a single plunger which slides between and through the cylinders. Bell-crank linkage connects this plunger to the tilt-box.

Figure 4-2 shows the details of this unit. The plunger (2) is a double-ended, solid steel, cylindrical bar with a slotted center yoke midway in its length. The yoke carries a steel sliding block which engages the bell crank (5) by a pin (4) fixed

it controls the output of the motor-driven Waterbury pump in response to the adjustments made by the steersman when steering by normal POWER.

The control cylinder assembly consists of a pair of small hydraulic cylinders, opposed and axially in line, having in common through the yoke. This pin serves as a pivot for the bell crank, the other end of which is keyed to a shaft (6).

Hydraulic oil under pressure from the telemotor is delivered to the change valve and is directed by it to one of the two ports (12). Oil is forced out of the other port (12)

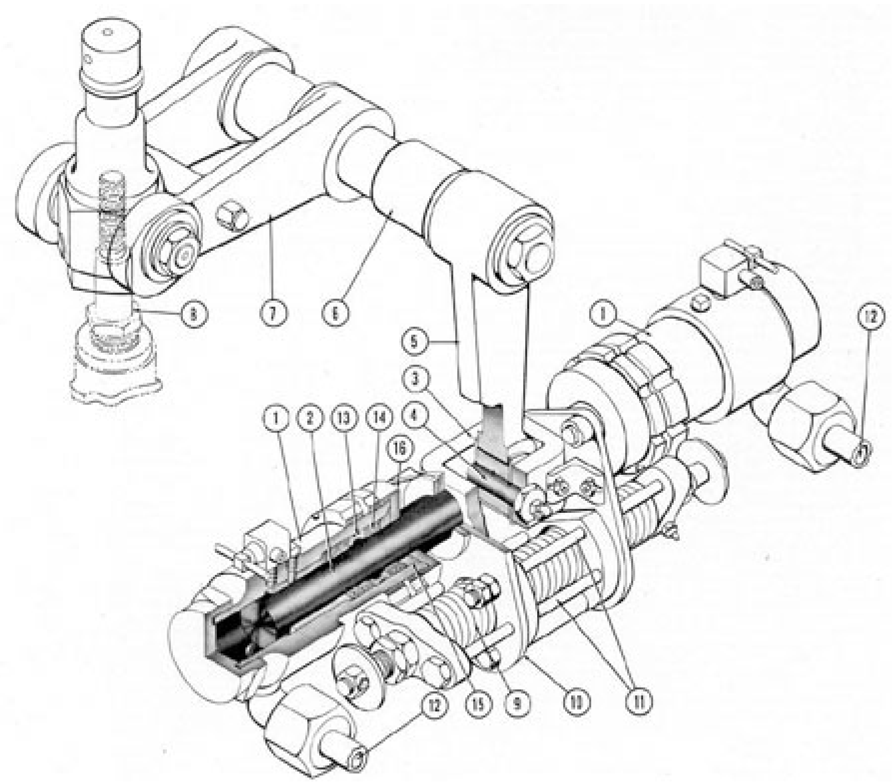

Figure 4-2. Cutaway of control cylinder assembly, with old-type centering spring. 1) Hydraulic cylinders; 2) plunger; 3) crosshead; 4) pin; 5) bell crank, 6) crankshaft; 7) double crank; 8) pump control shaft; 9) centering spring; 10) spring bracket; 11) pull-rods; 12) hydraulic ports; 13) metal space ring; 14) packing; 15) packing gland; 16) packing-gland cap.

by the plunger, back through the change valve, and into the return side of the telemotor pump. As the plunger moves back and forth between the cylinders, it turns the bell crank, rotating the shaft a few degrees in each direction. At the other end of the shaft, a double crank (7) is fixed and, as the shaft turns left or right, this crank moves the pump control shaft (8). This shaft alters steersman. The instant this effort is discontinued, the control shaft returns immediately to neutral. Thus it may be said that the centering spring provides a force which opposes any motion of the control shaft away from dead center.

For example, when the steering hand wheel is turned to the left, the telemotor pump immediately

the angle and direction of the tilt-box in the Waterbury pump. Figure 2-10 shows how the pump control shaft is linked to the tilt-box in the Waterbury pump.

The tilt-box is in the neutral position (zero stroke of the pistons) when it is exactly parallel to the cylinder barrel, that is, vertical. As its position is controlled by the linkage from the control cylinder, the tilt-box will remain at neutral as long as no oil is being directed by the steersman through the telemotor pump to either side of the control cylinder.

As soon as the steering wheel is turned left or right, a column of oil is sent to one side of the control cylinder, moving the control shaft up or down and tilting the tilt-box away from neutral. Unless the wheel were then turned back exactly to its former position, the tilt-box could not return to neutral. Therefore, in the absence of any other force, the steersman, to restore the tilt-box to a position of zero tilt would necessarily have to find the previous position of the steering wheel with the greatest precision otherwise the motor-driven A-end pump would continue to pump oil and the rudder would continue to move.

In practical operation, such precision of touch would be almost impossible to achieve, and the steersman would be obliged to hunt continuously for the neutral position of the wheel in order to keep the boat on a straight course. Therefore, some delivers oil into the left side of the change valve. The change valve, being in the normal POWER position, will direct the oil to the left end of the control cylinder. The control cylinder plunger is moved, compressing the centering spring and tilting the tilt-box. This allows the power driven Waterbury A-end pump to deliver oil immediately to the left side of its valve plate and then to a pressure line leading to the left side of the main steering manifold. Oil is distributed by the manifold to the forward starboard ram cylinder and the after-port ram cylinder, moving their plungers (port plunger forward, starboard aft) and causing the rudder to be moved to the left. As long as the steersman has the wheel turned to the left, the rudder will continue to swing to the left. By partially returning the wheel to its former position, the oil that was forced against the control cylinder plunger will be removed from the control cylinder, thus allowing the centering spring to recenter the plunger and tilt-box of the power-driven Waterbury A-end pump. Since the tilt-box has been returned to its neutral position, the pump will discontinue delivery of oil and the rudder will therefore remain at the designated rudder angle.

Through mechanical linkage and hydraulic pipe lines, the control shaft is linked with the steering wheel in an almost direct connection. That is, any motion of the steering wheel will be instantaneously translated into a corresponding motion of the control shaft. Since this rule works both ways, the resistance of the spring will be felt by the

other means of neutralizing, or centering, the tilt-box, must be provided. Such a device is the centering spring, a powerful spring connected into the control cylinder assembly in such a way as to hold the control shaft firmly in the intermediate or neutral position, until displaced by a definite and deliberate effort of the steersman. When the steersman turns the wheel in the opposite direction, the centering spring will return the control cylinder plunger to neutral. This addition to the control system eliminates all necessity for the

steersman to hunt for the zero, or neutral, position.

Figure 4-2 shows one type of centering spring, found on some older classes of vessels. The spring (9) goes through a hole in the brackets (10) and is seated in the yokes at each end. The brackets are bolted rigidly to the plunger crosshead (3). As this moves either way from the center, the bracket on this side will pull the pull-rod (11) along with it. This rod, sliding freely in the opposite bracket, will pull on the far yoke, compressing the spring, and causing it to resist the motion.

On some of the later classes of submarines, the control shaft which extends through the Waterbury A-end power-driven pump has the centering spring attached to one end of the control shaft, and the control cylinder on the opposite end.

Figure 4-3 illustrates this type of installation. The pump control shaft (1) enters at the bottom, connected to the tilt-box. The centering spring and its actuating spindle, against which the top end of the pump control shaft bears, are contained in the tall, pipelike housing (2) screwed onto the top of the power-driven Waterbury A-end pump.

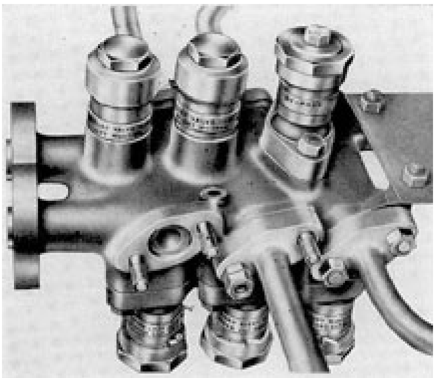

Figure 4-4. Steering system main manifold.

3. The steering system main manifold. The steering system main manifold (Figure 4-4) consists of a multiple-port housing containing nine valves built into the body, and eight ports which connect the main rams to the sources of hydraulic power.

Figure 4-5 shows the location of the ports as seen from a top view of the manifold. The two end ports (1 and 2) are connected directly to the Waterbury A-end pump. The

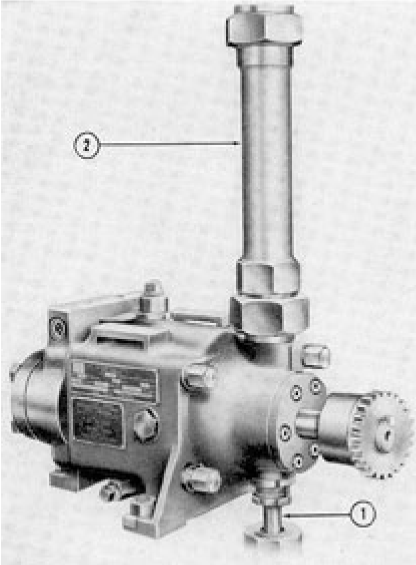

Figure 4-3. Motor-driven Waterbury A-end pump, with new-type centering spring.
1) Pump control shaft; 2) housing for centering spring.

four ports nearest that end (3, 4, 5, 6) are connected to the fore and aft ends of the port and starboard rams. The other two ports (7 and 8) are supply and return ports for auxiliary power, that is, either HAND or EMERGENCY, whenever the motor-driven Waterbury A-end pump is shut off.

Figure 4-5 also shows three of the valves. All the valves have name plates indicating their purpose. The two at the end nearest the pump (9 and 10) are relief valves, placed in the line between the power-driven Waterbury A-end pump and the rams to prevent the building up of excessive pressures. The valve in the center (10) is the right rudder relief valve; that nearest the power-driven Waterbury A-end pump (9) is the left rudder relief

valve. They are spring-loaded, and set to lift at a pressure of 1,200 pounds per square inch. The valve at the other end (11) is a hand

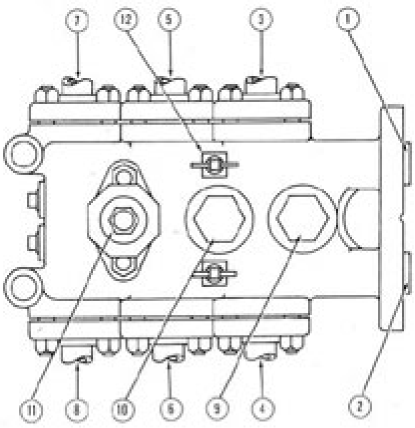

Figure 4-5. Diagram of steering system main manifold, top view. 1) Port to motor-driven Waterbury pump; 2) port to motor-driven Waterbury pump; 3) port to after end of port ram;

double ring (9) over which the valve disk (10) fits. This disk, when screwed all the way down, fits into the valve seat (11), closing the valve. To open or close the valve, the locking cap (12) is backed off a little with a large hex-wrench, to free the turn-nut. Then a small hex-wrench is applied to the top of the turn-nut which, as it turns, rotates the stem (7), causing it to travel up or down in the bonnet, closing or opening the valve. The upper and lower chambers (13 and 14) open into two channels within the manifold body which connect to the supply and return sides of whatever source of power is being utilized. Unseating the valve disk opens these chambers to each other, thereby bypassing the oil directly from the supply to the

4) port to forward end of port ram; 5) port to forward end of starboard ram; 6) port to after end of starboard ram; 7) port to auxiliary power line, HAND and EMERGENCY; 8) port to auxiliary power line, HAND and EMERGENCY; 9) left rudder relief valve; 10) right rudder relief valve; 11) hand bypass valve; 12) vent valve.

bypass valve, used, when needed, to bypass the hydraulic power by connecting the supply and return lines from the power-driven Waterbury A-end pump directly to each other. This bypass normally is closed.

Figure 4-6 is a bottom view of the manifold, showing the other six valves. These are all cut-out valves, used to shut off their corresponding ports. The four nearest the power-driven Waterbury A-end pump, (9, 10, 11, 12) are called power cut-out valves. The two at the left end (13 and 14), called hard and emergency cut-out valves, are used to shut off the two ports connected to the auxiliary power lines.

Figure 4-7 shows the internal structure of the valves. The hand bypass valve (1) on top of the manifold is a disk-type valve. It consists of a valve body or bonnet (6) containing a threaded traveling stem (7), its top end squared to fit into the square interior of the turn-nut (8), its lower end holding a

return side of the system. This valve, therefore, normally is closed, that is, the valve disk normally is screwed down into its seat.

The six cut-out valves on the underside of the manifold, four of which (4 and 5) can

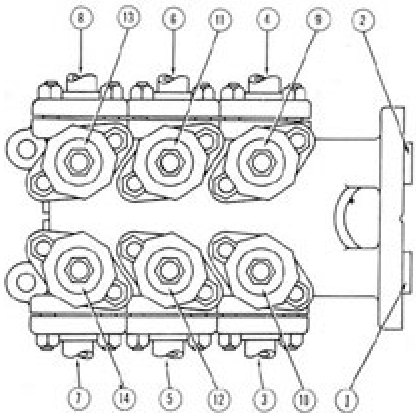

Figure 4-6. Diagram of steering system main manifold, bottom view.
1) Port to motor-driven Waterbury pump; 2) port to motor-driven Waterbury pump; 3) port to after end of port ram; 4) port to forward end of port ram; 5) port to forward end of starboard ram; 6) port to after end of starboard ram; 7) port to auxiliary power line, HAND and EMERGENCY; 8) port to auxiliary power line, HAND and EMERGENCY; 9) power cut-out valve, forward-port ram; 10) power cut-out valve, after-port ram; 11) power cut-out valve, after starboard ram; 12) power cut-out valve, forward starboard ram; 13) auxiliary power cut-out valve, HAND and EMERGENCY; 14) auxiliary power cut-out valve, HAND and EMERGENCY.

be seen in Figure 4-7, are

the manifold body. Thus, turning

structurally identical with the hand bypass valve described. The nearest valve is shown partially cut away. In each of these valves, the upper chamber (15) leads into the port nearest it (17), while the lower chamber (16) leads into one of the two internal channels running lengthwise through the stem (18) to the right and seating the valve disk (19) of any cut-out valve will blank, or cut out, the corresponding port. These valves normally are open. The cutaway also shows the internal structure of one of the relief valves (2). Here

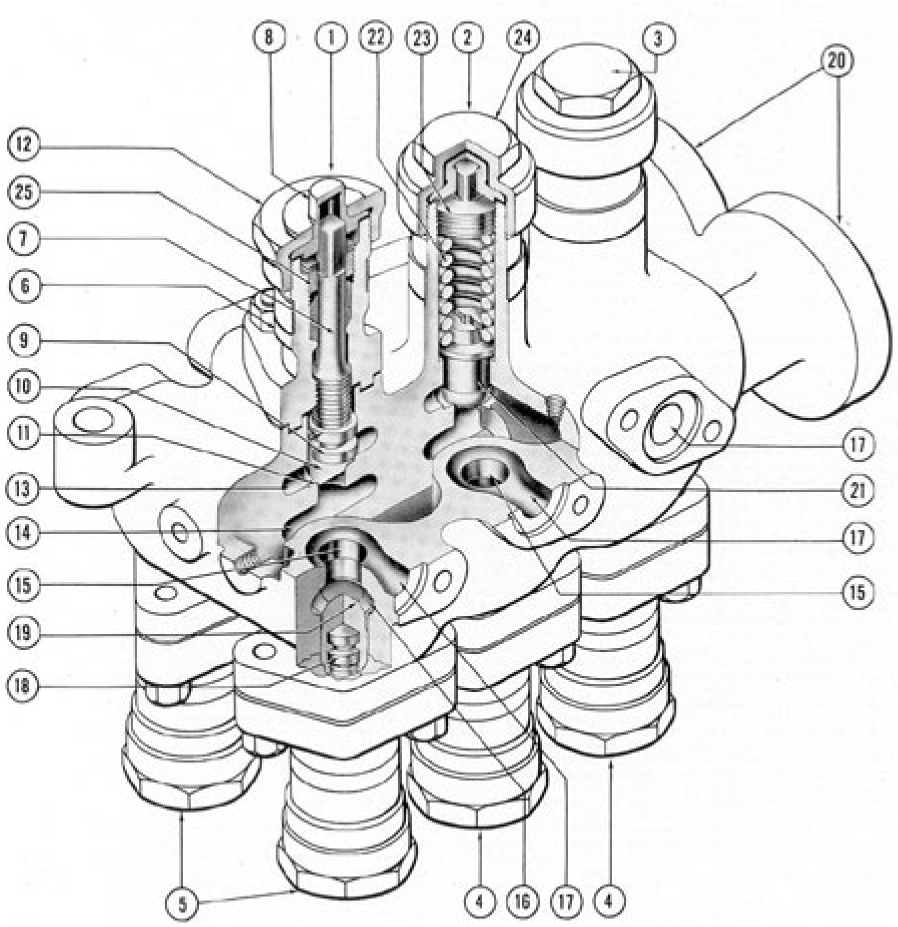

Figure 4-7. Cutaway of steering system main manifold.
1) Hand bypass valve; 2) right rudder relief valve; 3) left rudder relief valve; 4) ram cut-out valves; 5) auxiliary power cut-out valves, HAND and EMERGENCY; 6) bonnets; 7) stem; 8) turn-nut; 9) double ring; 10) valve disk; 11) valve seat; 12) locking cap; 13) upper chamber, hand bypass valve; 14) lower chamber, hand bypass valve; 15) upper chamber, cut-out valve; 16) lower chamber, cut-out valve; 17) ports above corresponding cut-out valves; 18) stem of cut-out valve; 19) valve disk of cut-out valve; 20) ports to motor driven Waterbury pump, supply and return; 21) disk of relief valve; 22) relief valve spring; 23) spring tension adjusting nut; 24) relief valve locking cap. 25) packing-gland nut.

the disk (21), instead of being seated by turning the nut with a wrench, is held seated by the loading spring (22). The spring supply or return, depending on whether the rudder is being turned left or right. Attached name plates differentiate the valves.

tension is adjusted by the adjusting nut (23), which can be reached by removing the cap (24). The two internal chambers of this valve, like those in the hand bypass valve, open into the channels leading to the power-driven Waterbury A-end ports. In practice, therefore, it will be seen that the relief valves are simply safety valves, kept closed by loading springs and opened only by excessive oil pressure, which is then able to bypass to the return side of the manifold. Two such valves are needed here, one on each side of the manifold, because either line may become alternately

Midway on the top of the manifold body, at each side of the right rudder relief valve, is a small vent valve (12, Figure 4-5), which may be opened, when required, to vent air which may have accumulated in the manifold.

b. The steering stand. The hydraulic power which moves the rudder is directed by the steersman from the steering stand, an assembly which contains the control equipment for all three methods of steering, POWER, HAND, and EMERGENCY (see . Figure 4-8).

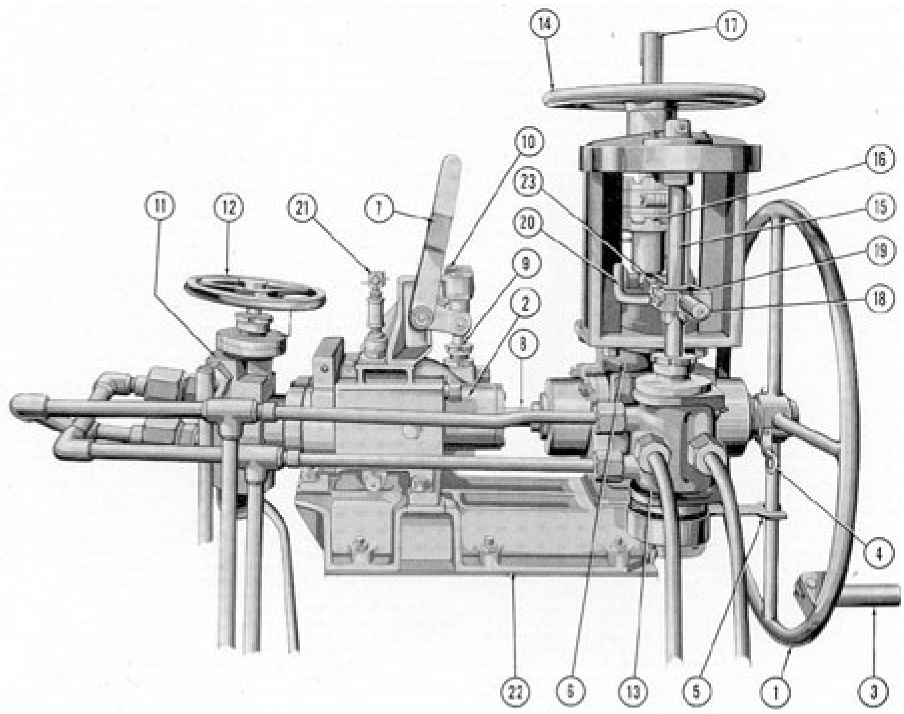

Figure 4-8. Control room steering stand.
1) Main steering wheel; 2) telemotor; 3) hand grip; 4) locking pin; 5) locking arm for steering wheel; 6) gear box; 7) pump control lever, 8) telemotor shaft; 9) pump control shaft; 10) pump control shaft locking screw; 11) change valve; 12) change valve handwheel; 13) emergency control valve; 14) emergency control valve handwheel (emergency steering wheel); 15) emergency control valve shaft; 16) clutch; 17) shaft to conning tower steering wheel; 18) clutch handle; 19) locking bar for emergency control valve shaft; 20) emergency control valve shaft locking arm; 21) vent valve on telemotor; 22) bed plate; 23) wing-nut clutch lock.

1. The telemotor pump. Since, in

flow of oil depends solely on

operation by normal power, it is the direction of the motor-driven Waterbury A-end pump tilt-box that determines which way the rudder moves (see Section 4B2a1), and since the position of this tilt-box is controlled by the movement of oil in the control cylinder, it is clear that, to steer the submarine, some device is needed to drive that oil in the direction required. The mechanism must be one which will respond readily to the steersman's touch, yet control accurately the powerful pressures developed by the motor-driven Waterbury A-end pump. Such a device is the telemotor pump (2, Figure 4-8), the steering stand's main unit. The telemotor pump is actually a hand-operated Waterbury A-end pump. A bracket is fitted externally to it and the pump control shaft so that its tilt-box always tilts in the same direction, though its angle, that is, the degree of tilt, may be changed. Consequently, the which way its shaft is rotated. If a large handwheel is fitted to this shaft, and the ports of the telemotor connected to opposite ends of the control cylinder, turning the wheel left or right will then pump oil to one end or the other of the control cylinder, which in turn tilts the tilt-box in the motor-driven Waterbury A-end pump, thus moving the rudder left or right. Therefore, turning a wheel fitted to the shaft of the telemotor pump will steer the submarine.

2. The main steering wheel. The main steering wheel (1, Figure 4-8) is mounted vertically at the after end of the steering stand. It is used for both POWER and HAND steering.

As HAND steering requires greater effort, a retractable spring hand grip (3) is built into the rim, which, during POWER steering, may be kept folded in.

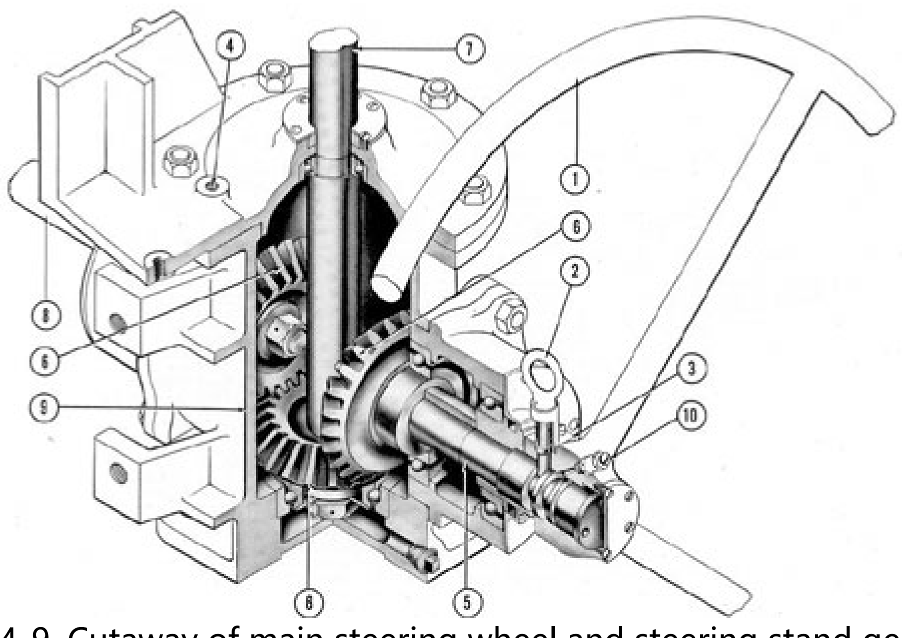

Figure 4-9. Cutaway of main steering wheel and steering stand gear box.
I) Main steering wheel; 2) locking pin (spring-loaded); 3) clutch jaw; 4) grease connection; 5) main wheel drive shaft; 6) bevel gears; 7) conning tower steering wheel shaft; 8) telemotor drive shaft; 9) gear box housing; 10) grease connection.

A spring-loaded locking pin (4) is built into the hub, which when pulled out allows the main steering wheel to be disengaged from its shaft. This keeps the main wheel from spinning uselessly when the submarine is being steered from the conning tower. Attached to the steering stand under the main wheel is a locking arm (5) with a forked end which can be swung out to keep the wheel stationary when it has been disengaged. The main steering wheel is connected to the telemotor pump through the gear box (6, Figure 4-8). This is shown partially cut away in Figure 4-9.

Figure 4-9 illustrates the manner in which the telemotor pump is connected both to the main steering wheel (in the control room) and the conning tower steering wheel.

The main steering wheel (1) is clutched into the main shaft (5) by a jaw clutch. It can be locked in either the clutched or de-clutched position by the spring-loaded locking pin (2). Keyed to the other end of the shaft is the bevel gear (6).

The conning tower drive shaft (7) has a similar bevel gear keyed to its lower end.

The telemotor pump drive shaft (8) also is keyed into a bevel gear.

These three gears, are meshed to form a gear train. Rotating the main wheel (1) will therefore cause the gear on the end of the change in the position of its tilt-box produces a large reaction at the rams, and fine and exact control is therefore needed. Such control is effected by setting the telemotor pump's tilt-box at a very small angle, the minimum piston stroke, so that turning the main wheel drives only a relatively small volume of oil into the control cylinder.

However, in HAND steering, the pressure developed in the telemotor pump by turning the main steering wheel, directly actuates the main rams. Therefore, the rudder is swung by the manual exertions of the steersman. This means that, to achieve the same fineness of control, there is no need to pump relatively small quantities of oil through the telemotor pump; on the contrary,what is wanted is a relatively large volume of oil pumped to the actuating cylinder without too many turns of the wheel. Therefore, the telemotor pump tilt-box should be set at a large angle or maximum piston stroke. This angle setting is done by means of the pump control lever (7, Figure 4-8), mounted on top of the telemotor pump, since the maximum stroke allowed by the pump control lever is determined by the bracket connection.

This is shown in more detail in Figure 4-10. It must be emphasized again that the tilt-box of a telemotor pump is always tilted away from neutral, and always in the same direction. For the steering system telemotor

telemotor pump shaft to rotate, but in the opposite direction, due to the intermediate (horizontal) bevel gear.

Of course, the vertical shaft leading to the conning tower drive shaft also rotates when the main wheel is turned, but a clutch (see Figure 4-17) disconnects this stub shaft from the conning tower driving shaft proper.

The gear housing (9) is lubricated through the grease connection (4).

3. The pump control lever. In POWER steering, as indicated above, the only function of the telemotor pump is to move the control cylinder plunger fore or aft; the actual work of swinging the rudder is then done by the power-driven Waterbury A-end pump. Since the power-driven Waterbury A-end pump is running at 440 revolutions per minute, a small pump there are only two angles, or settings, POWER and HAND, shown by the name plate (5) on the frame which holds the lever (1). Moving the lever to one or the other setting moves the pump control shaft (2), which is linked to the tilt-box inside the telemotor pump(3). Whenever a tilt-box is tilted away from the neutral position, the stroke of the pistons changes-which is precisely what causes pumping action. The pressure of the oil against the piston will tend to force the tilt-box to return to neutral. This is particularly true when the angle is large or when the tilt-box is set at the HAND position. To prevent any change in angle of tilt, the pump control shaft is extended up into the lever frame, and a heavy locking screw (4) is provided to clamp the control

shaft extension (6), notched for a positive grip, in the desired position.

4. The change valve. Since there are three methods of operating the steering system, POWER, HAND, and EMERGENCY, a change valve (11, Figure 4-8) is provided to open the lines being used, and close, or blank off, the others. This valve is mounted at the forward end of the steering stand, by a pair of flanged ports connecting directly to the pressure ports of the telemotor pump.

It is a piston-type, or traveling-nut-type valve, the various combinations of outlets being opened and shut off by a movable sleeve (1) as it is raised and lowered by the handwheel (2) This turns the shaft (3) a nonrising stem, whose male threaded end (4) engages the female threaded end of the sleeve. The sleeve and the internal chamber of the valve body (5) are accurately machined and lap-fitted to each other so that the shutoff action of the lands on the sleeve will be close-fitting. This is further improved by

The change valve has six ports. A movable internal mechanism enables the steersman to select one of three different combinations of ports, depending upon which one of the three steering methods is in use.

The cutaway view (Figure 4-11) shows how the operation of the change valve works.

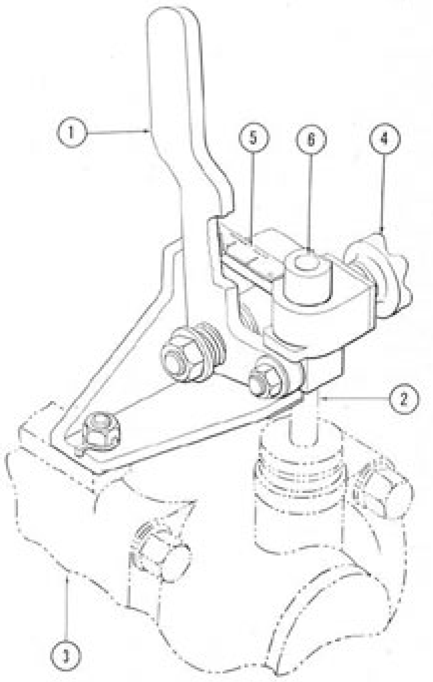

Figure 4-10. Telemotor pump control lever.
1) Pump control lever; 2) pump control shaft; 3) telemotor;4) locking screw; 5) name slate; 6) control shaft extension.

phosphor-bronze collars which are soldered onto the lands, the softer metal making a smooth, tight bearing surface for the steel body of the valve. Note that it is the sleeve that travels up and down,

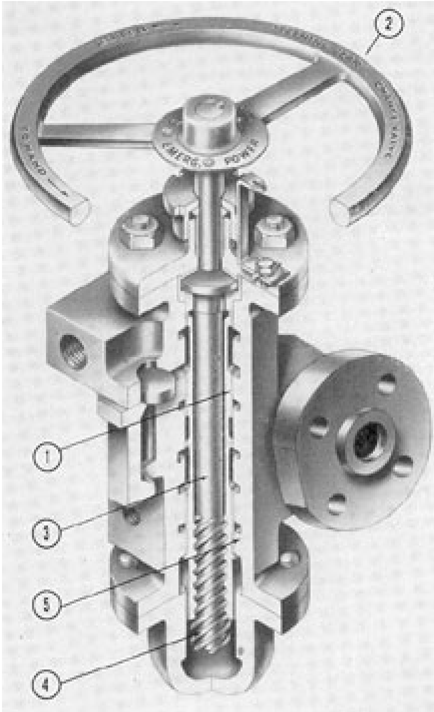

Figure 4-11. Cutaway of change valve.
1) Sleeve; 2) handwheel; 3) shaft; 4) threaded end of shaft; 5) valve body.

not the handwheel shaft, which merely turns left or right. The thread used on the shaft is a steeply pitched quadruple thread with a rapid travel, which raises or lowers the sleeve to the extreme limit of travel in three quarters of a turn of the wheel.

The three possible positions of the wheel are shown by a circular

steering system train manifold (4) (see Figure 4-6, ports 7 and 8), thus sending oil developed by the steersman in the telemotor pump, directly to the main rams.

At EMERGENCY, the sleeve is in the intermediate position; all ports are blanked off, preventing the high pressure oil (from the main hydraulic system's emergency

indicator plate screwed to the spokes near the hub. A black enameled strip of iron formed into an indicator and attached to the valve body shows where the wheel should stop for each position.

Figure 4-12 is a diagram of the change valve in all three positions, showing the relationships between the position of the sleeve and the various oil lines entering the valve. Active oil at high pressure from the emergency lines of the main hydraulic system is shown in red; active oil at low pressure in the telemotor and control cylinder circuit is shown in blue.

At POWER, the sleeve is fully raised; the telemotor pump ports (1) are connected to the control cylinder ports (2), sending oil at low pressure, developed by the steersman in the telemotor pump, to the control cylinder.

At HAND, the sleeve is fully lowered; the telemotor pump ports (1) are connected directly to the auxiliary power ports of the lines) from reaching the telemotor pump and motorizing it.

WARNING. Always place the change valve in the EMERGENCY position before opening the emergency control valve. Failure to do so may result in motorization of the telemotor pump and serious injury to the operator.

The three positions of the sleeve corresponding to POWER, HAND, and EMERGENCY, are shown diagrammatically in Figure 4-13. Oil from the supply side is shown in red; return oil from a cylinder in blue. Direction of flow is indicated by arrows. At POWER, the sleeve (1) is at its uppermost position (2); the telemotor pump ports are connected to the control cylinder ports through the sleeve channel; the ports to the main rams are blanked off. At HAND the sleeve is in the lowest position; the control cylinder is bypassed, while the telemotor pump ports are opened to the rams.

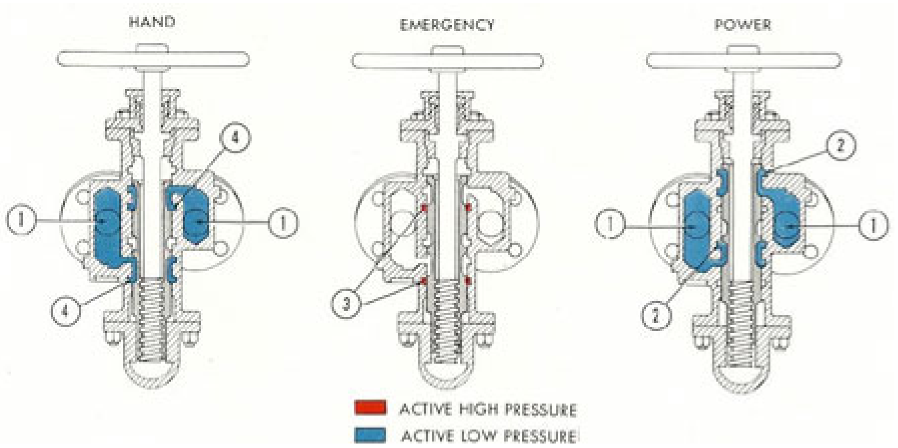

Figure 4-12. Diagram of change valve in three positions.
1) To telemotor; 2) to control cylinder; 3) emergency position; 4) to main steering manifold, HAND.

5. The emergency control valve. The emergency control valve is mounted to the left of the main steering wheel (looking forward from the wheel). It is shown at 13 in Figure 4-8. Its function is to allow the flow of oil from the main hydraulic system, in case of failure of the steering system's own power, and direct it to either side of the steering system manifold (using the same lines as those for HAND operation), from which it goes to the rams. Like the change valve, the emergency control valve is a piston-type, or traveling-nut-type, valve with a nonrising stem (see Figure 4-14). As the stem (1, Figure 4-14) is turned left or right, it raises or lowers the piston (2), opening either right rudder or left rudder port to the supply port (3) of the main hydraulic system, and thus allowing the oil to flow to one side or the other of the main steering manifold.

Details of the operating mechanism for the emergency control valve are shown in Figure 4-15. The stem is turned by a shaft (8) connected through a pair of horizontally mounted spur gears (6) to a handwheel (7) the emergency steering wheel- mounted horizontally above the main steering wheel, at about shoulder height. This handwheel has RIGHT RUDDER stamped into its rim with an arrow indicating how the wheel is to be turned for that operation. This wheel functions as the steering wheel when the vessel is being steered by EMERGENCY. Its position on the steering stand is shown at 14, Figure 4-8.

Figure 4-16 shows the emergency control valve in each of its three positions, indicating the relationship between the position of the piston and the flow of oil to the rams. The pressure side is shown in red, the return side in blue.

At NEUTRAL, the piston is in the intermediate position. The ports (3 and 4) leading to the steering system main manifold, and thence to the main rams, are both blanked off

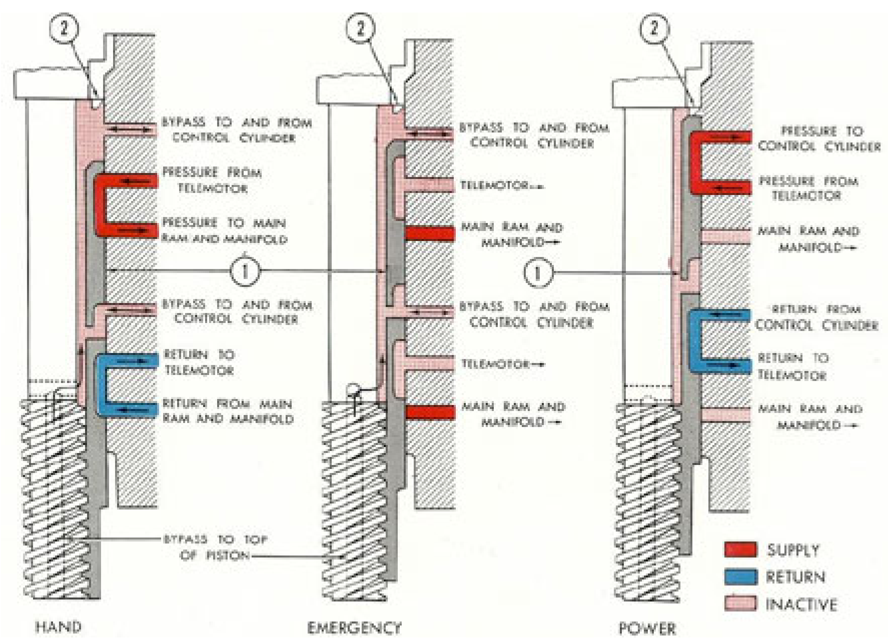

Figure 4-13. Schematic diagram of ports and lands in change valve. 1) Sleeve; 2) stop.

and the pressure from the supply port (1) cannot reach them.

At RIGHT RUDDER, the piston has moved to the bottom of its travel, the supply port (1) is opened to the port (3) leading to the after-starboard and forward-port rams; return oil from the after-port and forward-starboard rams comes in through the port (4) and out through the return port (2).

At LEFT RUDDER, the piston is at the top of its travel. Pressure from the supply port (1) goes out through the port (4) to the forward-starboard and after-port rams; return oil from the forward-port and after-starboard rams comes in through the port (3) and goes out through the return port (2).

6. The clutch. Across the shaft of the emergency control valve itself is the clutch handle (18, Figure 4-8) which, through appropriate linkage, raises and lowers the positive jaw clutch (16) located on the vertical conning tower drive shaft (17) just under the emergency handwheel spur gears. The clutch handle is fitted with a locking bar (19) which holds the emergency control valve shaft (15) firmly in place. It is fastened by a spring loaded locking arm (20) and a wing-nut clutch lock (23).

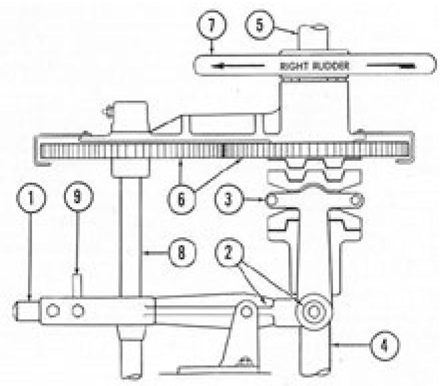

Figure 4-15. Diagram of clutch and emergency steering wheel spur gears, clutch handle up.
1) Clutch handle; 2) linkage; 3) clutch; 4) shaft from gear box; 5) shaft to conning tower steering wheel; 6) spur gears; 7) emergency steering wheel; 8) emergency control valve shaft; 9) locking arm.

The function of this clutch is shown in more detail in Figures 4-15 and 4-17. When the handle is down (Figure 4-17), the clutch is engaged to the emergency steering control wheel, and the steering can be done by POWER or HAND from the control room steering stand, or by EMERGENCY from the conning tower wheel. When the handle is up (Figure 4-15), the clutch is disengaged and steering can be done by POWER or HAND from the conning tower, or by EMERGENCY from the control room.

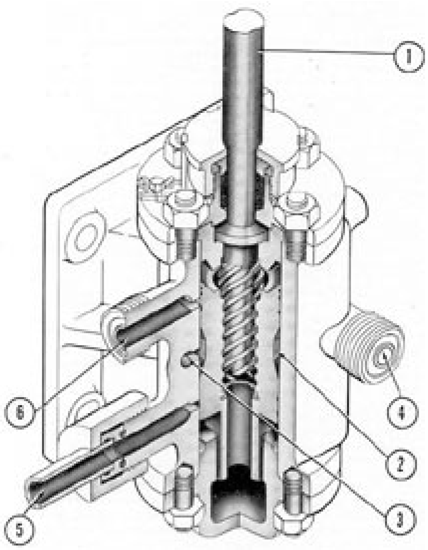

Figure 4-14. Cutaway of emergency control valve.
1) Nonrising stem; 2) piston; 3) supply port, from emergency lines, main hydraulic system; 4) return port, to emergency lines, main hydraulic system; 5) port to steering system main manifold and rams, forward-port, after-starboard; 6) port to steering system main manifold and rams, after-port, forward starboard.

7. The conning tower steering shaft. The conning tower steering shaft (7, Figure 4-9) connects the steering stand to the conning tower steering wheel.

As shown in Figure 4-9, the drive shaft (7) from the conning tower steering wheel ends in a horizontal bevel gear, the intermediate gear of a three-gear train (6). These gears are contained in the gear box (9), an oil filled housing located on the steering stand

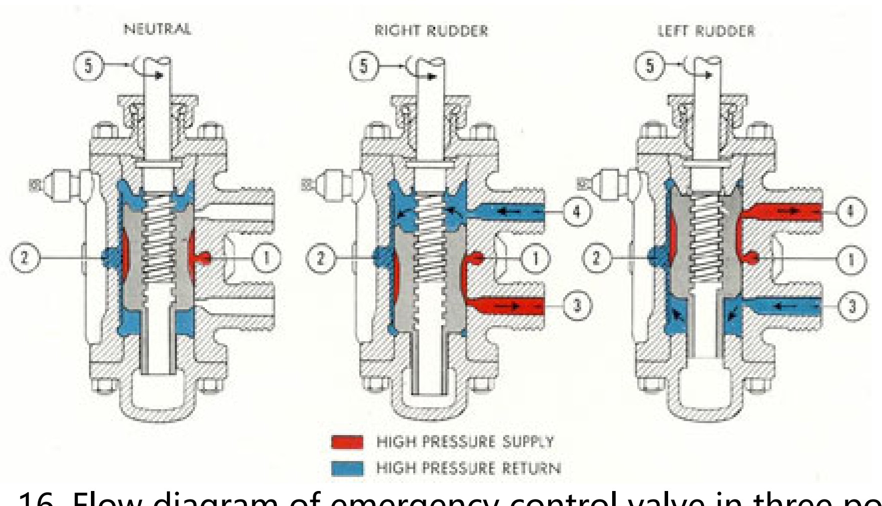

Figure 4-16. Flow diagram of emergency control valve in three positions.
1) To main hydraulic system, supply; 2) to main hydraulic system, return; 3) to main rams, forward-port, after-starboard; 4) to main rams, after-port, forward-starboard; 5) direction of rotation of emergency steering wheel for right rudder.

just forward of the main steering wheel (see 6, Figure 4-8). The conning tower steering wheel is connected and disconnected by means of the clutch, as described

aboard the submarine. The entire ram assembly is bolted to the framework through the brackets (7, Figure 4-18).

in the previous section (see Figures 4-15 and 4-17).

c. The rams. The main cylinder ram assemblies, usually referred to simply as the rams (port and starboard), transform hydraulic power into mechanical power to move the rudder. Figure 4-18 shows their structure. Each consists essentially of a pair of hydraulic cylinders (1) opposed and axially in line, having in common a plunger (2), or ram, which slides between and through them, and a hydraulic port(3) at each end into which oil is admitted, to move the rams forward or aft. At its center the plunger has a heavy yoke (4) forged integral with it. This yoke has a hole drilled into it to take the inboard connecting rod (5) which is locked into it at this point by heavy locknuts, one on each side of the yoke. The inboard connecting rod slides through the bearings (6). Oil leakage past the plunger is prevented by the packing (10). Figure 4-20 is an exploded view of this chevron packing, which shows clearly the cross-sectional shape of the rings. This type of packing is used in various hydraulic units

Mounted at the forward end of the ram shown in Figure 4-18 is the mechanical rudder-angle indicator pointer (8), which shows the angle of rudder deflection in degrees on the indicator dial (9). Another rudder-angle transmitter, electrically operated, is located on the other ram (not shown). It transmits the angle of deflection electrically to a rudder

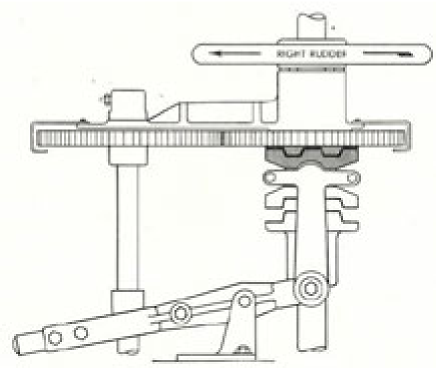

Figure 4-17. Diagram of clutch and emergency steering wheel, clutch handle down.

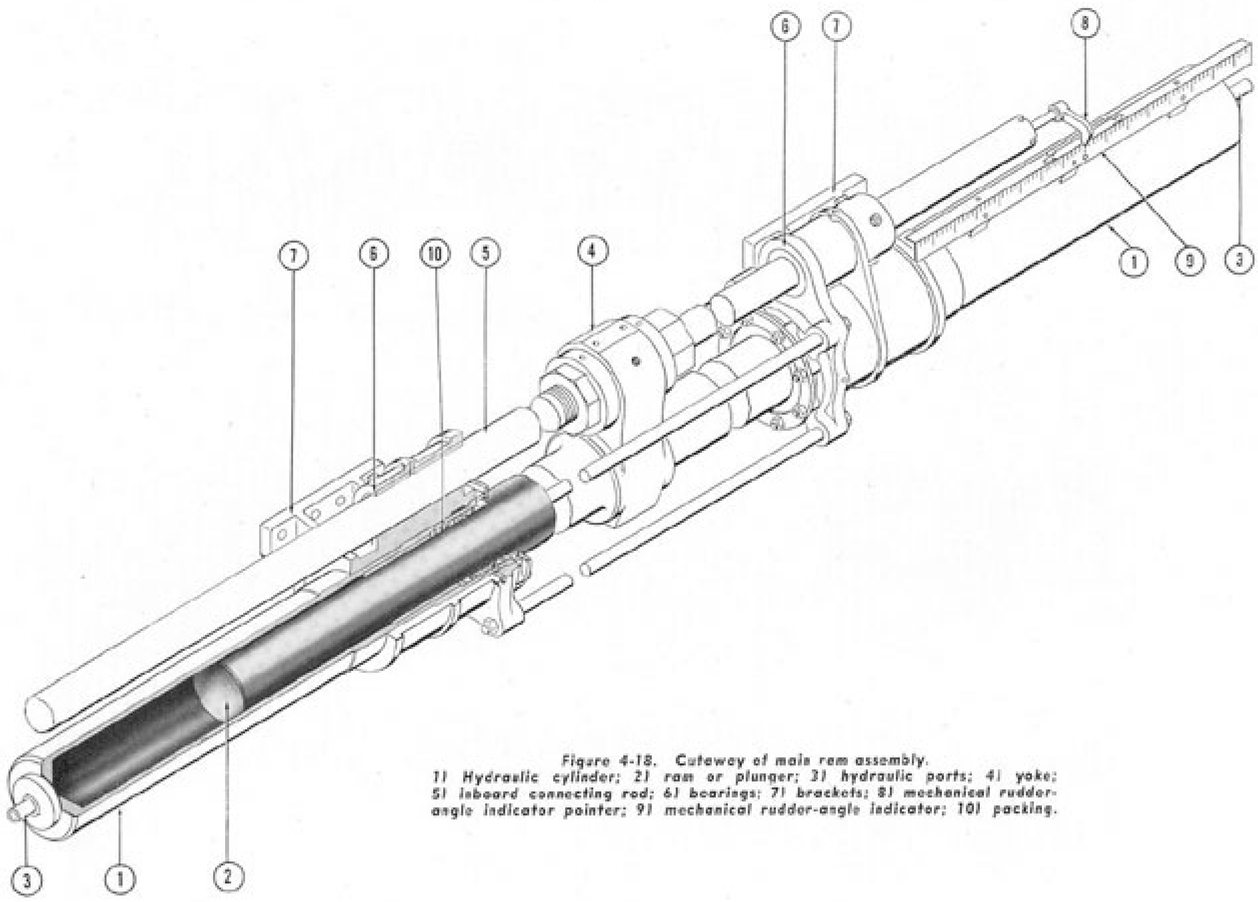

Figure 4-18. Cutaway of main ram assembly.
1) Hydraulic cylinder; 2) ram or plunger; 3) hydraulic parts; 4) yoke; 5) inboard connecting rod; 6) bearings; 7) brackets; 8) mechanical rudder-angle indicator pointer; 9) mechanical rudder-angle indicator; 10) packing.

angle indicator on the instrument board in the control room. Figure 4-19 shows the packing used in the main ram.

Figure 4-19. Packing used in main ram.

d. The rudder assembly. The rudder assembly is shown in Figure 4-21. The after end of each inboard connecting rod (1) rudder stock (10), to which the rudder (11) itself is attached. As the connecting rods are pushed in opposite directions by the hydraulic pressure, they swing the crosshead, turning the rudder.

e. Other units. Besides the principal parts already described, the steering system also contains a vent and surge tank, a vent and replenishing manifold, and several hand cut-out valves located at various points in the pipe lines.

1. The vent and surge tank. The vent and surge tank is an oil reservoir that normally

goes into a guide (2) which is simply an open ended cylinder containing a sliding member, the guide piston (3). Through the guide piston, the inboard connecting rod is linked to the outboard connecting rod (4). The guides are located beyond the point at which the inboard connecting rods emerge, through watertight packing (5), from the pressure hull (6) into the sea.

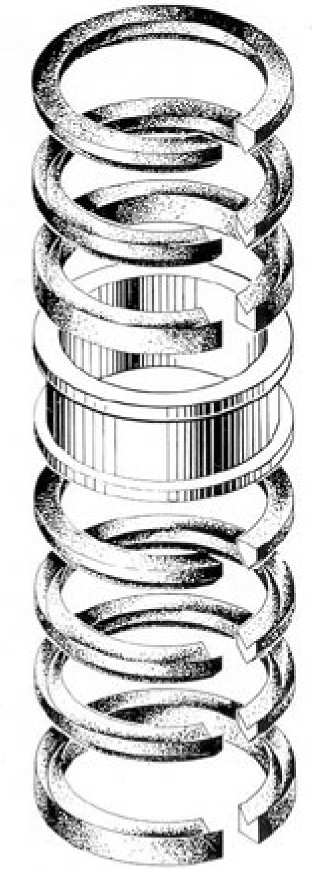

Figure 4-20. Exploded view of chevron packing for steering system main ram.

Since the guide pistons are not water tight, sea water is always present in the closed end (7) of the guide cylinders. Therefore to prevent a sudden build-up of water pressure at this point when the guide piston moves inward-a pressure which would tend to lock the pistons against further movement-the closed ends of the guide cylinders are connected to each other by a pipe (8) called the equalizing bypass. This provides a free passage between the closed ends of the cylinders for the sea water trapped behind the guides, whenever the pistons are moved.

The two outboard connecting rods are linked to opposite ends of the crosshead (9), which actually swings the rudder. Through the center pivot of the crosshead passes the

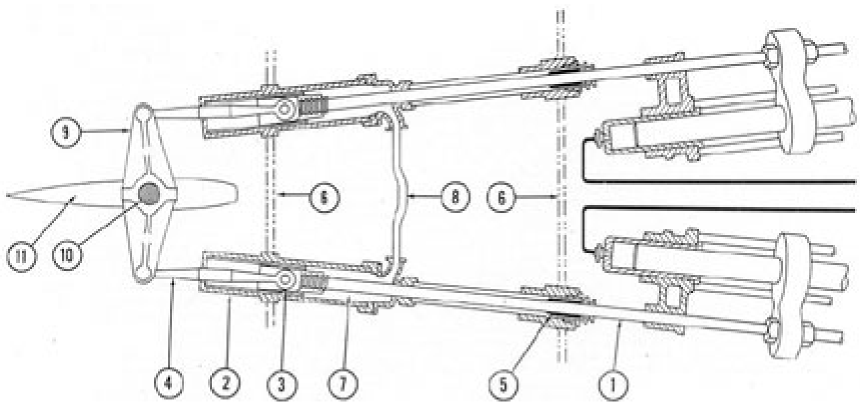

Figure 4-21. Diagram of rudder assembly and guides. 1) Inboard connecting rod; 2) connecting rod guide cylinder; 3) guide piston; 4) outboard connecting rod; 5) packing; 6) pressure hull; 7) forward (closed) end of guide cylinder; 8) equalizing line, or bypass; 9) crosshead; 10) rudder stock; 11) rudder.

is kept half full. It has three separate functions:

a) Venting. It vents air which has accumulated in the system. The tank is placed at a level higher than the Waterbury pumps and motor, allowing elimination of air and replenishing of oil as well as thermal expansion of the oil in the inactive sides of the Waterbury pumps and motor.

b) Replenishing. The vent and surge tank provides replenishment of oil to the inactive side of the Waterbury speed gear, replacing oil which has been delivered from the case into the active system (see Section 2C4h).

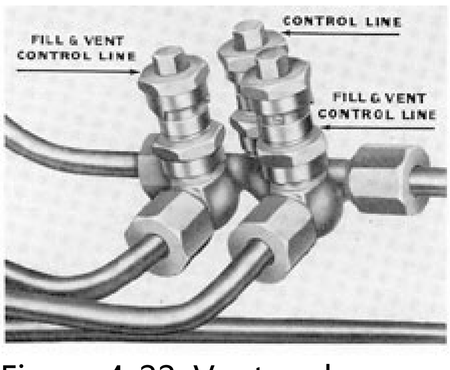

Figure 4-22. Vent and replenishing manifold.

When the steering system is operating under normal power furnished by the motor driven Waterbury speed gear, oil is replenished from the case, or inactive, system into the active system by means of replenishing valves (see Section 2C4h). The reserve oil in the vent and surge tank is used to make good this loss, as well as other losses due to leakage throughout the system. It is fed into the case of the Waterbury speed gear by means of a 10- to 25-pound back-pressure. This back pressure is received from the main supply tank through the replenishing line since the vent on the vent and surge tank normally is closed. A relief valve mounted on the vent and surge tank is set to lift at 48 pounds per square inch.

c) Surges: thermal expansion. Oil circulated at high pressure throughout a hydraulic system soon becomes heated and increases in volume. For proper functioning, the system must provide room for this expansion. The vent and surge tank provides this room. As the oil expands, the level in the tank rises, relieving the other parts of the system of the strain which would otherwise be

placed on them if the increased pressure had no means of escape.

The location of the vent and surge tank in the steering system is shown schematically in the piping diagram of the steering system (27, Figure 4-1).

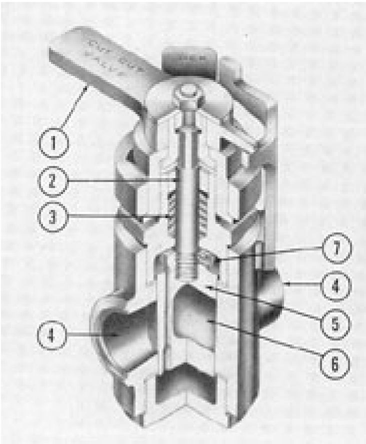

Figure 4-23. Cutaway of quick-throw, plug-type, hand cut-out valve.
1) Handle; 2) stem; 3) packing; 4) line port; 5) valve plug; 6) valve plug port; 7) setscrew.

Besides its function in the steering system, this tank, because of its convenient location, is also used to perform the same services for the stern diving plane system. (see Chapter 5).

2. The vent and replenishing manifold. The vent and replenishing manifold is a three-valve manifold (see Figure-22) installed in the lines at the forward end of the steering stand. It consists of three identical cut-out valves whose structure and operate oral principles are the same as the cut-out valves on the steering system main manifold (see Section 4b2a3). Its internal

The two outer valves normally are closed, except when it becomes necessary to fill or vent the system. The center valve connected to the control cylinder power line normally is open.

The location of the vent and replenishing manifold is shown in the schematic piping diagram (26, Figure 4-1).

3. Quick-throw cut-out valves. Several plug-type, quick-throw cut-out valves may be installed at various points in the hydraulic lines for the purpose of quickly shutting off the flow of oil between the units in case of a ruptured line or other emergency.

A cutaway view of this type of valve is shown in Figure 4-23. The throw, or amount of turn, of this valve stem is 90 degrees, or a quarter-turn. The stem (2) has a squared upper end fitting snugly into the hollow portion of the handle assembly ring, to which it is secured by a hex-nut and washer screwed down over the top of the stem. The lower, threaded end of the stem is screwed into the valve plug (5) and locked there by a small setscrew (7), which can be seen in the illustration at the right of the threaded portion of the stem. Running through the plug is a channel called the plug port (6).

mechanism is illustrated in Figure 4-7.

When this is lined up with the two line ports (4), the valve is OPEN. When the plug is rotated 90 degrees, this channel is at a right angle to the line between the ports, and the valve is closed. The cutaway view shows the valve in the CLOSED position.

When these two cut-out valves are closed, the motor-driven Waterbury is isolated from the rest of the steering system. On later classes of submarines, these valves have been installed between the motor-driven pump and main manifold.

C. OPERATION

4C1. Introduction. A detailed description has just been given of the essential parts of the hydraulic steering system. In this section their operation is described. As has been indicated, there are three methods of steering, called POWER, HAND, and EMERGENCY, according to the source of hydraulic pressure utilized. For clarity, a single rudder movement-from 0 degrees to 20 degrees right rudder-is described as it occurs in each method. By so doing it is possible to show how each unit, previously taken up in detail, functions as part of the coordinated whole. The paths taken by the oil are also shown.

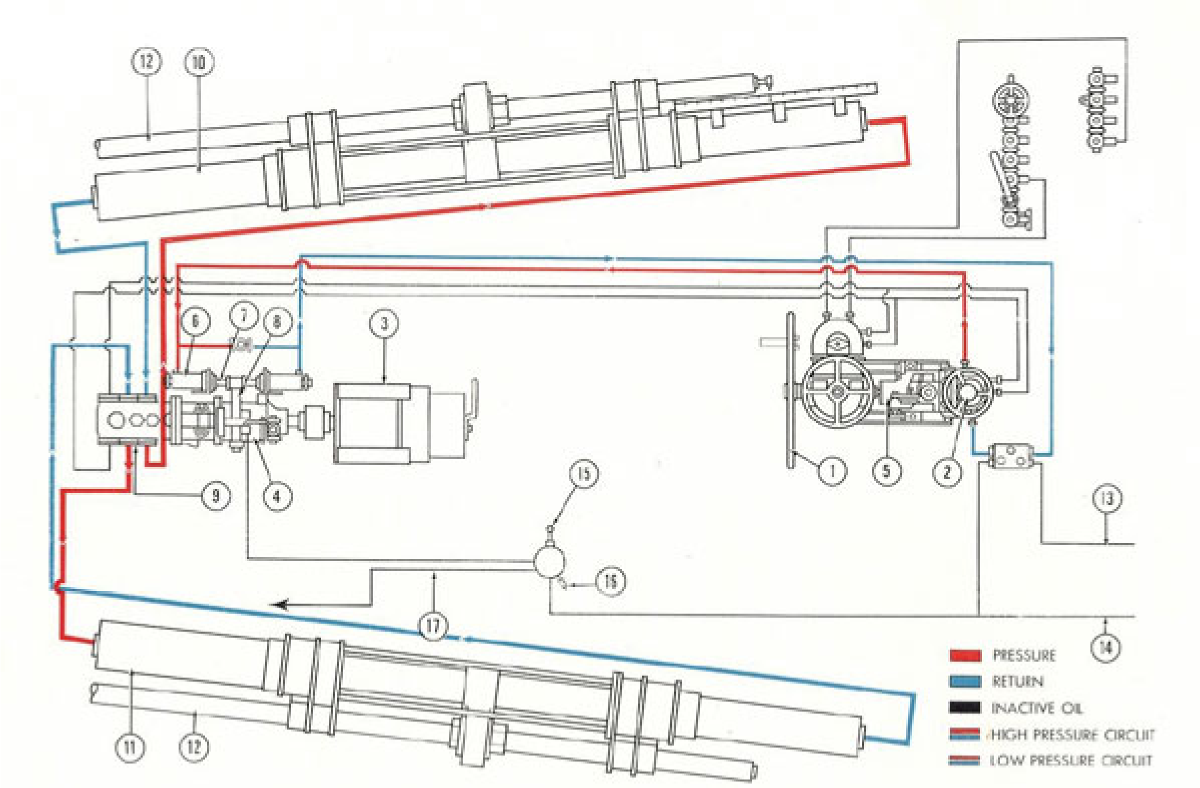

Figure 4-24. Operation diagram of steering system by normal POWER. 1) Main steering wheel; 2) change valve; 3) 15-horsepower electric motor, speed 440 revolutions per minute; 4) motor-driven Waterbury A-end pump; 5) telemotor pump; 6) control cylinder; 7) plunger; 8) bell-crank shaft; 9) steering system main manifold; 10) port main cylinder, or ram, after end; 11) starboard main cylinder, or ram, after end; 12) inboard connecting rods; 13) line to main supply tank; 14) vent and replenishing line to supply tank; 15) gage; 16) relief valve (48 pounds); 17) vent and replenishing line to stern plane Waterbury A-end pump.

4C2. POWER steering. a. Explanation of the diagram. Figure 4-24 shows the coordinated action of the system during POWER steering. Direction of oil flow for right rudder is shown by arrows. The power pump or high-pressure oil circuit is shown in heavy lines, red for the supply side of the line, blue for the return side. The telemotor pump or low-pressure circuit is shown in thinner lines, red for the supply side, blue for the return side. Areas and lines inactive during POWER steering are shown in black. All colors and directions shown are for right rudder. For left rudder, or a gear box to the telemotor pump (5), which, drives oil at low pressure through the change valve (2) into the control cylinder pressure line. Oil is thereby driven into the after end of the control cylinder (6), moving the plunger (7) forward.

This swings the bell-crank shaft (8), tilting the tilt-box in the motor-driven Waterbury A-end pump. Instantly its pistons pump oil at high pressure through one side of the manifold (9), into the forward end of the port ram (10) and the after end of the starboard ram (11). The port ram moves aft, the starboard ram moves forward; the connecting. rods (12), pulled in

return to a smaller angle of right deflection, all arrows would point in the opposite direction, and colors would be reversed in each circuit. Refer to each index number on the diagram as it occurs in the text.

b. Operation of the system on POWER. The main steering wheel (1) is engaged in the shaft clutch and locked into its shaft by the locking pin.

The pump control lever mounted on the telemotor pump is set at POWER and locked there by the locking screw.

The change valve (2) is also set at POWER.

The clutch handle is down.

The steering main manifold ram cut-out valves are OPEN.

The various gages and levels are, checked to make sure that the system is completely filled with oil. The motor (3) which drives the Waterbury pump (4) is started by pressing the switch button at the control room steering stand insuring that the switch on the steering control panel aft is in the ON position.

The system is now ready for operation under POWER.

The submarine rudder is actuated by turning the large main wheel to right or left. Let us suppose the submarine is running on a straight course, the rudder indicator showing zero degrees deflection. The steersman receives the order, "Right, 20 degrees rudder." He turns the wheel to the right. opposite directions, swing the crosshead and rudder to the right.

The steersman either holds the steering wheel steady, or continues to turn it to the right (depending on how swift a reaction is needed) until the rudder indicator shows 20, degrees right rudder. Then he turns the wheel partially to the left, releasing the oil pressure. The centering spring will then bring the control cylinder plunger to a neutral, balanced position (see Section 4B2a), and recenter the control shaft, neutralizing the Waterbury pump's tilt-box and stopping any further pumping of oil to the rams. This locks the main cylinder rams or plungers in that position for as long as desired, holding the rudder steady at that angle.

But we have not yet followed the movement of oil in the system to the completion of its cycle. Both the oil in the low pressure circuit from the hand-rotated telemotor pump (5) and the oil at high pressure from the motor-driven Waterbury (4) have a return flow in their respective circuits.

We followed the oil in the low pressure circuit until it reached and actuated the plunger in the after control cylinder. It has moved forward, driving oil out of the forward end of the control cylinder, back through the change valve, into the return port of the telemotor pump, completing its cycle.

We followed the oil in the high pressure circuit from the motor-driven Waterbury A-end pump until it reached and actuated the

Its motion is transmitted through the

rams. The port ram has moved aft, and the

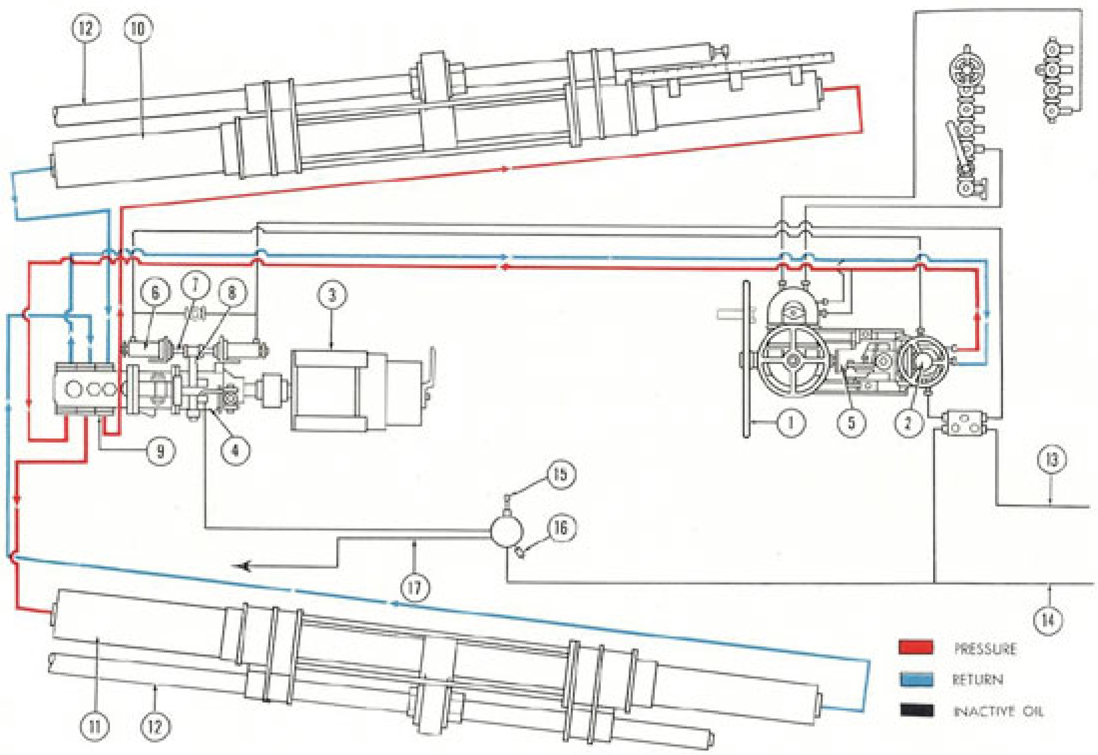

Figure 4-25. Operation diagram of steering system, by HAND.
1) Main steering wheel; 2) change valve; 3) electric motor, 15-horsepower, speed 440 revolutions per minute; 4) motor-driven Waterbury A-end pump; 5) telemotor; 6) control cylinder; 7) control cylinder plunger; 8) bell-crank shaft on control cylinder; 9) steering system main manifold; 10) port ram; 11) starboard ram; 12) inboard connecting rods; 13) line to main supply tank; 14) vent and replenishing line to main supply tank; 15) gage; 16) relief valve (48 pounds); 17) vent and replenishing line to stern plane Waterbury A-end pump.

starboard ram has moved forward, driving oil out of the opposite end of their main cylinders, back through the manifold (9) into the return port of the motor-driven Waterbury A-end pump, completing its cycle.

4C3. HAND steering. a. Explanation of the diagram. Figure 4-25 shows he coordinated action of the system during HAND steering. Direction

much farther to achieve the same degree of rudder deflection.)

Its motion is transmitted through the gear box to the telemotor pump (5) which drives oil under pressure through the change valve to one of the auxiliary power ports in the manifold (9), into the forward end of the port ram (10) and the after end of the starboard ram (11). The port ram moves aft, the starboard ram moves forward and the connecting rods (12),

of oil flow for right rudder is shown by arrow's. In HAND steering, the entire steering action is accomplished by oil pressure developed in the telemotor pump by the steersman's turning of the main steering wheel. The supply side of the line is shown in red, the return side in blue. Areas and lines inactive during HAND steering are shown in black. All colors and directions shown are for right rudder. For left rudder, or a return to a smaller angle of right deflection, all arrows would point in the opposite direction, and colors would be reversed. Refer to each index number on the diagram as it occurs in the text.

b. Operation of the system on HAND power. The steering wheel (1) is locked into its shaft by the locking pin. The retractable hand grip is unfolded for use, at a right angle to the rim.

The pump control lever on the telemotor pump is set at HAND and locked there by the locking screw.

The change valve (2) is also set at HAND.

The clutch handle is down.

The steering manifold (9) hand cut-out and ram cut-out valves are OPEN.

The motor (3) and Waterbury pump (4) are OFF.

The system is now ready for operation by HAND.

The submarine is steered from the control room-by turning the pulled in opposite directions, swing the crosshead and rudder to the right.

The steersman continues to turn the wheel to the right until the rudder indicator shows 20 degrees right rudder.

It is essential to understand that, in the operation by HAND just described, the telemotor pump takes the place of the motor driven Waterbury speed gear, supplying the hydraulic power to actuate the rams and move the rudder.

But we have not yet followed the movement of oil in the system to the completion of its cycle.

The path of the oil has previously been traced from the hand-rotated telemotor pump until it reached and actuated the rams. When the port ram has moved aft and the starboard ram has moved forward, the oil is driven out of the opposite ends of their main cylinders, back through the manifold (9), out through the other auxiliary power port, back through the change valve, and into the return port of the telemotor, completing its cycle.

4C4. EMERGENCY steering. a. Explanation of the diagram. Figure 4-26 shows the coordinated action of the system during emergency steering. Direction of oil flow for right rudder is shown by arrows. In emergency steering, the entire steering action is accomplished by oil at high pressure from the emergency lines of the main hydraulic system. The supply side of the line is shown in red, the return side in blue. Areas and lines inactive during EMERGENCY

large main wheel right or left. Let us suppose the submarine is running on a straight course, the rudder indicator showing zero degrees deflection. The steersman receives the order, "Right, 20 degrees rudder." He turns the wheel to the right. (The wheel is much harder to turn under HAND than under POWER, and must be turned

steering are shown in black. All colors and directions shown are for right rudder. For left rudder, or a return to a smaller angle of right

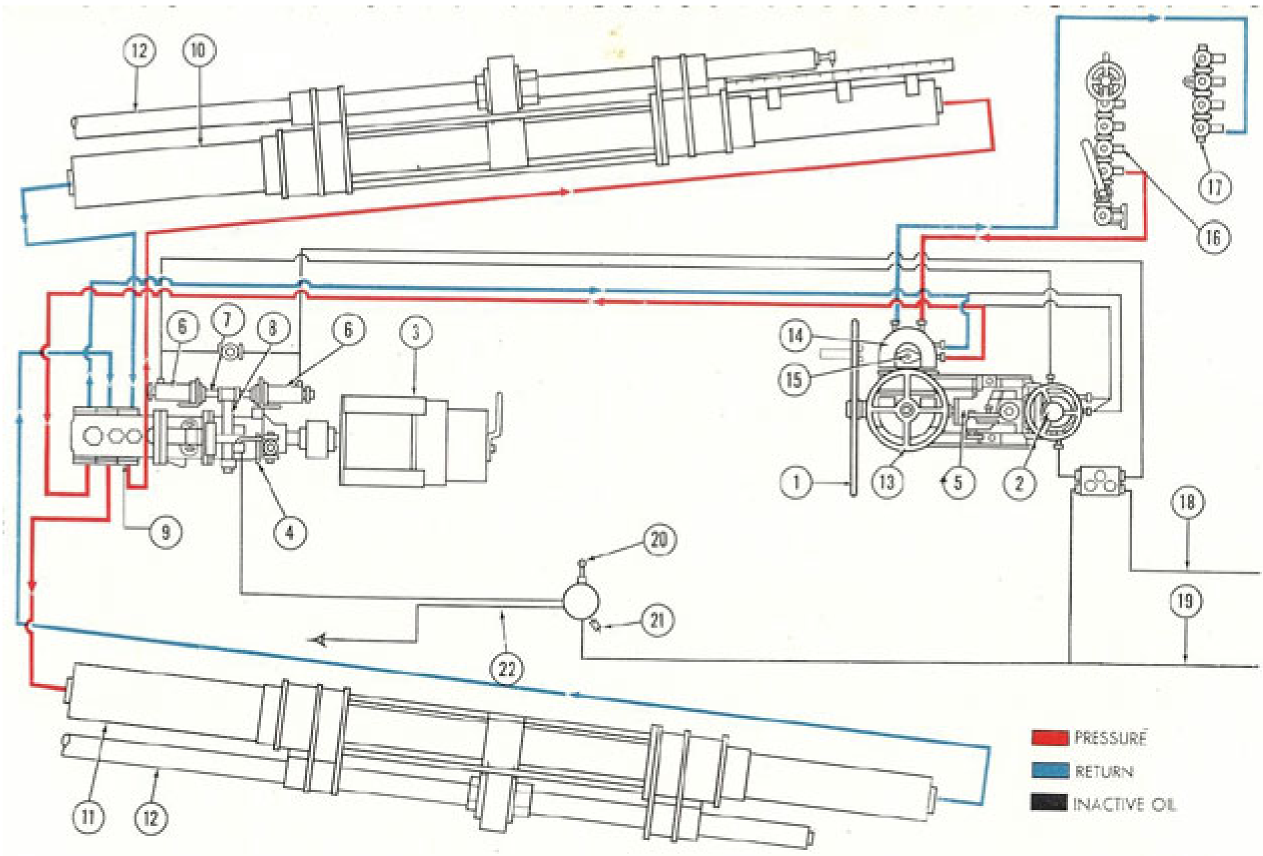

Figure 4-26. Operation diagram of steering system, by EMERGENCY. 1) Main steering wheel; 2) change valve; 3) electric motor, 15-horsepower, speed 440 revolutions per minute; 4) motor-driven Waterbury A-end pump; 5) telemotor; 6) control cylinder; 7) control cylinder plunger; 8) bell-crank shaft on control cylinder; 9) steering system main manifold; 10) port ram; 11) starboard ram; 12) inboard connecting rods; 13) emergency steering wheel; 14) spur gears; 15) emergency control valve shaft; 16) main supply manifold, main hydraulic system; 17) main return manifold, main hydraulic system; 18) line to main supply tank; 19) vent and replenishing line to main supply tank; 20) gage; 21) relief valve (48 pounds); 22) vent and replenishing line to stern plane Waterbury A-end pump.

deflection, all arrows would point

then flow through the emergency

in the opposite direction, and colors would be reversed. Refer to each index number on the diagram as it occurs in the text.

b. Operation of the system on EMERGENCY power. The steering wheel (1) is disconnected from its shaft by pulling out the locking pin in the hub, and then pulling the wheel aft, disengaging it from the clutch jaw on the drive shaft. The locking arm underneath the wheel is pulled up to a horizontal position to hold one of the wheel spokes in its fork, and locked in that position by inserting the pin under it.

The change valve (2) is set at EMERGENCY.

The clutch handle (1, Figure 4-15) is up, the locking bar arm (9, Figure 4-15) is pulled out and turned, allowing the shaft of the emergency control valve to be turned.

The motor (3, Figure 4-26) is OFF.

The steering manifold (9) hand cut-out and ram cut-out valves are OPEN.

The emergency steering valves in the main hydraulic system main supply and return manifolds (16 and 17) are now opened (see Chapter 3).

The system is now ready for operation on EMERGENCY.

The submarine is steered from the control room by turning the small emergency hand wheel (13). Let us suppose the submarine is running on a control valve to the manifold (9), into the forward end of the port ram (10) and the after end of the starboard ram (11). The port ram moves aft, the starboard ram moves forward; the connecting rods (12) swing the crosshead and rudder to the right.

But we have not yet followed the movement of oil in the system to the completion of its cycle. We have already traced the path of the oil from the main hydraulic system until it reached and actuated the rams. When the port ram has moved aft and the starboard ram has moved forward, the oil is driven out of the opposite ends of the main cylinders, back through the manifold (9) into the return port of the emergency control valve, and out into the return line to the main hydraulic return manifold, completing its cycle.

WARNING. It is necessary to turn the change valve to EMERGENCY before operating the emergency control valve. Turning the change valve to EMERGENCY blanks off all lines except the bypass ports around the telemotor pump, and thus protects the rest of the equipment from the effects of the sudden entrance of oil at a pressure of 600 pounds to 700 pounds per square inch. Oil under high pressure will actuate various moving parts accessible to it, motorize pumps, and may cause various sudden, and possibly dangerous, results to apparatus or personnel. Disconnecting the main steering wheel when changing the system over to EMERGENCY, is an added precaution.

straight coarse, the rudder indicator showing zero degrees deflection. The steersman receives the order, "Right 20 degree rudder." He turns the emergency steering wheel to the left.

Its motion is transmitted through the spur gears (14) to the emergency control valve shaft (15). This turns the nonrising stem inside the valve, raising the sleeve and opening the channel from the pressure line of the main hydraulic system to one of the lines leading to the auxiliary power ports on the steering system main manifold (9).

Oil from the main hydraulic system will

4C5. Steering from the conning tower. The conning tower has its own steering wheel connected to the steering stand in the control room by a vertical shaft (see 7, Figure 4-9). Any of the three methods described (POWER, HAND, or EMERGENCY) is available from the conning tower wheel, depending on the position of the clutch. For POWER or HAND steering from the conning tower, the clutch handle should be up (see Figure 4-15). For EMERGENCY steering from the conning tower, the clutch should be down (see Figure 4-17).

5
BOW AND STERN PLANE SYSTEMS

A. INTRODUCTION

5A1. General. Hydraulic power is used to tilt the bow and stern planes. Each system (bow and stern planes) has its own power supply system. Except in emergencies, the power facilities of each system are adequate for its own individual operation independent of power from the main hydraulic system.

The control units for diving and rising are assembled in a diving control stand, located in the control room. There is a set of controls for stern plane tilting, a set for bow plane tilting, and a control valve for bow plane rigging. The control panel also has diving indicators, gages, and motor switches.

Three methods of plane tilting are available at the control panel, based on three different sources of hydraulic power. They are designated as follows:

a. POWER, in which power is developed independently in each plane tilting system by the motor-driven Waterbury A-end pump be longing to that system.

b. HAND, in which power is developed in the telemotor pump, connected to each system, by the manual efforts of the diving stand operator.

c. EMERGENCY, in which power is obtained from the main hydraulic system.

EMERGENCY is used only when the normally used POWER fails. HAND is employed when the other two sources are in operative, or when silent operation of the submarine is necessary to prevent detection by the enemy.

In addition to bow and stern plane tilting, this chapter also contains a description

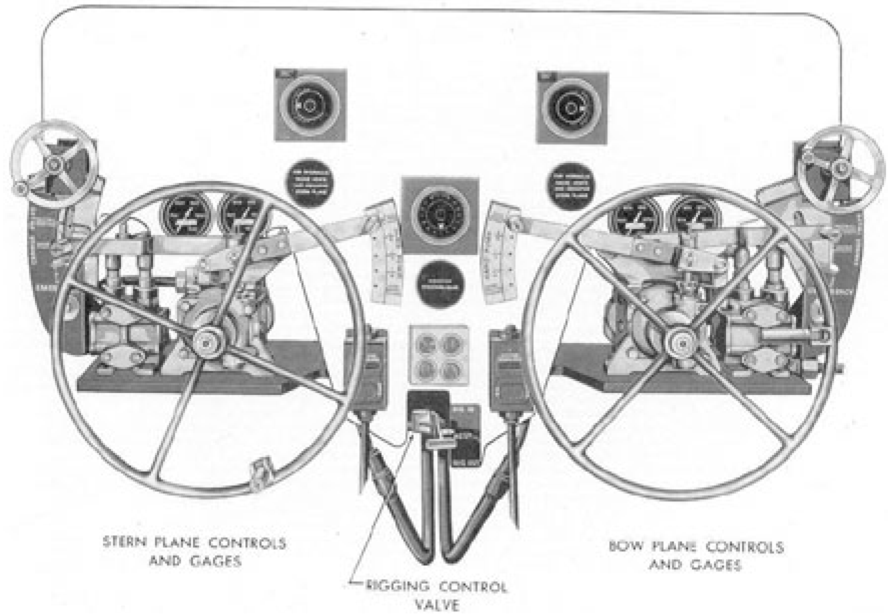

Figure 5-1. Diving control stand.

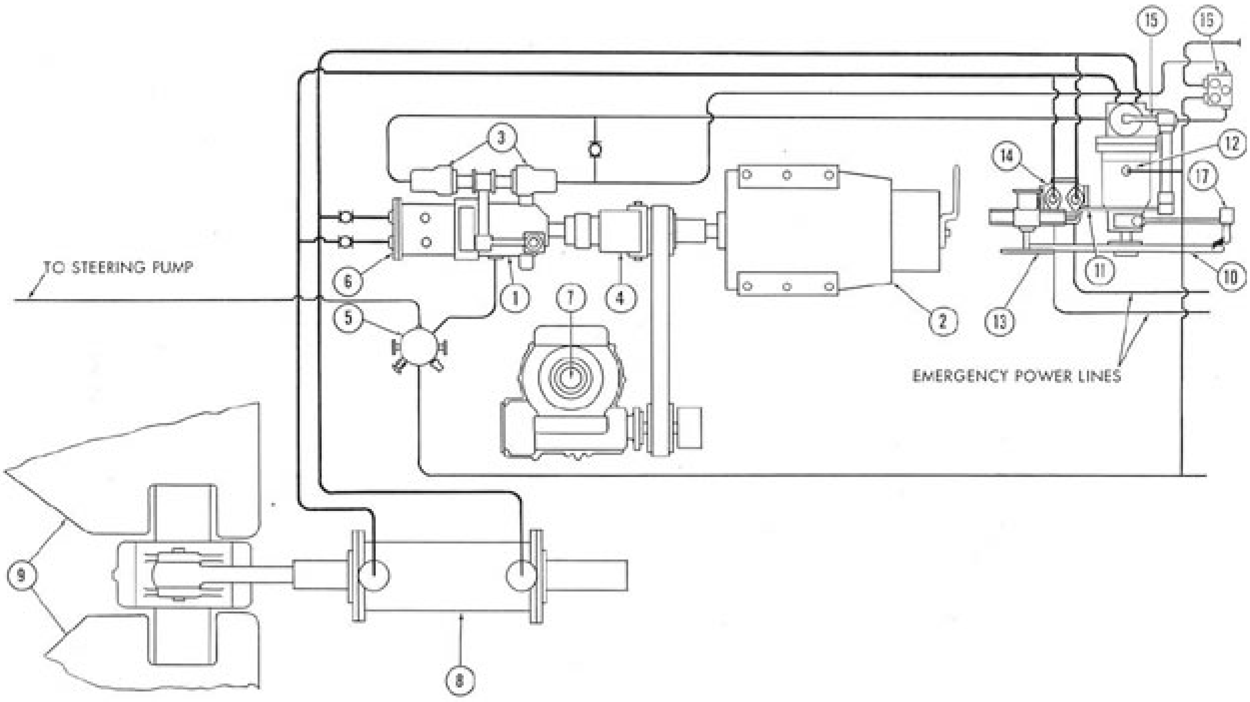

Figure 5-2. Piping diagram of stern plane system.
1) A-end pump; 2) motor; 3) control cylinder; 4) clutch; 5) vent and surge tank; 6) relief valve manifold; 7) capstan gear; 8) main cylinder; 9) stern planes; 10) main diving wheel; 11) change valve handle; 12) telemotor pump; 13) emergency control wheel; 14) emergency control valve; 15) change valve; 16) vent and replenishing manifold; 17) pump-stroke setting lever.

of bow plane rigging and forward windlass-and-capstan operation. Although they derive their hydraulic power from the in connection with the main hydraulic system.

A schematic view of the bow and stern plane systems and their

main hydraulic system, they are very closely associated with bow plane tilting and are, therefore, described in the bow plane system instead of associated equipment is illustrated in Figure 7-3 at the back of the book.

B. STERN PLANE SYSTEM

5B1. General arrangement. The units of the stern plane system fall conveniently into three groups:

a. The control units at the diving control panel, consisting of handwheel, telemotor pump, change valve, and emergency control valve.

b. The power supply system, consisting of a Waterbury A-end pump, the motor which drives it, the control cylinder, and two pressure relief valves.

c. The main cylinder and planes assembly, consisting of the hydraulic cylinder, the piston, the piston rod, the guide cylinder and guide piston, and the tiller which tilts the planes.

Figure 5-2 shows the units of the stern plane system in their proper schematic arrangement. It also includes miscellaneous equipment which will be described in detail in the following paragraphs.

The power and control units of the stern plane system are practically identical with the corresponding units of the steering system and hence, in the discussion which follows, frequent reference is made to illustrations of the steering system in Chapter 4. and their structure and functioning will be more clearly understood if frequent reference is made to the detailed description of parts in Section 4B2b. Similarities and differences are pointed out as they occur.

1. The control panel. One immediate difference to be seen between steering and diving plane controls is that the diving plane controls are all located on the front of a single panel; the various valves and units themselves are mounted behind the panel. Figure 5-3 is a front view of the stern plane half of the panel; Figure 5-4 shows the rear view.

2. The telemotor pump. The main wheel (1, Figure 5-3) rotates the telemotor pump (2) as on the steering stand. The function of the telemotor pump, as in the corresponding steering unit, is to drive hydraulic oil at low-pressure to one side or the other of the control cylinder, for POWER operation, or directly to one side or the other of the ram for HAND operation.

Like the steering stand telemotor pump, the diving stand telemotor pump has a one direction, variable-angle tilt-box. However, the control shaft on the steering stand telemotor pump has only two settings, POWER and HAND, while the control shaft on the diving stand may, theoretically at

5B2. Detailed description. a. The diving control stand. Both the bow and the stern diving planes are operated from the diving control stand Figure 5-1. Stern plane controls occupy the after half of the stand and bow plane controls occupy the forward half. The bow plane rigging control valve is at the bottom center of the panel on certain classes of submarines. We shall concern ourselves exclusively here with the location of control units for the stern plane system.

A schematic layout of the system as a whole is shown in Figure 5-2. Its control units correspond with those of the steering system,

least, be set at any angle from ZERO stroke to FULL stroke, as shown by the pointer at the end of the pump-stoke setting lever (3), and read directly on the indicator dial (4).

In practice, the internal arrangement of the control shaft is such that it can never be set at absolute ZERO, that is, with the tilt-box at neutral, since some hydraulic power must be instantly available to the operator. To operate it at FULL stroke would take more physical strength than a normal man possesses.

This lever is usually set between 1/4-stroke for POWER operation and 3/4-stroke for

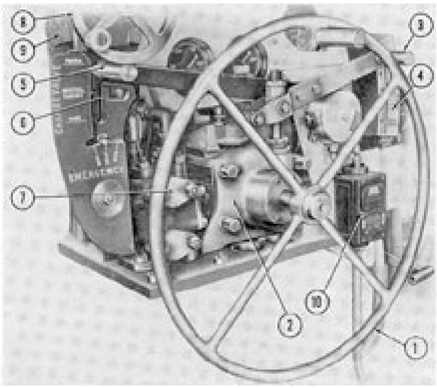

Figure 5-3. Front view of diving control stand (stern plane).
1) Stern plane main wheel, POWER and HAND; 2) stern plane telemotor; 3) stern plane pump stroke setting lever; 4) indicator dial pump-stroke setting; 5) stern plane change valve lever; 6) stern plane change valve mechanical interlock; 7) stern plane emergency control valve; 8) stern plane emergency control valve handwheel; 9) stern plane emergency control valve

supply side of the line is shown in red; from the stern plane telemotor, in blue.

Note that in the EMERGENCY position the piston completely blanks off all lines entering the valve body. The purpose of this position is to prevent the high pressure oil from the main hydraulic system (used in emergency control) from reaching the telemotor pump and motorizing it, with consequent danger to equipment or personnel.

4. The emergency control valve. When the change valve lever (5, Figure 5-3) is set at EMERGENCY-NEUTRAL, its position in the cross-shaped groove of the mechanical interlock (6) permits the planes to be operated by the emergency

quadrant gear; 10) stern plane motor switch.

HAND operation, depending on the strength of the operator.

3. The change valve. The function of the change valve on the diving stand is exactly the same as that of the corresponding unit on the steering stand. It allows the operator to select any one of the three available methods for controlling, the diving planes POWER, HAND, or EMERGENCY.

The only difference in internal structure of the two change valves is that on the diving stand the piston is moved up and down directly by the action of a lever instead of having a movable sleeve threaded into a revolving stem. It is operated, through linkage, by the change valve lever (5, Figure 5-3). A pointer at the hand end of this lever indicates the valve setting on the indicator plate of the change valve mechanical interlock (6).

The diagram, Figure 5-5, shows the change valve successively in all three positions: POWER, HAND, and EMERGENCY. The ports marked (1) go to opposite sides of the telemotor pump; those marked (2) go to the control cylinder; those marked (3) go to the ram. Active oil from the main power

control valve (7). This valve has the same function as the corresponding unit on the steering stand; it permits flow of hydraulic power from the main hydraulic system (in the event of failure of normal power) and directs it to one side or the other of the ram. The valve is operated by the emergency control valve handwheel (8) which,

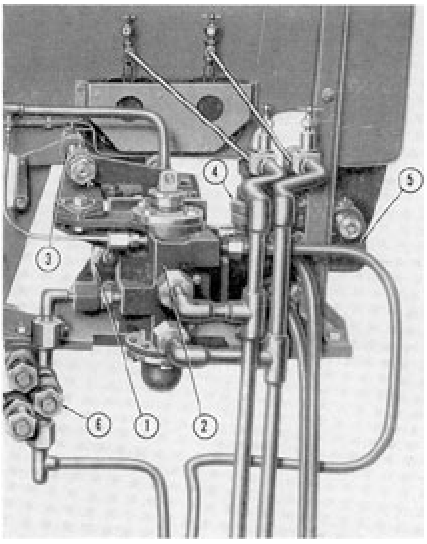

Figure 5-4. Rear view of diving control stand (stern plane).
1) Stern plane telemotor; 2) stern plane change valve; 3) stern plane change valve linkage; 4) stern plane emergency control valve; 5) stern plane emergency control valve linkage; 6) stern plane vent and replenishing valve manifold.

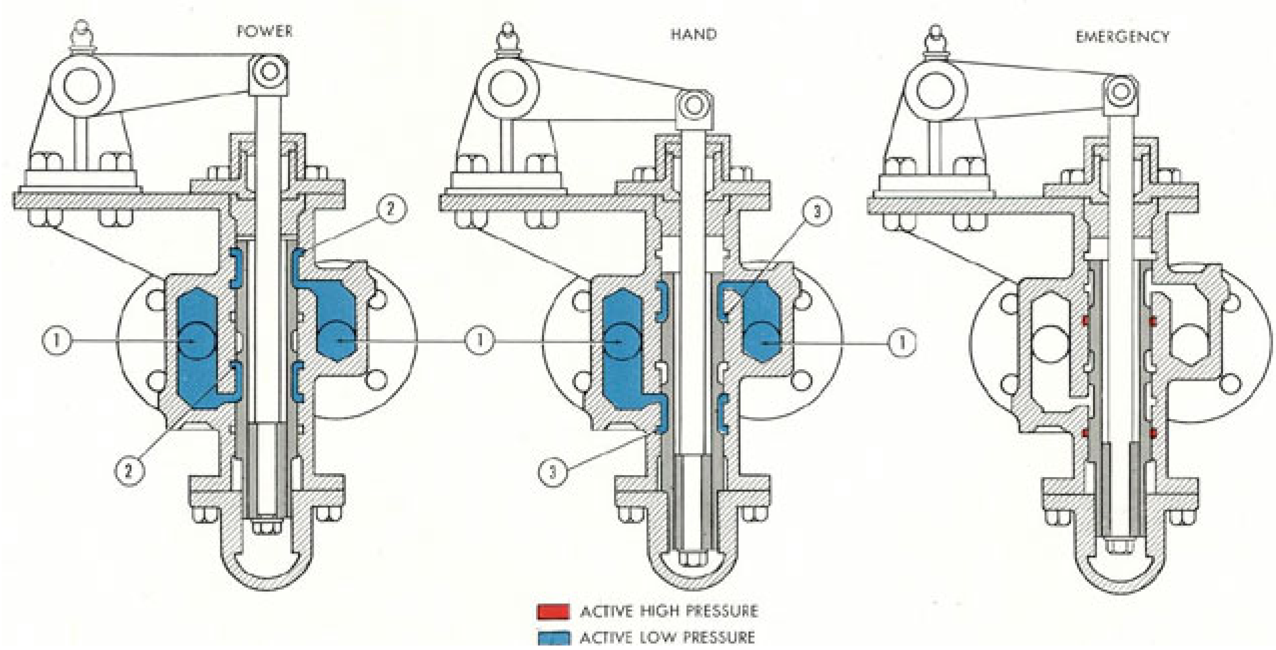

Figure 5-5. Change valve in three positions. 1) To telemotor; 2) to control cylinder; 3) to ram.

when turned, moves the quadrant gear (9), and this in turn moves the emergency control valve piston in or out.

Figure 5-6 shows the emergency control valve successively in its three positions. The only difference in internal structure is that here the piston is moved in and out directly by the action of a lever, while on the steering stand unit it is a movable sleeve threaded into a rotating stem. The ports (1 and 2) go to the main hydraulic system; the ports (3 and 4) go to opposite ends of the ram, or actuating cylinder. Oil from the supply line of the main hydraulic system is shown in red; from the return side in blue. Direction of flow is shown by arrows.

5. Rear view of panel. A rear view of the same section (stern plane controls) of the control panel is shown in Figure 5-4. Shown here are some of the units of which emergency control valve (4) can be seen, as well as its piston and linkage (5), which are moved by the quadrant gear seen in the front view. The vent and replenishing valve manifold is shown at (6).

b. Power supply system. 1. The Waterbury A-end pump. In normal operation, the hydraulic power is developed by a Waterbury A-end pump driven by a 7.1 horsepower electric motor at a constant speed of about 440 revolutions per minute.

This pump is identical with the A-end pump used in the steering system. It rotates in a clockwise direction as viewed from the motor end of the shaft. The speed and direction of oil delivery for the actuation of the main piston vary according to the angle of the tilt-box which is governed by the action of the control cylinder.

2. Control cylinder. As in the steering system, the angle of the

only the control handles are visible in the front view (Figure 5-3). Only part of the telemotor pump (1) can be seen. At its end is mounted the change valve (2) whose piston and linkage (3) connect to the change valve hand lever on the front of the panel. A portion of the tilt-box is determined by the action of the control cylinder (see Figure 5-7) which raises or lowers the control shaft of the A-end pump. Oil under pressure is directed from the telemotor pump to either side of the control cylinder (1) through the

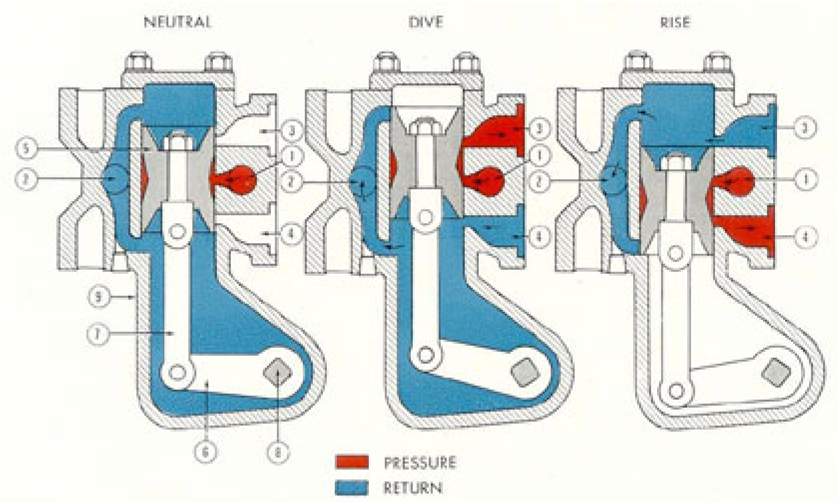

Figure 5-6. Emergency control valve in three positions.
1) Port from supply line, main hydraulic system; 2) port from return line, main hydraulic system; 3) port from stern plane ram, forward end; 4) port from stern plane ram, after end; 5) spool valve; 6) arm; 7) link; 8) shaft; 9) valve body.

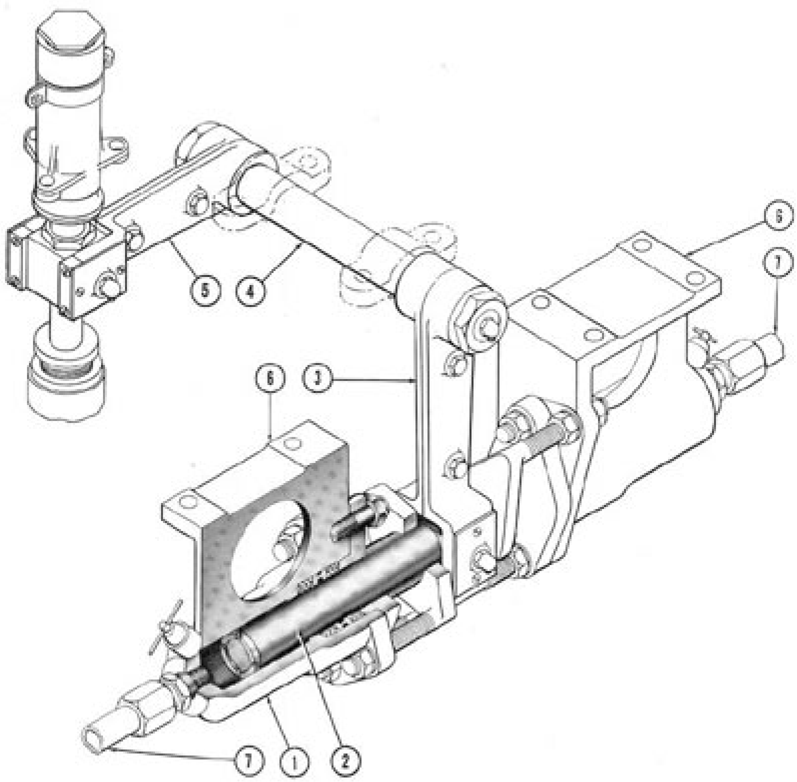

Figure 5-7. Cutaway of control cylinder.

1) Cylinder; 2) piston; 3) bell crank; 4) crankshaft; 5) pump control arm; 6) mounting bracket; 7) port.

ports (7) and act's against the piston (2). Displacement of the piston causes sidewise movement of the bell crank (3), which is transmitted to the pump control arm (5). The control shaft is attached directly to the tilt-box of the A-end pump so that the amount and direction of the-oil pumped by the A-end pump are determined by the action of the control cylinder. Thus far, this is similar in operation to the steering control cylinder. One difference may be seen in Figure 5-7. The centering spring, for returning the control shaft to a neutral position, is installed on the shaft on the same side at which it enters the Waterbury pump housing, instead of on the opposite side as in the steering system. Therefore, this spring is much shorter than that in the steering system installation, to correspond with the shorter travel of the stern plane control cylinder plunger.

3. Relief valves. A relief valve is installed in each line just behind the ports of the Waterbury A-end pump, to prevent excessive pressure from developing in whichever line is functioning as the discharge line, by bypassing the oil back to the suction side of the pump.

c. The ram. The hydraulic power developed by the motor-driven Waterbury A-end pump is transmitted to the stern planes through the ram assembly (see Figure 5-8).

Unlike the steering system, the stern plane system has only a single ram, a cutaway

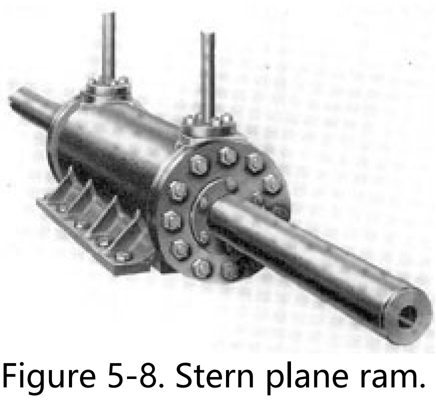

Figure 5-8. Stern plane ram.

view of which is shown in Figure 5-9. It consists of a hydraulic cylinder (1), through which slides a piston rod (2). To move this piston rod, hydraulic pressure is admitted to either one of the two ports (4), forcing the piston (3) to move away from that port. One end of the piston is connected through appropriate linkage to the stern plane tilting gear so that, as the piston moves one way or the other, it will tilt the planes to RISE or DIVE.

The after end of the piston slides through a guide, into which a keyway has been milled. A key attached to the piston shaft acts as a drift stop to regulate piston travel and also to keep the piston shaft, which consists of two separate pieces, from unscrewing in the piston. A pin mechanism which fits into a hole provided in the forward end of the shaft serves

as a drift stop to regulate piston travel.

d. The capstan. The after capstan receives its power from a chain drive directly connected to the 7.1-horsepower electric motor, which also drives the stern plane Waterbury A-end pump. Thus, the power for the capstan does not come from any of the hydraulic units (see Figure 5-2).

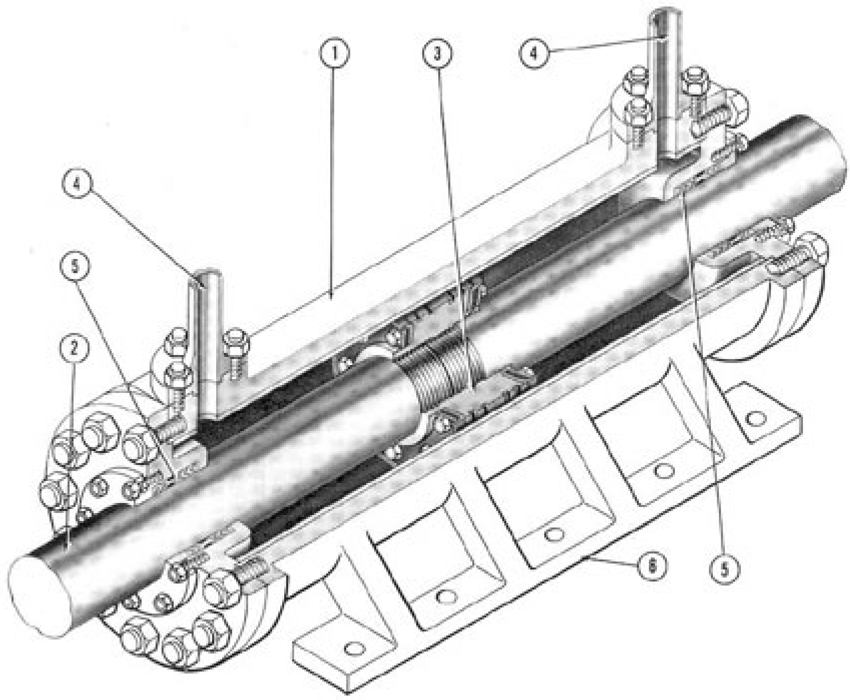

Figure 5-9. Cutaway of stern plane ram.
1) Cylinder; 2) piston rod; 3) piston; 4) pressure port; 5) packing; 6) bracket frame.

When the capstan is to be used, a coupling arrangement provides the means for connecting the chain drive to the motor shaft. This consists of a pair of spring-loaded pins attached to Woodruff keys which have two positions. In the ON position, the keys are engaged in keyways in both the motor-shaft collar and the chain-drive sprocket. In the OFF position, the keys are slid over to one side so that they engage only the motor-shaft keyway, but not the chain-drive

telemotor pump (1), driving oil at low-pressure through the uppermost part of the change valve (2) and into the after end of the control cylinder (3). The piston of the control cylinder moves forward, driving oil through the return line and into the middle port of the change valve, and from there back into the return port of the telemotor pump, completing the pressure-and-return cycle of the oil in the low pressure, or control, system. The control cylinder tilts the tilt-box in the

keyway. This type of coupling does not disconnect the electric motor from the Waterbury A-end pump. On later classes of submarines, this clutch has been eliminated, since the chain is removed whenever the capstan is not being used.

5B3. Operation. a. Power operation. Figure 5-10 illustrates the operation of the stern plane system as a whole for tilting the planes to RISE by POWER. The pressure side of the line is shown in red, the return side in blue, inactive in lighter red, and the direction of flow is indicated by arrows.

The main wheel turns the shaft of the motor driven A-end pump (4) which delivers oil at high pressure to the after end of the ram (5), moving the ram forward and forcing oil out of the other side of the ram and back to the return port of the Waterbury A-end pump. This completes the pressure-and-return cycle in the high pressure system. The forward motion of the ram, through the linkage, tilts the stern plane to RISE. When the planes are tilted to DIVE, the flow of oil is in the opposite direction and the pressure side becomes the return side.

b. Emergency operation. To operate by, EMERGENCY power, the change valve (2)

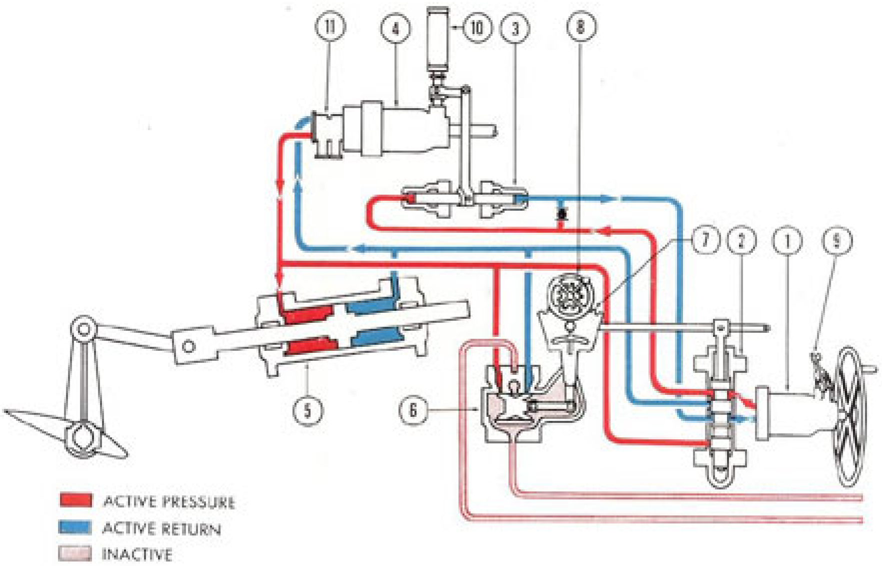

Figure 5-10. Flow diagram of stern plane system.
1) Telemotor; 2) change valve; 3) control cylinder; 4) motor-driven Waterbury A-end pump; 5) ram assembly; 6) emergency control valve; 7) quadrant gear; 8) emergency control handwheel; 9) pump-stroke control lever; 10) centering spring; 11) relief valve manifold.

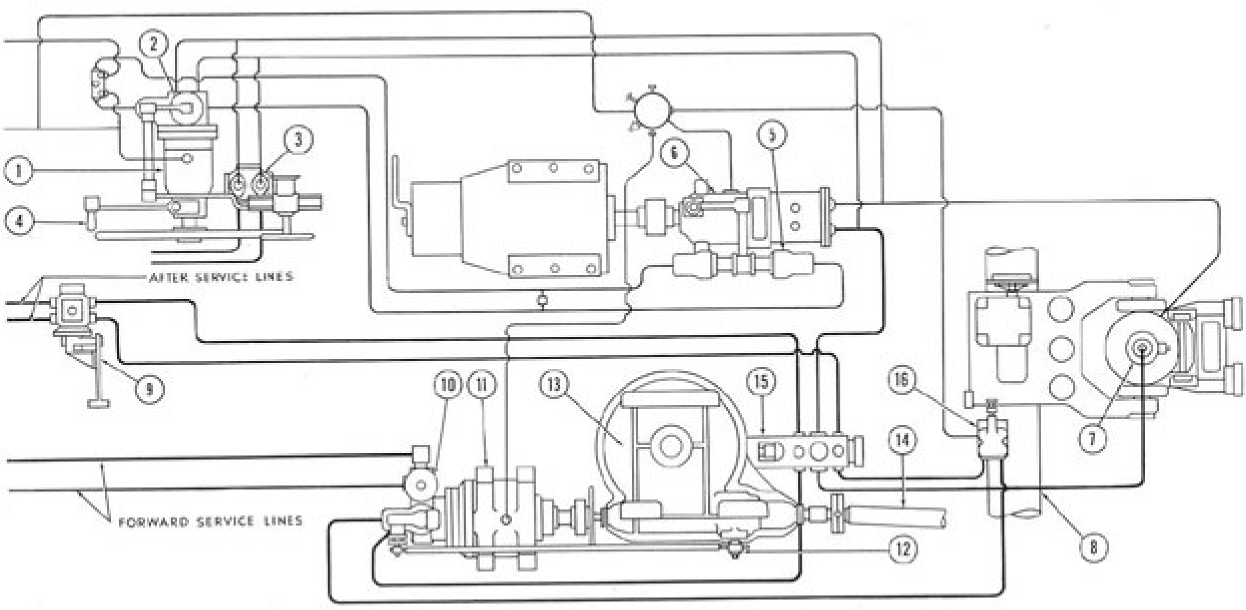

Figure 5-11. Piping diagram of bow plane system.
1) Telemotor; 2) change valve; 3) emergency control valve; 4) pump-stroke control lever; 5) control cylinder; 6) motor-driven Waterbury A-end pump; 7) hydraulic cylinder; 8) plane stock; 9) rigging control valve; 10) windlass-and-capstan control-and-change valve; 11) Waterbury No. 10 B-end hydraulic motor; 12) rigging windlass-and-capstan clutch; 13) rigging gear box; 14) shaft to windlass-and-capstan; 15) rigging interlock; 16) tilting interlock.

is set at NEUTRAL-EMERGENCY. This blanks off the lines from the telemotor pump (1) so that high pressure oil cannot reach and motorize it. At the same time it also places the change valve hand lever in the horizontal slot of the quadrant gear (7). The emergency control handwheel (8) can now turn the quadrant gear left or right, moving the spool of the emergency control valve (6). This admits high pressure oil from the main hydraulic system directly to one side or the other of the ram (5), tilting the stern planes to RISE or DIVE.

c. Hand operation. For hand operation, the change valve (2) is set at HAND. This opens the lines from the telemotor pump (1) directly to the ram (5). The pump stroke lever (9) is set for a fuller stroke (the exact setting depending on the operator's strength), increasing the angle of the telemotor pump tilt-box, so that more oil will be driven through the lines for each turn of the wheel. When the main wheel is turned to RISE or DIVE, the telemotor pump delivers oil directly to one side or the other of the ram (5), instead of to the control cylinder as in the POWER operation. The movement of the ram tilts the stern planes to DIVE or RISE.

C. BOW PLANE SYSTEM

5C1. General. The bow plane tilting system is operated from the same control board as the stern planes (see Figure 5-1). From the control panel to the power supply units, the bow plane tilting system is identical with the stern plane system in equipment and operation. This includes all diving control units, A-end pump and motor, control cylinder, and pressure relief valves. But beyond this point there are important differences in the two systems.

The hydraulic cylinder assembly differs in that in the bow plane system the cylinder moves and the piston is stationary, which is the reverse of the arrangement for the stern plane system.

In addition to the tilting mechanism, the bow planes are also equipped with a rigging mechanism, which pulls them flush against the sides of the boat, or extends them to their normal operating position. Since it might damage the planes to rig them in while tilting at any considerable angle there must also be interlocks which automatically prevent rigging and tilting at the same time. The rigging mechanism receives its power from the main hydraulic system. However, because it functions as an essential unit of the bow plane controls, it is more convenient to describe it as part of the bow plane system.

The forward windlass-and-capstan operating gear, which also receives power from the main hydraulic system, is described in this section, since it is mechanically connected, through a clutch, with the rigging mechanism.

Figure 5-11 shows a general schematic diagram of the layout of units in this system.

5C2. Detailed arrangement. a. The tilting mechanism: power and control. As indicated, Waterbury A-end pump power supply and controlling, devices for the bow plane tilting system are identical with those of the stern

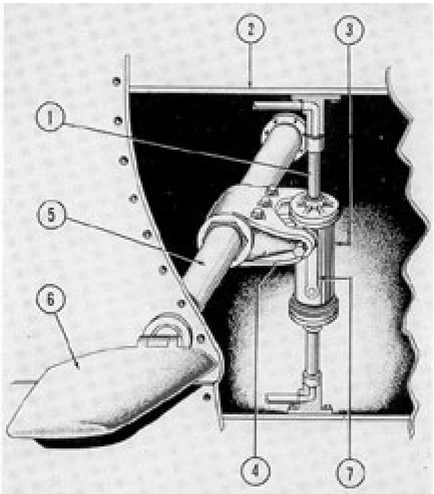

Figure 5-12. Ram and filler assembly.
1) Piston rod; 2) overhead frame; 3) hydraulic cylinder; 4) filler; 5) plane stock; 6) bow plane; 7) linkage.

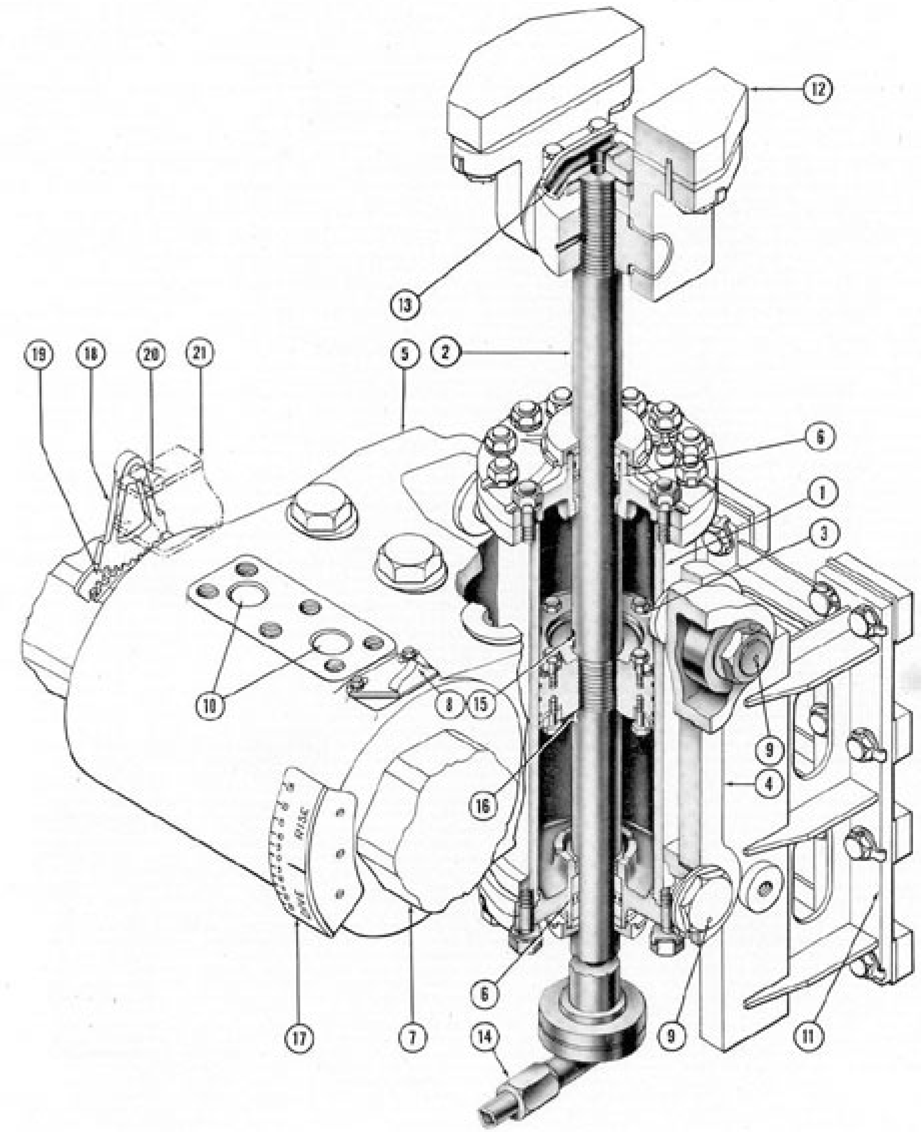

Figure 5-13. Cutaway of bow plane ram.
1) Hydraulic cylinder; 2) piston rod; 3) piston head; 4) linkage; 5) tiller; 6) packing; 7) plane stock; 8) cam; 9) link pins; 10) taper pin holes; 11) cylinder guide bearing; 12) securing pad; 13) port to piston rod; 14) port to piston rod; 15) port to top of piston head; 16) port to bottom of piston head; 17) hub indicator dial; 18) sector gear; 19) quadrant gear; 20) angle transmitter shaft; 21) electric angle transmitter box.

plane system just described (see Section 5B2). The bow plane tilting controls occupy the forward half of the control board (see Figure 5-1).

b. Cylinder and planes assembly. In the stern plane system, the cylinder is fixed, or stationary, from the top of the piston rod down to a point just above the piston. This hole leads into two ports, the edge of one of which (15) is shown just above the piston head (3). Another hole exactly like it (shown in the "broken" portion of the rod near the bottom of this view) leads from the bottom of the

and the piston moves. In the case of the bow planes (see Figure 5-12), the piston rod (1) is fixed to the overhead frame (2) and the cylinder (3) slides up and down on it. A heavy double crank, connected through linkage (7) to the body of the cylinder, serves as the tiller (4) which, through the stocks (5), tilts the bow planes (6).

Figure 5-13 shows a cutaway of the bow plane mechanism. The stationary piston rod (2) has a hole lengthwise through its center, piston rod to similar ports, one of which (16) can be seen under the piston head. The pressure fittings (13 and 14) go to the hydraulic pressure lines. Oil enters at either of these fittings and goes through the hole and out the ports on either side of the piston head, forcing the cylinder (1) to slide

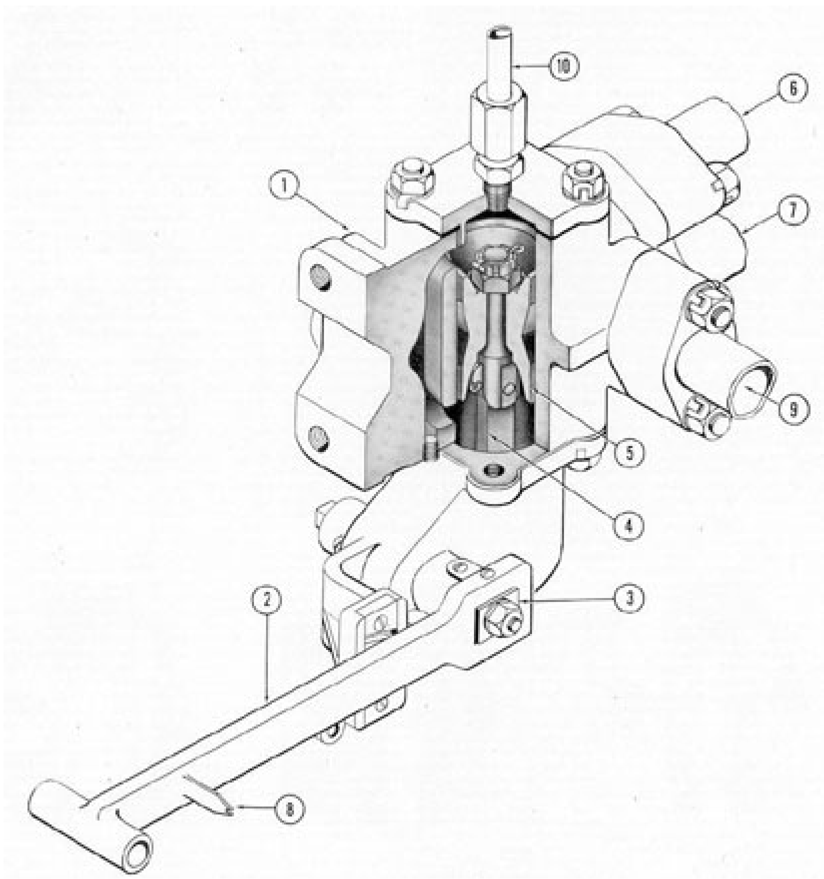

Figure 5-14. Cutaway of rigging control valve.
1) Valve body; 2) hand lever; 3) shaft for hand lever; 4) link; 5) spool valve; 6) port to B-end motor; 7) port to B-end motor; 8) position pointer; 9) supply port from after service line; 10) vent line.

up or down. The linkage (4) moves the tiller (5), into the hub of which are fastened the bow plane stocks (7). The cam (8) connecting link (4), moves the spool valve (5) up and down, admitting pressure from the main hydraulic system through the

serves to actuate the tilting interlock, which is described in the next section. The holes (10) are for taper pins (not shown) to hold the tiller shaft firmly in place inside the hub.

The hub indicator dial (17), graduated in degrees, shows the angle of rise or dive of the bow planes. A quadrant gear (19) is bolted to the bow plane stock. This engages with a sector gear (18), suspended from an angle frame. The position of the sector gear and planes is transmitted electrically to an indicator on the diving control stand, providing the operator with a continuous indication of the tilt of the bow planes.

c. The rigging mechanism. To bring the bow diving planes flush to the hull, when not actually in use, a mechanism is provided which will rig them in. This mechanism consists of two heavy connecting rods actuated, through suitable linkage and gear trains, by a Waterbury B-end motor in the forward torpedo room and controlled by a rigging control valve located at bottom center of the diving control board in the control room a change valve, and suitable interlocks, to protect the system against operational errors.

Figure 5-14 shows a cutaway view of this rigging control valve which is a spool-type valve. The hand lever (2), through the supply port (9), out through the ports (6 or 7), through the rigging interlock, tilting interlock, and change valve, to the B-end hydraulic motor. The motor used is a No. 10-B Waterbury hydraulic motor, the only B-end motor used on the vessel. A No. 10 Waterbury B-end motor is installed because the power requirements of the heavy rigging gear and the forward windlass-and-capstan exceed the capacity of a No. 5 Waterbury B-end. To rig in, the handle is raised to the RIG IN position; to rig out, it is lowered to the RIG OUT position; the intermediate position is NEUTRAL. The pointer (8) indicates these positions on a name plate (not shown) attached to the control board.

Figure 5-15 shows the internal structure of the rigging control valve in each of its three positions. The port marked (1) is connected to the supply, or pressure, side of the service line of the main hydraulic system; the port marked (2) is connected to the return side. The two ports marked (3) go through the rigging and tilting interlocks to opposite sides of the Waterbury B-end, hydraulic motor. Oil from the supply side is shown in red; oil from the return side in blue. Direction of flow is indicated by arrows.

A diagram of the rigging gear layout as a whole is shown in Figure 5-16. The rigging

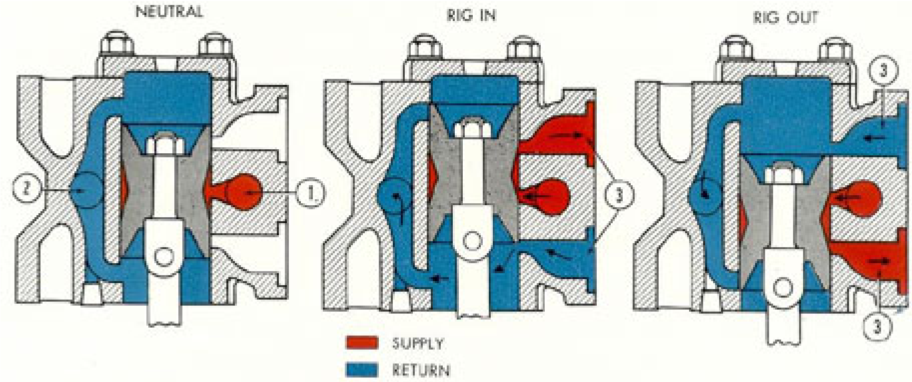

Figure 5-15. Rigging control valve in three positions.
1) From after service line, supply; 2) to after service line, return; 3) to Waterbury B-end hydraulic motor.

control valve (1) receives the power from the after service line (2) and directs this power through the interlocks and change valve (3) to one side or the other of the Waterbury B-end motor (4), causing the shaft (5) to turn in the required direction. The two bevel gear boxes (6) transmit its motion to the upper horizontal shaft (7) where, through a spur gear (8), it is transmitted to the large sector gears (9). These gears pull in or push out the connecting rods (10) which rig the diving planes (11) in or out. Leakage is prevented at the point where the vertical shaft passes through the pressure hull by a brass-lined stuffing box containing 1/2-inch-square rings of flax packing.

The diving planes (11) are connected to the outboard end of the connecting rod by a ball-and-socket joint (12) which permits sufficient lateral rotation to allow for tilting at least 25 degrees in either direction.

d. The rigging and tilting interlocks. If an attempt were made to rig in the planes while tilted, or to tilt them while rigged interlocks are placed in the line through which the hydraulic power must pass on its way to the rigging and tilting mechanisms. They are known as the rigging and tilting interlocks.

The rigging interlock is a three-spool piston valve, mechanically operated by the rigging worm gear, which prevents tilting of the planes until they are fully rigged out. The interlock also acts as a throttle or cut-out, to retard the flow of oil to the Waterbury B-end motor when the planes are almost in the rigged-in or rigged-out position. To allow the rigging sector gears to come against their positive stops gently, the line delivering the pressure oil to the Waterbury B-end motor is completely blocked by the valve when the planes are in the fully rigged-in or rigged-out position.

The tilting interlock is a single-spool valve piston that prevents rigging in of the planes when the planes are on any degree of rise or beyond 15 degrees' dive. It will allow rigging in when the planes are between 0 degrees' and 15 degrees' dive.

in, either the hull or the planes, or both, would be damaged. To prevent this, two valves called

1. The tilting interlock. The line carrying power to rig out the planes must pass

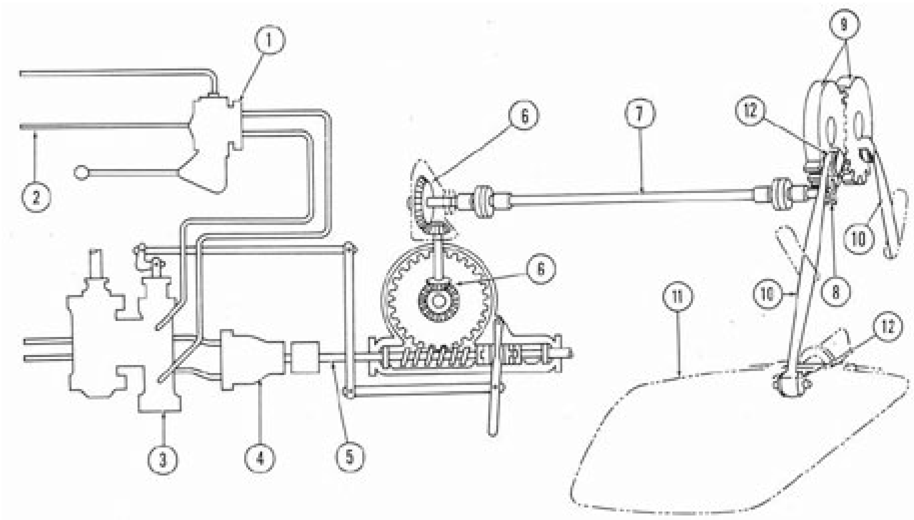

Figure 5-16. Bow plane rigging system. 1) Rigging control valve; 2) after service line; 3) change valve; 4) Waterbury B-end motor; 5) shaft; 6) bevel gear boxes; 7) horizontal shaft; 8) spur gear; 9) sector gear; 10) connecting rods; 11) diving planes; 12) ball-and-socket joint.

through the tilting interlock (see Figure 5-17). When the planes are moving to zero degrees' tilt, the cam (10) on the tiller will raise the roller lever (3), turning the crankshaft (4) to the left which, through the bell crank (5) and link (6) moves the spool valve (2) to the OPEN position, allowing the oil which operates the rigging gear to pass through the valve. However, when the shaft turns in either direction-RISE or DIVE -the high point of the cam moves away from the roller on the roller lever, and a return spring (7) pushes the spool valve back into the CLOSED position, cutting off the line to the rigging gear.

A special feature of this interlock deserves attention. If, while rigged in, the planes should be accidentally knocked out of position by enemy gunfire, depth position just when the need for diving control was most urgent. To provide against such an emergency, a check valve (8) is built into the tilting interlock, which will allow rigging power to pass through even when the spool valve is closed, but only in the rigging out direction.

2. The rigging interlock. The line carrying power to tilt the planes must pass through the rigging interlock (see Figure 5-18). The shackle (3) is connected to an eccentric cam arrangement on the rigging gear drive shaft. When the gear is in the fully rigged-out position, this cam will have pushed the piston valve spool (2) all the way to the right, thereby opening the ports (5) in the tilting line and allowing the power which operates the tilting gear to pass. But with the gear in the rigged-in position, the spool valve (2) will be pulled to

charge, or some other circumstance beyond the control of the operator, the resulting tilt and position of the cam might close the interlock and prevent rigging the planes out into their operating

the CLOSED position, cutting off the ports to the tilting gear oil lines.

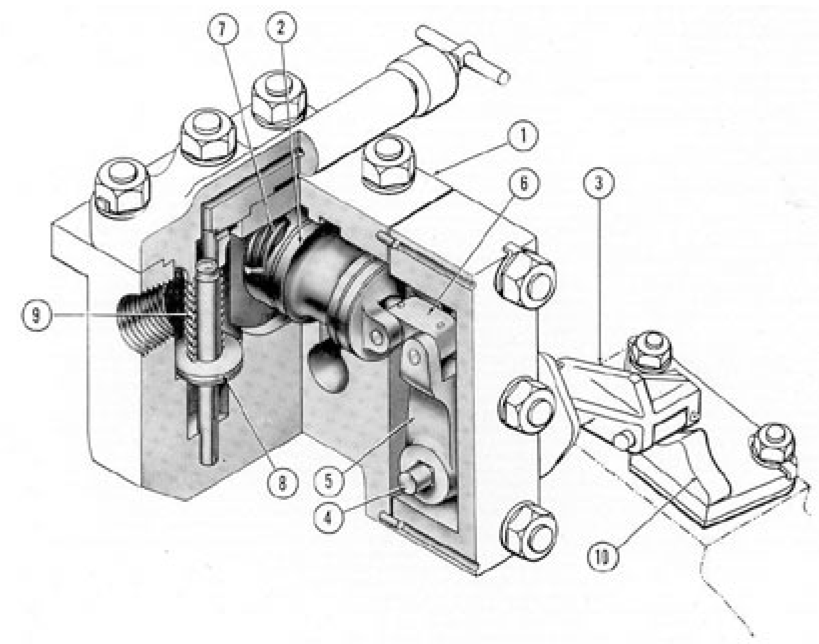

Figure 5-17. Cutaway of tilting interlock.
1) Valve body; 2) spool valve; 3) roller arm lever; 4) shaft; 5) crank lever; 6) link; 7) valve spring; 8) check valve; 9) check valve spring; 10) cam.

The rigging interlock has an additional function. To eliminate the shock of the rigging gear hitting the hard stop at each end while rotating at full power, the rigging lines themselves pass through the rigging interlock in such a way that when the rigging gear is approaching either the fully rigged-in or fully rigged-out position, the rigging power line will be partially closed off by the action of the rigging interlock spool valve, bringing the gear to an easy stop.

The check valves (7, Figure 5-18) allow pressure oil to pass in one direction, RIG IN or RIG OUT. They permit the operation of the

is shown by arrows. Inactive oil is shown in lighter red.

The bow planes are assumed to be between zero tilt and 15 degrees' dive, and the cam on the tiller hub (1) is therefore at its highest point under the lever arm when at zero tilt, holding the spool valve of the tilting interlock (2) in the OPEN position. The handle of the rigging control valve (3) is placed in the RIG OUT position, moving the spool valve up. This allows oil from the supply side of the after service line to enter the control valve at (4) and go out through the line (5), through the rigging interlock (6) whose spool valve is open to permit the RIG OUT pressure to

gear to begin when the cam action upon the spool valve has closed off the rigging lines. As the ports in these lines are then opened by the spool valve, the check valves close again.

e. Operation to rig out. Figure 5-19 shows the direction of flow of hydraulic pressure in the rigging system for rigging out. The pressure side of the line is shown in red, the return side in blue; the direction of flow pass after the planes begin to rig with the initial flow through the check valve. From there it passes in through the right-hand port of the tilting interlock (7) and out of the left-hand port through the windlass-and-capstan and bow plane rigging change valve (8), and into one side of the Waterbury B-end hydraulic motor (9). The pressure oil rotates the motor, turning the

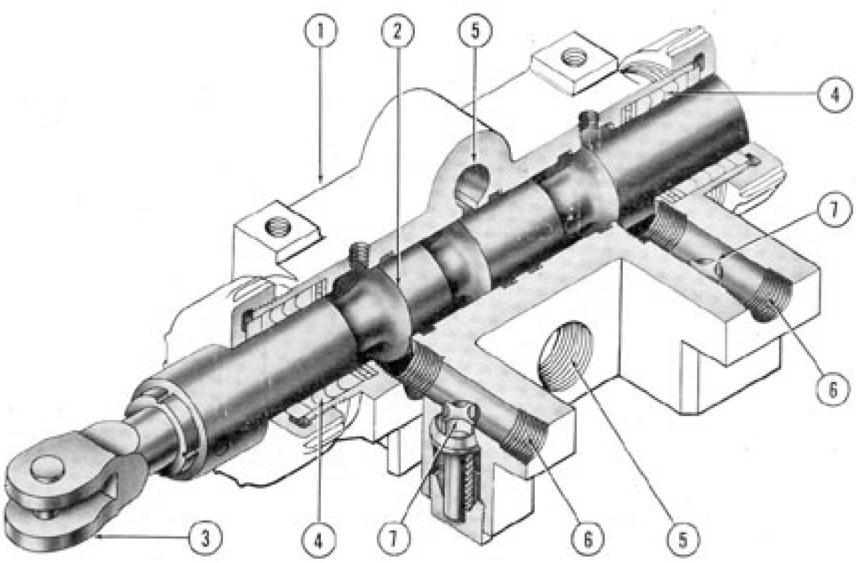

Figure 5-18. Cutaway of rigging interlock.
1) Valve body; 2) spool valve; 3) shackle; 4) packing; 5) ports to tilting lines; 6) ports to rigging lines; 7) check valves.

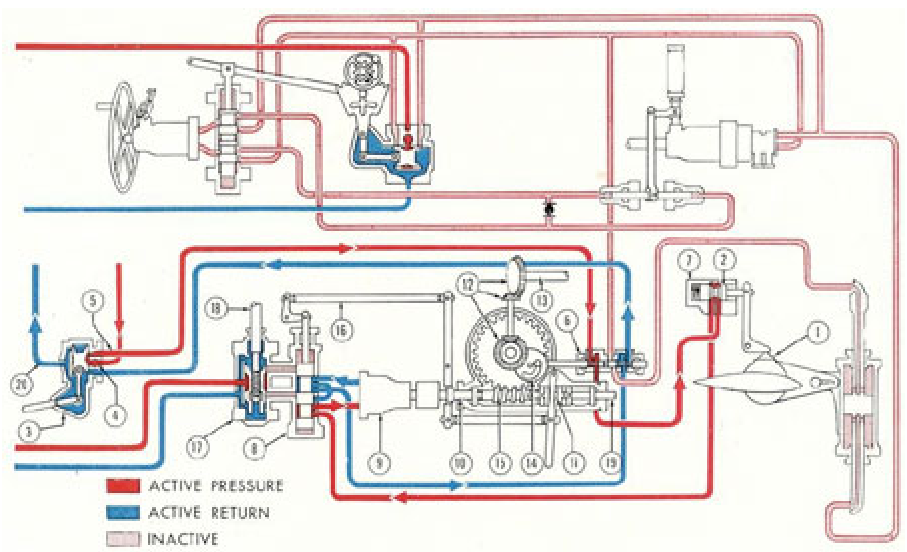

Figure 5-19. Bow plane system in rigging position.
1) Cam on tiller; 2) tilting interlock spool valve; 3) rigging control valve; 4) port,

from supply side, after service line; 5) port, to B-end motor; 6) rigging interlock; 7) tilting interlock; 8) change valve; 9) B-end motor; 10) drive shaft; 11) clutch handle; 12) bevel gears; 13) rigging gear drive shaft; 14) cam to operate rigging interlock; 15) worm and gear; 16) clutch to change valve connecting rod; 17) windlass-and-capstan control valve; 18) windlass-and-capstan control shaft; 19) windlass-and-capstan drive shaft; 20) port, to return side, after service line.

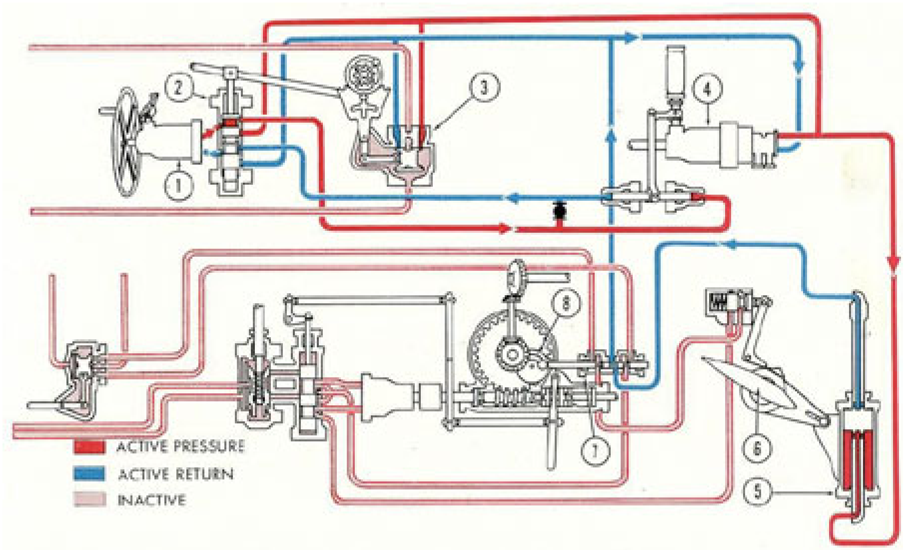

Figure 5-20. Bow plane system in tilting position.
1) Telemotor; 2) change valve; 3) emergency control valve; 4) motor-driven Waterbury A-end pump; 5) hydraulic cylinder; 6) bow plane assembly; 7) rigging interlock; 8) rigging gear interlock cam.

drive shaft (10) whose motion, through the clutch (11), worm gear, and bevel gears (12), is transmitted to the rigging gear shaft (13), thereby rigging out the planes.

Meanwhile, oil from the return port of the B-end motor passes back through the change valve, thence through the rigging interlock (whose spool valve still permits it to pass), to the return side of the rigging control valve, and through its return port (20) to the after return service line. This completes its cycle from the supply manifold to the return manifold of the main hydraulic system.

the small ports on the underside of the piston rod, into the lower side of the cylinder, causing it to move downward, and tilting the bow plane (6) to DIVE. Meanwhile, oil is driven out of the upper side of the cylinder, through the ports above the piston, thence through the upper end of the piston rod, into the reline. From there it passes through the rigging interlock (7) and back through the opposite side of the relief manifold into the return port (the left port) of the motor-driven Waterbury pump, completing the pressure-and-return cycle in the high pressure system.

When the bow plane is tilted to RISE, the flow of oil is in the opposite direction from that

As the planes approach the fully rigged out position, the rigging interlock spool valve begins to cut off the flow of oil. The B-end motor is slowed down and the sector gears are brought to an easy stop.

f. Operation to dive. Figure 5-20 shows the direction of flow of hydraulic pressure in the bow plane tilting system for DIVE. The pressure side of the line is shown in red, the return side in blue, the direction of flow is shown by arrows. Inactive oil is shown in lighter red.

It is to be assumed that the gear is in the fully rigged-out position, so that the cam (8) which moves the spool valve of the rigging interlock (7) is in a position which will permit oil from the tilting system to pass. The handwheel on the telemotor pump (1) is turned to the right, driving oil out of the uppermost port of the range valve (2) to the right-hand side of the control cylinder.

The oil on the opposite side of the control cylinder passes back through the change valve to the return side of the telemotor pump, completing the pressure-and-return cycle in the low pressure, or control, system.

The movement of oil in the control cylinder has actuated the bell-crank linkage connecting the plunger with the control shaft in the motor-driven Waterbury A-end pump. When the tilt-box in the motor-driven Waterbury pump (4) is tilted, its pistons then pump oil at high pressure through the relief valve manifold shown in Figure 5-20 and the pressure side becomes the return side.

g. Windlass-and-capstan clutch and change-and-control valve. The change-and-control valve and windlass-and-capstan clutch, which are structurally associated with the rigging system, are shown in Figures 5-19 and 5-20. Further examination of Figure 5-19 will be of help in understanding their function. The change valve (8, Figure 5-19) serves as a selector unit for the B-end motor (9), determining by its position whether the B-end receives power through the windlass-and-capstan control valve (17), with which the change valve is integrally mounted in a single housing (see Figure 5-21), or through the rigging control valve (3, Figure 5-19).

The change valve is operated by linkage from the clutch (11, Figure 5-19), which, like the change valve, has two positions: RIGGING and WINDLASS-AND-CAPSTAN.

As the clutch is moved into the required position, the clutch connecting rod (16), through linkage, moves the piston in the change valve (8) into a position which lines up the ports leading to the B-end motor (9) with the ports leading to the rigging control valve (3). Then this valve will operate the B-end motor to rig the bow planes in or out. This valve receives its power from the after service lines.

1. Clutch in RIGGING position. When the clutch (11, Figure 5-19) is in the RIGGING position, the rotary motion of the shaft of the

and into the line to the lower end of the hollow piston rod on the actuating cylinder assembly (5). This admits oil through

B-end motor (9) is transmitted through the worm and gear (15) to the horizontal drive shaft (13) which operates the rigging gear.

2. Clutch in WINDLASS-AND-CAPSTAN position. When the clutch (11, Figure 5-19) is placed in the WINDLASS-AND-CAPSTAN position, the rotary motion of the shaft of the B-end motor (9) is transmitted through the gear box to the horizontal stub shaft (19) which drives the windlass-and capstan gear.

At the same time, the clutch connecting rod (16) moves the piston in the change valve (8) into a position which lines up the ports from the B-end motor with the windlass-and-capstan control valve, through internal channels inside the change-and-control valve housing (13, Figure 5-21). The B-end motor can now be operated by the windlass-and-capstan control valve (17, Figure 5-19). This valve receives its hydraulic power from the forward service lines.

It must be clearly understood that the clutch handle performs two functions simultaneously: (1) it connects the drive shaft of the hydraulic motor either to the rigging gear or to the windlass-and-capstan gear; (2) it lines up the change valve either with the rigging control valve or with the windlass-and-capstan control valve (17, Figure 5-19). At no time can the rigging gear and the windlass-and-capstan gear be operated simultaneously, since the clutch-and-change valve can be in only one position at a time.

Figure 5-21 shows a cutaway view of the change-and-control valve. The windlass-and-capstan control mechanism is seen at the left of the unit, the change valve mechanism at the right. The clutch connecting rod (6), through the lever arm (5), crankshaft (4), and bell crank (3), moves the change valve piston (2) to the desired position. When lined up to permit operation of the windlass-and-capstan mechanism, controlling is then done by the windlass-and-capstan control shaft (10), which extends up to the main deck. This shaft has a squared end over which a special T-wrench is placed for operation of the wind lass-and-capstan gear. The shaft turns the threaded portion of the nonrising stem (8), which raises and lowers the sleeve (9), opening and closing the desired combination of ports in the control valve, and thereby directing pressure from the forward service lines of the main hydraulic system to one side or the other of the Waterbury B-end motor.

5D1. Bow plane system on earlier classes of submarines. On earlier classes of submarines, a bow plane tilting system which differs in some important details from the one just described is still being used (see Figure 5-22).

From the diving control stand to the A-end pump, the older system is the same as the system described. This includes the controls, the A-end pump and the motor which drives it, and the control cylinder.

Here the resemblance ends. In this system the Waterbury A-end pump delivers oil under pressure to a Waterbury No. 5 B-end motor (4), instead of directly to a main cylinder or ram. The rotary motion developed by the B-end motor is transmitted through a gear box (5) to rotate the herringbone gear (6) clockwise or counterclockwise. The direction and rate of rotation are, of course, determined by the angle of the tilt-box in the A-end PUMP.

Finally, the herringbone gear, which is meshed with the sector gear (7), turns the tiller (8) which is attached by a collar to the plane stocks (9).

On submarines in which this combination of A-end and B-end Waterbury gears is used for bow plane tilting, the planes are rigged by means of an electric motor.

However, the forward windlass-and-capstan is hydraulically operated also by a combination of a Waterbury No. 5 A-end and a No. 10 B-end speed gear. The A-end pump receives its power from the electric motor which drives the rigging gear. A clutch directs the motor power to either the rigging or the A-end of the windlass-and-capstan, as

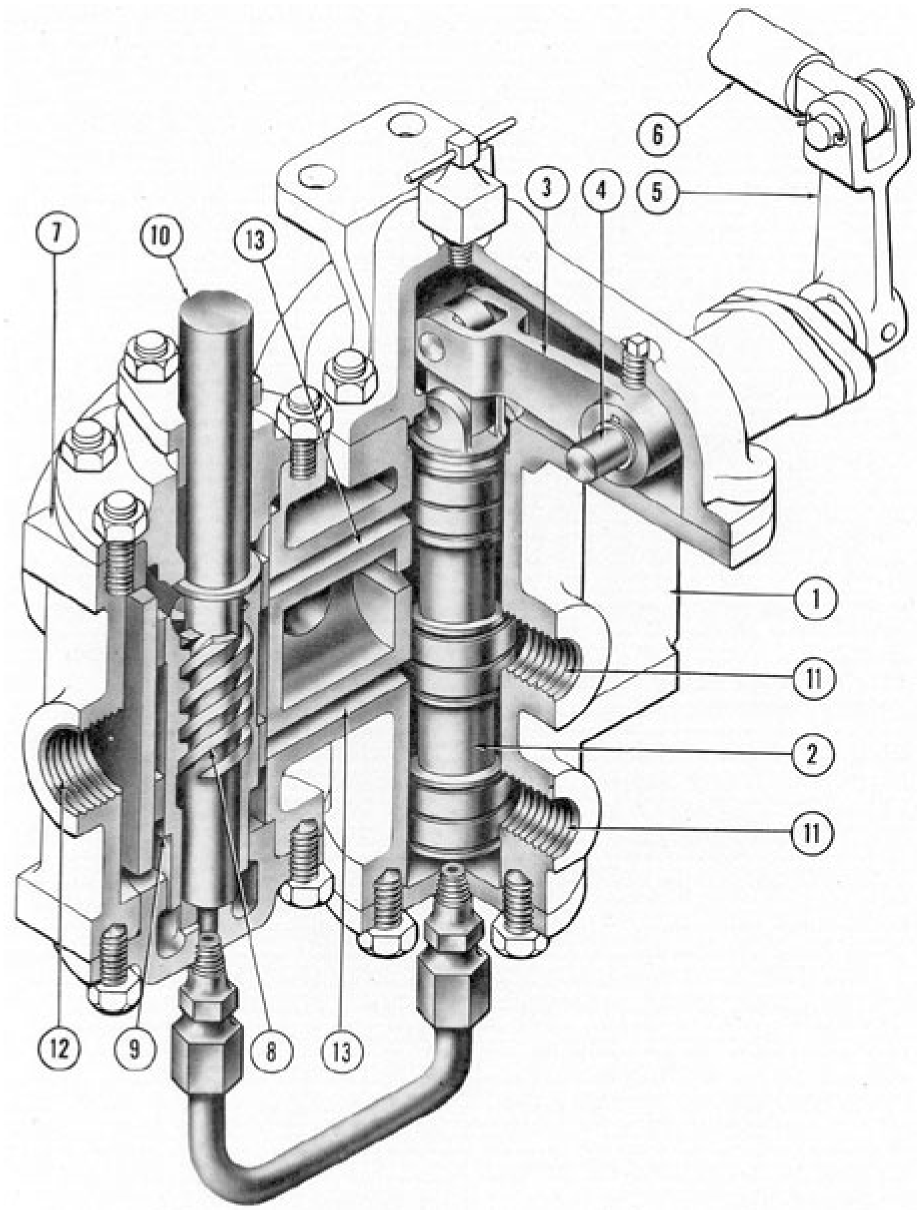

Figure 5-21. Cutaway of change-and-control valve.
1) Change valve body; 2) change valve; 3) bell crank; 4) crankshaft; 5) lever arm; 6) clutch connecting rod; 7) windlass-and-capstan control valve; 8) nonrising stem; 9) traveling sleeve; 10) windlass-and-capstan control shaft; 11) ports to rigging control valve; 12) port to forward service line; 13) internal channels, from change valve to windlass-and-capstan control valve.

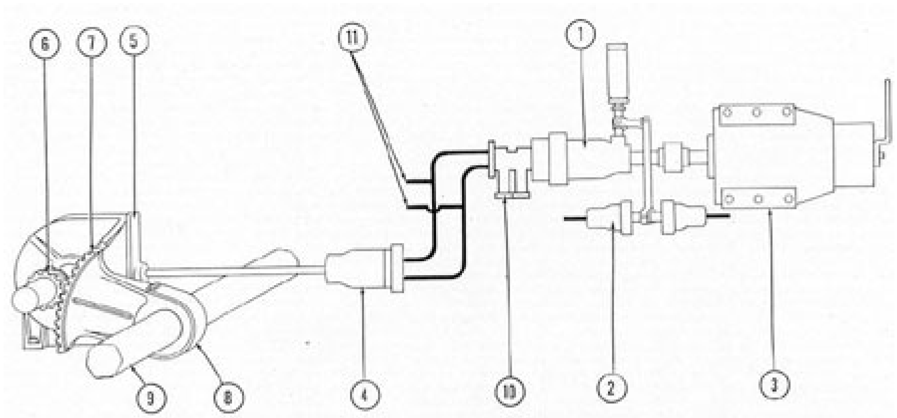

Figure 5-22. Diagram of bow plane system using Waterbury A-end and B-end.

1) Waterbury A-end pump; 2) control cylinder; 3) motor; 4) Waterbury B-end motor; 5) gear box; 6) herring bone gear; 7) sector gear; 8) tiller; 9) plane stocks; 10) relief valve manifold; 17) hand and emergency tilting lines.

desired. Both cannot be operated simultaneously. A control on the top deck is connected to the control shaft of the A-end, enabling the operator to regulate the speed and direction of the windlass-and-capstan operation.

5D2. Bow plane system on Electric Boat Company submarines. a. General arrangement. On recent classes of submarines built by the Electric Boat Company the bow plane system differs considerably from that described in sections 5C1 and 5C2. The new system is shown schematically in Figure 5-23. Its similarities to and differences from the Portsmouth type are described in following section.

b. Detailed description. 1. Control units. Except for minor modifications in appearance, the main wheel and telemotor pump (1, Figure 5-23), change valve (2), and emergency control valve, (4) in the Electric Boat Company bow plane system are practically identical with the corresponding installation on the Portsmouth boats. The rigging, control valve is also basically the same, in that it directs hydraulic power from the main hydraulic system to rig the planes (21) in or out.

However, there are many important differences in the two systems.

The most radical departure from the Portsmouth System is found in the hand rigging and tilting arrangement. In the Electric Boat Company system, the bow planes can be rigged in or out by hand, by the use of the telemotor pump in the bow plane tilting system.

This requires a special change valve in addition to the one with which we are already familiar, to direct the power developed by hand in the bow plane telemotor pump to either the tilting or the rigging system.

2. Hand rigging and tilting control valve. This special valve, called the hand rigging and tilting control valve (8, Figure 5-23), has three positions, TILT, RIG, and NEUTRAL. When it is placed at TILT, it allows oil pressure from the bow plane telemotor pump to pass to the bow plane tilting cylinder (19). At RIG, it directs the pressure to the B-end motor (17) which operates the rigging gear. At NEUTRAL, both these lines are off.

As a study of Figure 5-23 shows, the hand rigging and tilting control valve is mechanically interlocked with the normal (power) rigging control valve (7) in such a way that the handle (9) of the power-rigging valve cannot be moved from its own NEUTRAL position unless the handle (11) of the hand rigging and tilting valve is at NEUTRAL.

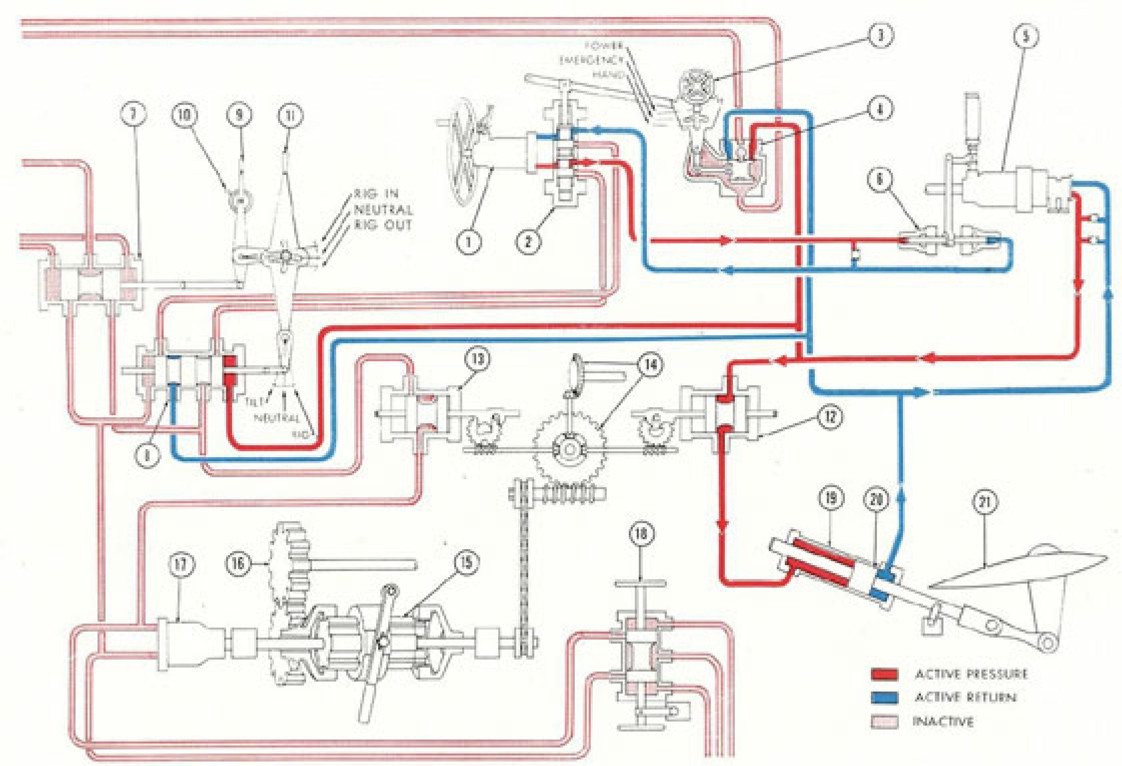

Figure 5-23. Bow plane system used in Electric Boat Company submarines, POWER tilting. 1) Telemotor and main handwheel; 2) change valve; 3) emergency control valve handwheel; 4) emergency control valve; 5) motor-driven A-end pump; 6) control cylinder; 7) rigging control valve; 8) hand tilting and rigging control valve; 9) rigging control valve handle, 10) solenoid release handle; 11) rigging-tilting control handle; 12) tilting cut-out; 13) rigging cut-out; 14) bow plane rigging gear; 15) clutch for rigging and windlass-and-capstan; 16) windlass-and-capstan gear; 17) Waterbury B-end motor; 18) windlass-and-capstan control valve; 19) tilting cylinder; 20) piston; 21) bow plane.

3. Solenoid locking device. The Electric Boat Company bow plane system does not have the hydraulic interlock valves between the rigging and tilting systems which, in the Portsmouth system, prevent rigging while the planes are tilted, or tilting while they are rigged in.

Instead, there is a spring-loaded plunger, actuated by an electrical solenoid, or magnetic coil (10), which locks the rigging control valve in NEUTRAL whenever the planes are tilted to any degree of rise or more than 15 degrees' dive.

the tilting and rigging lines pass through automatic cut-out valves, similar in principle to the rigging interlock cut-out feature on the Portsmouth design. The rotation of the rigging gears in either direction operates a pair of automatic cut-out valves (12 and 13) which, as the rigged-in or rigged-out position is approached, cuts off the flow of oil in the rigging or tilting lines.

5. Actuating units. As in the Portsmouth installation, the bow planes are tilted by the action of a hydraulic cylinder and are rigged in and out by a No. 10 B-end

The solenoid is operated by a contact maker on the bow plane ram (19). When the planes are anywhere between zero tilt and 15 degrees' dive, the solenoid is closed, or energized; the plunger is held out by magnetic force, and the rigging control valve is unlocked and ready to function. As soon as the ram has moved, however, to tilt the planes to any degree of rise, or to more than 15 degrees' dive, the contact maker opens the circuit to the solenoid, the magnetic coil is deenergized, and the loading spring snaps the plunger into the hole, locking the rigging valve in NEUTRAL, as seen in Figure 5-23.

The solenoid can still be pulled out, however, by a manually operated electric push-button on the control panel, which is itself spring-loaded and will energize the solenoid only while the operator holds the button down with his finger.

In the event of failure of the electric power, the solenoid plunger control as a last resort be pulled out by hand to allow emergency operation of the rigging valve.

4. Hydraulic cut-out valves. In the description of the Portsmouth system of hydraulic interlock valves, it was explained that the rigging interlock (Portsmouth design only) not only controlled the passage of tilting pressure, but also acted as an automatic cut-out in the rigging pressure lines themselves to prevent the rigging gears from coming against the hard stops at each end of their travel (see Section 5C2d).

Waterbury speed gear used as a hydraulic motor.

a) Tilting. (See Figure 5-23.) It will be recalled that, in the Portsmouth boat, the bow plane hydraulic cylinder arrangement was somewhat unusual in that the piston was fixed, while the cylinder moved up and down over it. However, in the Electric Boat Company design, the bow plane tilting arrangement is more familiar-the cylinder (19) is fixed and the planes (21) are tilted by the movement of a piston, or ram (20). In appearance and operation this bow plane ram is practically identical with the stern plane ram on the Portsmouth boat.

b) Rigging. The mechanism used for rigging (14, 15, and 17, Figure 5-23) is practically identical with that described in connection with the Portsmouth boats.

c. Operation of Electric Boat Company system. 1. Tilting by normal POWER. Figure 5-23 illustrates schematically In the flow of oils in the Electric Boat Company system during the operation of tilting to RISE by normal POWER. As will be seen by a comparison with Figure 5-20, this operation is the same as the corresponding operation on the Portsmouth boat.

Active pressure oil is shown in red, active return oil in blue; oil in the inactive parts of the system is shown in lighter red. Direction of flow is indicated by arrows.

2. Rigging by HAND. Figure 5-24 illustrates the operation involving the most radical differences between this system and the

In the Electric Boat Company system, there are no hydraulic interlocks, but both Portsmouth: namely, rigging out by HAND.

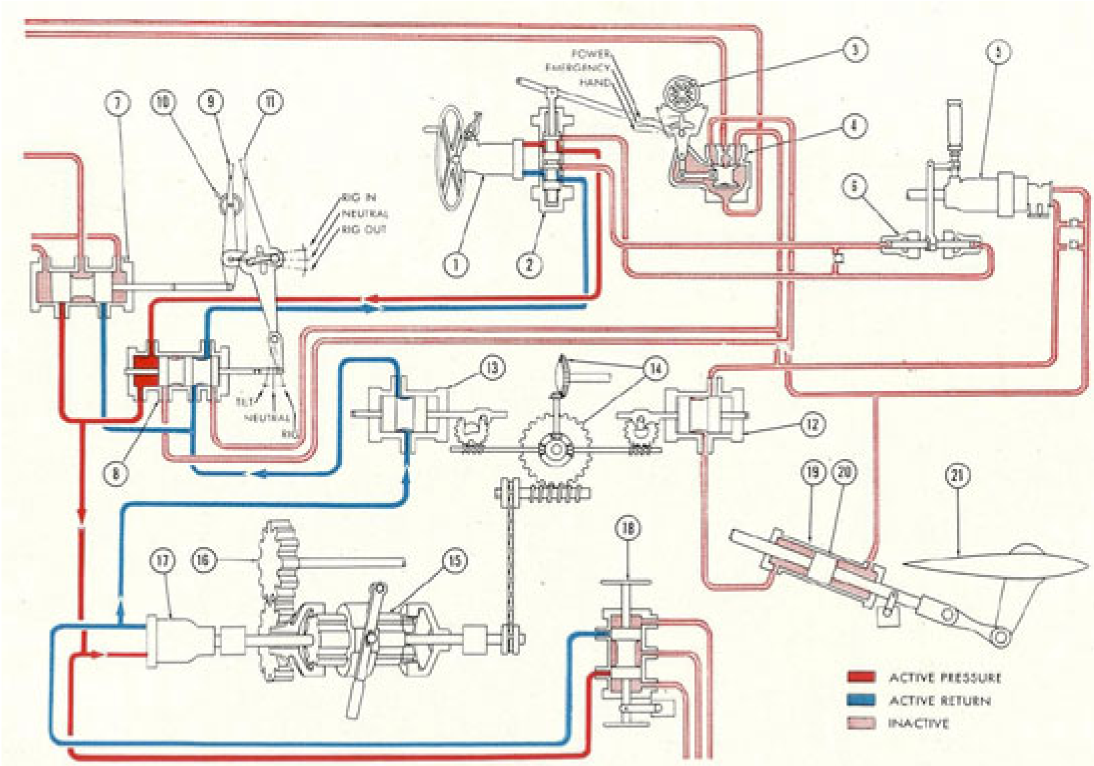

Figure 5-24. Bow plane system used in Electric Boat Company submarines, HAND rigging.
1) Telemotor and main handwheel; 2) change valve; 3) emergency control valve handwheel; 4) emergency control valve; 5) motor-driven A-end pump; 6) control cylinder; 7) rigging control valve; 8) hand tilting and rigging control valve; 9) rigging control valve handle; 10) solenoid release handle; 11) rigging-tilting control handle; 12) tilting cut-out; 13) rigging cut-out; 14) bow plane rigging gear; 15) clutch for rigging and windlass-and-capstan; 16) windlass-and-capstan gear; 17) Waterbury B-end motor; 18) windlass-and-capstan control valve; 19) tilting cylinder; 20) piston; 21) bow plane.

Active pressure oil is shown in red, active return oil in blue; oil in the inactive parts of the system is shown in lighter red. Direction of flow is indicated by arrows.

The bow plane change valve (2) is set at HAND.

The handle (9) of the power rigging valve (7) is at NEUTRAL, for windlass-and-capstan operation. There is only a control valve (18, Figure 5-23) which is located in the forward torpedo room. The windlass-and-capstan receives its power from the Waterbury B-end motor (17) which operates the rigging gear. A slide clutch (15) engages one of the two services it operates. When one service is engaged through the

locked there by the solenoid plunger (10).

The handle (11) of the hand rigging and tilting control valve (8) is set at RIG.

Now the telemotor pump (1) is activated by rotating the main wheel to the right (clockwise). This sends oil under pressure through the upper part of the telemotor pump, through the - change valve and hand rigging and tilting control valve, and into one of the rigging lines, which leads to the Waterbury No. 10 B-end motor (17).

The return oil from the Waterbury motor follows the same path in reverse, except that it must pass through the rigging cut-out (13) on its way back to the change valve and telemotor pump. As the planes approach the fully rigged-out position, this cut-out will automatically shut off the flow of oil in the circuit, allowing the oil to be bypassed through a small-sized pipe and throttling valve which slows down the hydraulic motor.

d. Forward windlass-and-capstan operation. In this system there is no change valve clutch, the other is disconnected. A contact maker on the windlass-and-capstan control valve handle indicates in the control room which way the clutch is engaged.

NOTE. 1. Due to the requirement that the bow planes be rigged out in the specified time with only one main hydraulic plant pump in operation, the Waterbury No. 10-B motor has been replaced by a No. 10-A unit with provisions for placing the tilt block on reduced stroke during rigging out, and on full stroke during rigging in. Since the power requirement during rigging out of the planes is not great, the No. 10-A motor is run at an increased speed during this period as the displacement per revolution has been reduced by decreasing the stroke. The other features of this installation as previously described remain essentially the same.

2. On later classes of the Electric Boat Company design, the hand rigging and tilting control valve has been discarded and the bow plane change valve has been redesigned to incorporate the features previously found in the aforementioned control valve.

6
SERVICE TROUBLES

A. INTRODUCTION

6A1. General. The submarine hydraulic system, like any other complex mechanism, will not function at maximum efficiency unless it is kept in perfect condition. This chapter lists some common service troubles, with their probable causes and suggested remedies.

6A2. IMO pump: troubles and repairs. a. Packing. The packing is a 8-inch-square flexible metallic packing (five rings). Adjustment is made with the pump in operation.

b. Adjusting bolts. Adjusting belts should be left at factory position. Any change will cause faulty alignment to the pump block bore.

c. Individual guide pins. Individual guide pins provide pump alignment for sections of block bore.

6A3. Waterbury pump: troubles and repairs. a. Oil seal. The most common trouble is with the seal. If it leaks excessively, it should be completely renewed. The shaft should be checked for burrs when removing the key from the keyway to make sure that seal ring burrs do not damage the ring when putting on new neoprene. Vaseline should be used to enable the ring to slip valve plate must be sharp and flat to insure a good oil seal.

f. Cylinder barrel. The cylinder barrel must be set within 0.002-inch clearance on barrel keys to permit the barrel to be maintained against the valve plate when the shaft is forced back by thrust.

g. Roller bearing (axial thrust and radial thrust). Rollers occasionally crack and break. When facilities permit, renew the entire bearing. If bearings are not available, rollers can be staggered to equalize the load onto the bearing.

h. Races. Races become worn through considerable operation and should be renewed.

i. Relief-replenishing valves. Relief-replenishing valves should be checked periodically to see if the ball check is worn and to check the seats of the valve.

Check the spring to see if it is in proper tension.

Most submarine units have relief valves mounted externally in the pressure line, in which case the pump has a replenishing valve only.

6A4. Oils. Approved oils for use with hydraulic power transmissions are covered by yearly contracts

easily over the shaft and into place. The pressure surface of the steel seal ring should be checked to see that it has flat and sharp surfaces to insure a good seal. Also the end-plate of the pump should have a similar pressure surface.

b. Control shaft. No end-play of the control shaft is tolerated.

c. Piston socket and socket ring socket joints. The clearance allowed for No. 5 units is 1/2-thousandth of an inch. Any clearance greater than this will cause noisy operation.

d. Pistons. Pistons are not interchangeable.

e. Cylinder barrel and valve plate. The pressure surfaces of the cylinder barrel and

and carried in stock as force feed and motor cylinder oil, light, and should be used as follows:

Waterbury, and Northern, symbol 2110, viscosity 90-120 seconds Saybolt Universal at 130 degrees Fahrenheit.

Northern, symbol 2075, viscosity 70-90 seconds Saybolt Universal at 130 degrees Fahrenheit.

Hele-Shaw, symbol 2250, viscosity 245 280 seconds Saybolt Universal at 130 degrees Fahrenheit.

When very low temperatures are expected, ice machine oil, also procured under

yearly contract, should be used temporarily. However, oils with a pour point as low as zero degrees Fahrenheit or lower have been tested in speed gears at temperatures causing complete solidification and found to work satisfactorily, as they liquefy almost immediately when the gear is operated. Manufacturers' instruction books should also be consulted for recommended grades of oil.

It is not necessary that all oil used in any installation be of the same brand or trade mark, provided it is all of the same grade.

The most efficient working temperature of a hydraulic unit is

valves must be opened or closed. The two filling and vent control valves on the vent and replenishing manifold are opened, and the control line valve on the vent and replenishing manifold is closed. The bypass valve, between the two control lines by the control cylinder is open. The change valve should be on POWER.

The operator turns the steering wheel to the right. The telemotor pump takes a suction from the main supply tank through one of the opened filling and control valves and delivers the oil through the right rudder control line through the opened bypass valve by the control cylinders. From there it passes back through the

120 degrees Fahrenheit, considering the question of wear. In close coupled installations, oil temperature may attain 200 degrees Fahrenheit. In other installations where there are large radiating surfaces, the temperature of the oil seldom exceeds 140 degrees Fahrenheit. When running under continuous load, cooling of the oil may be necessary if operating temperatures exceed 200 degrees Fahrenheit, in which case the Bureau of Ships should be advised.

6A5. Venting. a. Venting the main hydraulic system. When the main supply tank has been filled with oil, the operator should open the air bleeder valves one at a time throughout the power generating system until a solid stream of oil flows out of the bleeder valve.

To vent the lines and unit cylinders of air, place the control manifold levers on the HAND position and build up the air pressure in the volume tank to 25 pounds. Then open all bleeder valves throughout the ship, one at a time until no more air is present. Operate the units by hydraulic power a few times. Repeat the above procedure again. This will have to be done a few times until all the air is vented off. It should be noted that the unit cylinders in present installations are the highest points in the main system.

b. Venting the steering system. 1. Steering control system. In venting the steering control system the following units are vented: control cylinders, change left rudder control line, through the other opened filling and vent control valve, to the vent and replenishing line, and back to the supply tank.

The air is picked up by the oil being pumped through the lines and left in the supply tank. However, some of the air will still remain in the lines and must be vented off through the air bleeder valves located at all high points of the lines.

2. Main steering power system. In venting the steering power system the following units are vented: the four ram cylinders, the main steering manifold, the active side of the motor-driven pump, and the hand and emergency lines.

In filling and venting the steering power system, emergency power (for example, power from the main hydraulic system) is used. Shift to emergency steering in the control room (see Section 4C4), open the bypass, valve on the maim steering manifold, then turn the emergency steering wheel to left or right rudder. This will allow the oil from the main hydraulic system to pass through the hand and emergency return line to the main supply tank, carrying the air with it.

To create pressure in the ram cylinders, manifolds and lines, close the emergency steering return valve on the main return manifold, restricting the flow until the oil pressure shown on the steering gages reaches 200 pounds per square inch; the pressure will then be the same throughout the entire

valve, active side of telemotor pump, and the lines leading from the telemotor to the control cylinders.

Before venting the system, the following

steering power system. Begin venting the air out of the lines, cylinders, manifold, and pump through the air bleeder valves. This procedure must be repeated as often as is necessary to eliminate all the air from the system.

To eliminate air from the ram cylinders, the following procedure should be followed. When the boat is diving, the steersman should shift the rudder slowly from left to right a few degrees, with the steering in normal POWER or EMERGENCY; as he does so, vent the two after cylinders. As the angle of the boat is down by the bow, the after cylinders will be at an up angle and all the air in them will be trapped at the air bleeder valve, allowing it to be vented off. The same procedure should be followed for the forward cylinders when the boat is surfacing.

WARNING. Never open the air bleeder valve unless the oil pressure is being directed to that cylinder, as air would be drawn in the pump as it is taking a suction on that cylinder. Always open the air bleeder valve to the cylinder that has pressure directed to it.

c. Venting the bow and stern plane control system. These systems are vented in the same way as the steering control system, except that the diving wheels must be turned toward DIVE.

d. Venting the bow and stern plane power system. In venting the bow and stern plane power system, shift to EMERGENCY power.

Rig out the bow planes, tilt them to hard dive (against the stops), and with emergency power on the dive pressure line, vent that line through the air bleeder valves; this includes the bottom part of the tilting cylinder, rigging interlock, and tilting interlock. When all air has been vented from that part of the system, shift planes to hard rise and vent the rise pressure line through the air bleeder valves; this includes the top of the tilting cylinder, rigging interlock, and tilting interlock.

e. Venting the stern planes. With emergency power on stern planes, tilt the planes to hard dive, vent the dive pressure line through the air bleeder valves until all air has been vented. Shift planes to hard rise, and vent the rise pressure line until all air has been vented.

B. DETAILED SERVICE TROUBLES, CAUSES, AND REMEDIES

6B1. Main hydraulic system.

TROUBLE	PROBABLE CAUSES	REMEDIES
IMO pump very noisy.	1. Supply tank low on oil; pump has lost suction. 2.Supply cut-out valve closed. 3. Strainer clogged. 4. Foreign matter in pump.	1. Replenish oil to proper level in supply tank. 2. Open supply tank cut-out valve. 3. Clean strainer. 4. Disassemble pump, clean, and renew damaged parts.
Excessive oil pressure when hand bypass is closed.	1. Cut-out valve between accumulator and accumulator air flask closed. 2. Excessive oil added to oil seal, causing oil to spill over into cylinder. 3. Accumulator air flask has accumulated excessive water.	1. Open stop valve. 2. This trouble will be indicated as soon as the pump has been started and the hand bypass closed. The oil pressure will go higher and higher as the accumulator is loading. Drain oil from bottom of accumulator air cylinder and also drain some oil from oil seal. 3. Drain accumulator air flask.

TROUBLE	PROBABLE CAUSES	REMEDIES
Accumulator plunger squeaks or jumps when discharging.	1. Lost oil seal. 2. Packing gland uneven.	1. Renew oil seal. 2. Take up or loosen up on packing-gland nuts until gland seats evenly all around.
Accumulator plunger travels down against positive stops, causing oil relief valves to lift.	1. Valves in pilot valve or automatic bypass control lines closed. 2. Automatic bypass valve stem bent. 3. Foreign matter in automatic bypass piston. 4. Leather guide cup washer worn.	1. Open cut-out. 2. Manufacture and install new valve and piston unit. 3. Disassemble automatic bypass and clean. 4. Renew leather cup washer. If none is available, take a cut on the small brass washer on top of the cup washer.
Accumulator cycles continuously with all control valves under pressure.	1. Spool valves and their cylinders are worn, allowing oil to leak from pressure side to return side of system.	1. Rebore and relap cylinders. Manufacture and lap spool valves.
Accumulator cycles continuously when quick-throw valve on main supply manifold is closed.	1. Nonreturn valve leaking. 2. Automatic bypass valve piston leaking excessively. 3. Nonreturn valve sticking; pilot valve plunger worn.	1. Grind in and free up valve. 2. Rebore and relap automatic bypass valve. Manufacture new piston and valve. 3. Renew.
Accumulator short cycles.	1. Nonreturn valve leaking. 2. Automatic bypass valve piston leaking excessively. 3. Nonreturn valve sticking; pilot valve plunger worn.	1. Rebore and relap pilot valve cylinders and manufacture new piston. 2. Same as No. 1 3. Tighten holding-down bolts.

Loss of air from accumulator air flask.	1. Oil seal in accumulator lost. 2. Packing glands on valves leaking. 3. Bleeder valve leaking. 4. Relief valve leaking.	1. Renew oil seal. This is the most common trouble. 2. Tighten packing glands. 3. Grind in bleeder valve. 4. Grind in and reset relief valve.
Male and female joints leaking oil.	1. Improperly set up. 2. Copper gasket too hard.	1. Anneal copper gasket and set up evenly on all bolts of the flange. 2. Same as No. 1.

TROUBLE	PROBABLE CAUSES	REMEDIES
Valve on main supply or return manifold cannot be opened.	1. Valve jammed on seat.	1. Loosen valve body, loosen packing-gland nut, then open valve before tightening valve body.
Hydraulically operated unit cannot be started.	1. Foreign matter in operating mechanism. 2. Lack of lubrication.	1. Clean mechanism. 2. Thoroughly grease and lubricate operating mechanisms.
Leakage of oil at operating end of unit cylinder and piston.	1. Packing gland leaking. 2. Piston head plug leaking.	1. Loosen packing gland; operate unit allowing sufficient oil to flow out through packing; then tighten. 2. Remove cylinder head, remove piston head plug, and anneal copper

		gasket which is under the plug. Note: The operator must look very closely to determine whether the oil is leaking from the packing gland or from the piston, as they are very close together.
Control manifold valve stuck with no pressure on system.	1. The valves and cylinders are so made that the valves are lapped into the cylinder, which makes it very hard to operate. As soon as the system is under pressure, they operate freely, as the cylinders are expanded by the pressure of the oil.	1. None.
Control manifold valve stuck with system under operating pressure.	1. Foreign matter between valve and cylinder. 2. Operating linkage frozen. 3. Improperly lapped.	1. Remove valve, flush cylinder, and clean valve. 2. Disassemble and free up. 3. Remove valve and polish with crocus cloth.
Main ballast tank vent or any hydraulically operated unit closes or opens when lever on control manifold is set in HAND or EMERGENCY position.	1. Valve unit improperly set, not allowing operating mechanism to go into locked position. 2. Unit mechanism dirty, lack of lubrication. 3. Spool valve in control manifold improperly set.	1. Chalk-mark valve seat, measure valve opening, and then set valve to proper clearances. 2. Lubricate unit thoroughly. 3. Spool valve may not overlap ports properly, allowing pressure oil to flow to open or closed side of valves.

TROUBLE	PROBABLE CAUSES	REMEDIES
Safety or negative flood valve does not indicate CLOSED, and operator is unable to close it by hand operation.	1. Ball joint(s) on flood valve out of adjustment. 2. Frozen operating mechanism.	1. Readjust ball joint. It will have to be partially unscrewed from the flood valve. 2. Grease and free mechanisms.
Safety or negative flood valve indicates CLOSED but tanks continue to flood.	1. Ball joint(s) on flood valve out of adjustment. 2. Gaskets blown out. 3. Sea connection lines leading through tank are leaking.	1. Readjust ball joint(s). It will have to be screwed part of the way into the valve. 2. Renew gasket. 3. Plug line and renew or put on temporary patch.

6B2. Steering system.

TROUBLE	PROBABLE CAUSES	REMEDIES
Rumbling noise in steering system when system is being operated.	1. Air in system.	1. Vent system.
Steering pump very noisy, with loss of power.	1. Pump casing not full of oil. 2. System air bound.	1. Vent, then fill surge tank with oil. 2. Vent system.
Rudder oscillates back and forth when steering wheel is not being moved.	1. Air in system. 2. Control mechanism binding.	1. Vent system. 2. Free any tight joints on control mechanisms. 3. Grease all bearings.

	3. Lack of lubrication on bearings of control mechanisms.	
Rudder continues to move in direction in which steering wheel was last turned.	1. Packing gland too tight on control cylinder. 2. Control linkage joints too tight. 3. Control linkage joints too loose; keys and keyways have excessive clearance.	1. Loosen packing gland. 2. Loosen and grease linkage bearings. 3. Disassemble and refit bearings and keys.
Rudder creeps in one direction, for example, if steering wheel is turned for right rudder, then as the rudder stops at a given degree of rudder, it starts back to left rudder without moving the steering wheel.	1. Steering pump tilt-box control shaft not set on neutral. 2. Centering spring has too much tension 3. Centering spring has too little tension	1. Loosen locking nut on trunnion on control shaft; rotate trunnion until tilt-box control shaft is in neutral position. 2. Readjust springs. 3. Readjust springs.

TROUBLE	PROBABLE CAUSES	REMEDIES
Rudder operates with jerky motion.	1. Packing on steering rams of rams dry.	1. Grease exposed sections of rams, allowing ram to carry

		lubricant into packing. Use a heavy oil (Symbol 5190).
Rudder operates at normal rate of speed in one direction, but operates at a reduced rate in opposite direction.	1. Control cylinder plunger stops incorrectly set. 2. Control cylinder packing is not allowing plunger to travel freely in opposite direction.	1. Reset control cylinder plunger stops. 2. Loosen packing until plunger operates freely.
In hand or emergency steering, the steering pump and motor turn when pressure is applied to rams.	1. Motor brake does not hold.	1. Readjust brake. Note: Check neutral setting of tilting block on pump.
Sufficient pressure cannot be built up with hand steering to move rudder.	1. Excessive leakage between ports of change valve. 2. Bypass or relief valves on main steering manifold leaking. 3. Control room steering pump leaking excessively by piston or between cylinder barrel and valve plate.	1. Renew change valve. 2. Grind in relief and bypass valves. 3. Completely overhaul steering pump.
Squealing noise is heard in the A. T. tank when rudder is operated.	1. Connecting rod guide and cylinder binding.	1. Grease.

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Figure 7-1. LOCATION OF HYDRAULIC SYSTEM COMPONENTS.

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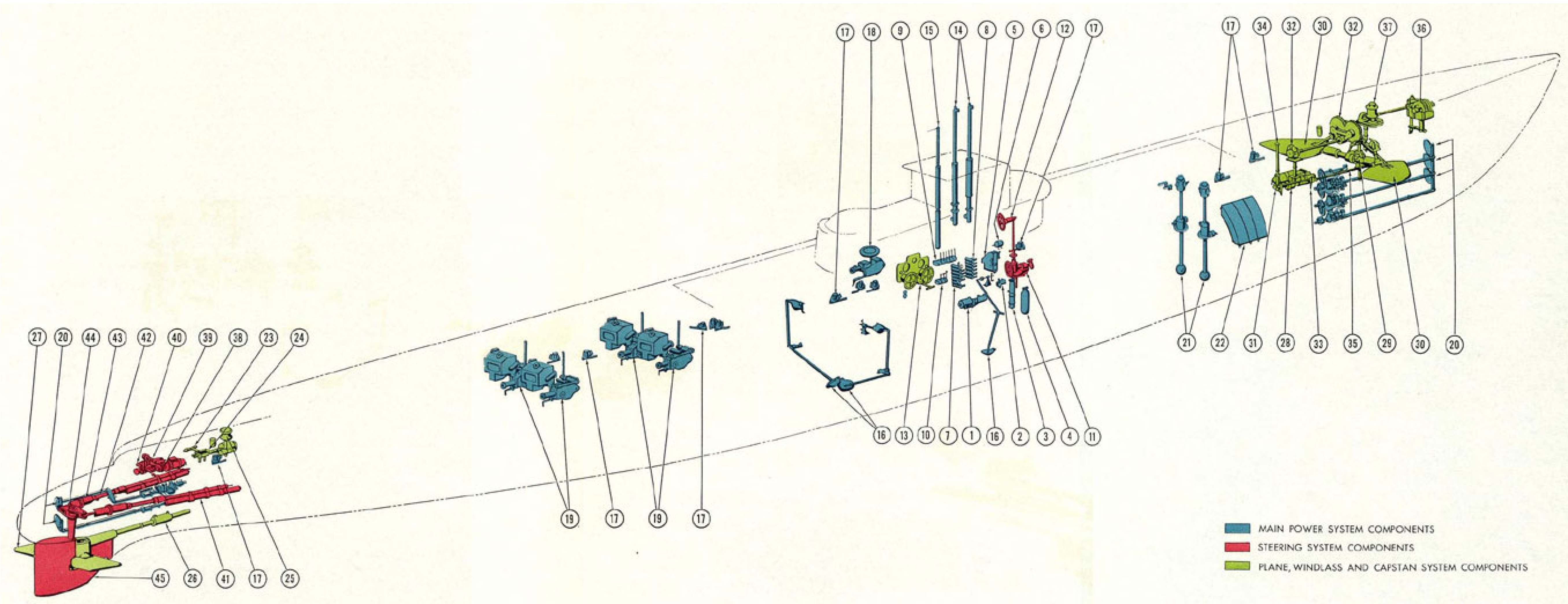
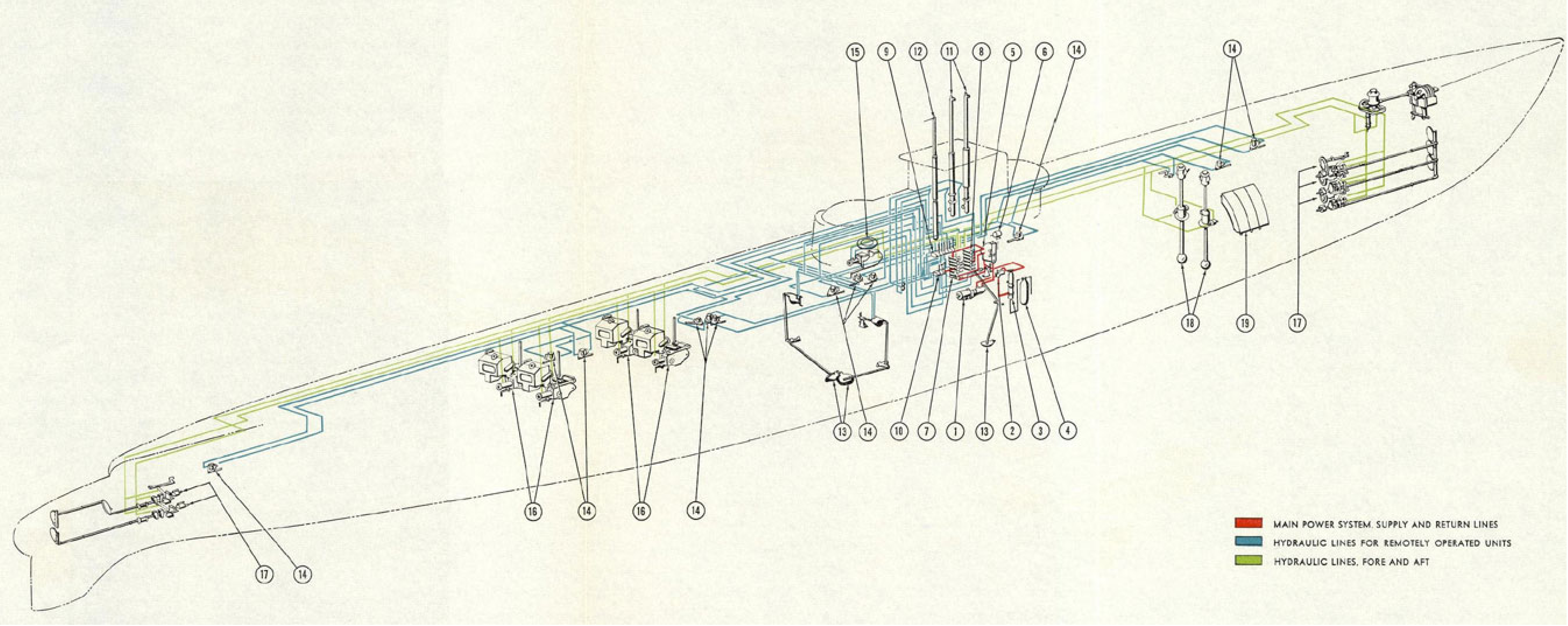


1) Motor-driven IMO pump; 2) automatic bypass and nonreturn valve; 3) accumulator; 4) high pressure air flask; 5) main supply tank; 6) back-pressure air, or volume, tank; 7) main supply manifold; 8) main return manifold; 9) main vent control manifold (six-valve manifold); 10) safety and negative and hull ventilation control manifold (three-valve manifold); 11) control room steering stand; 12) conning tower steering stand; 13) diving control stand: 14) periscope; 15) antenna mast; 16) flood valves; 17) vent valves; 18) hull ventilation and engine air induction valve; 19) main engine exhaust valves and operating gear; 20) torpedo tube outer door operating gear; 21) echo-ranging and detecting apparatus; 22) hydraulic fluid reserve tanks; 23) stern plane control cylinder; 24) stern plane motor-driven Waterbury A-end pump; 25) after capstan; 26) stern plane ram; 27) stern plane assembly; 28) bow plane motor-driven Waterbury A-end pump; 29) bow plane tilting cylinder assembly; 30) bow plane; 31) change-and-control valve; 32) rigging operating gear; 33) rigging windlass-and-capstan clutch; 34) windlass-and-capstan control shaft; 35) windlass-and-capstan drive shaft, 36) forward windlass; 37) forward capstan; 38) steering motor-driven Waterbury A-end pump; 39) control cylinder; 40) steering system main manifold; 41) ram; 42) inboard connecting rod; 43) guide; 44) crosshead; 45) rudder.

Figure 7-2. MAIN POWER SYSTEM. Sub Hydr. Home Page



1) Motor-driven IMO pump; 2) automatic bypass and nonreturn valve; 3) accumulator; 4) high pressure air flask; 5) main supply tank; 6) back pressure air, or volume, tank; 7) main supply manifold; 8) main return manifold; 9) main vent control manifold (six-valve manifold); 10) safety and negative and hull ventilation control manifold (three-valve manifold); 11) periscopes; 12) antenna mast; 13) flood valves; 14) vent valves; 15) hull ventilation and engine air induction valve; 16) main engine exhaust valves and operating gear; 17) Torpedo tube outer door operating gear; 18) echo-ranging and detecting apparatus; 19) hydraulic fluid reserve tanks.

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Figure 7-3. PLANES, WINDLASS-AND-CAPSTAN SYSTEM.

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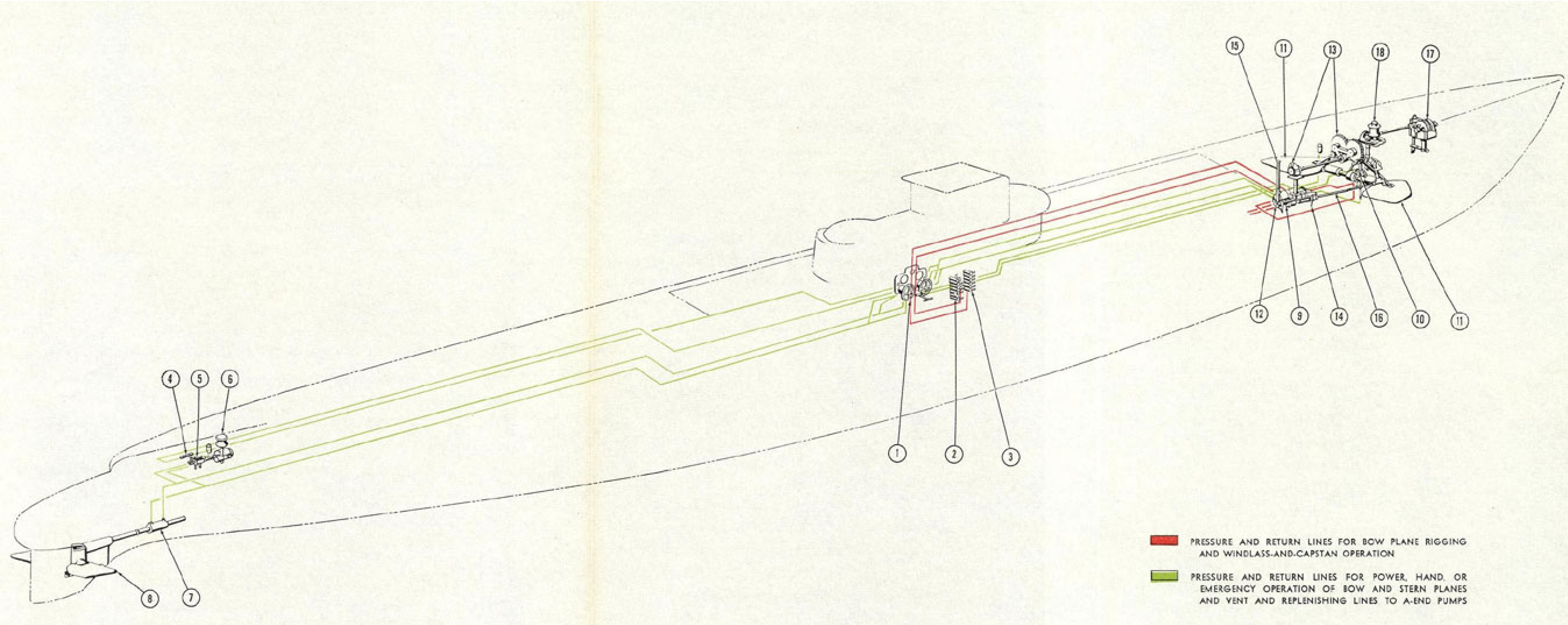

1) Diving control stand; 2) main supply manifold; 3) main return manifold; 4) stern plane control cylinder; 5) stern plane motor-driven Waterbury A-end pump; 6) after capstan; 7) stern plane ram; 8) stern plane assembly; 9) bow plane motor-driven Waterbury A-end pump; 10) bow plane tilting cylinder assembly; 11) bow plane; 12) change-and-control valve; 13) rigging operating gear; 14) rigging windlass-and-capstan clutch; 15) windlass-and-capstan control shaft; 16) windlass-and-capstan drive shaft; 17) forward windlass; 18) forward capstan.

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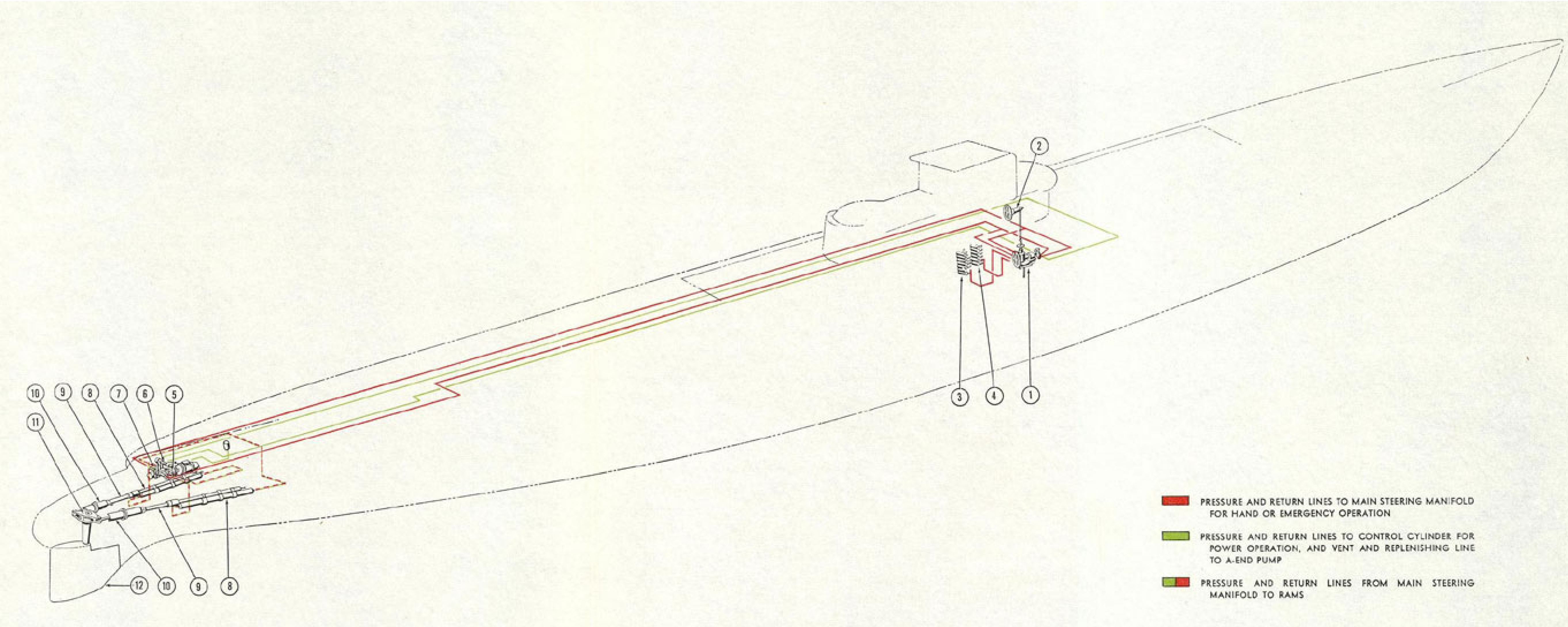
Figure 7-4. STEERING SYSTEM. Sub Hydr. Home Page



1) Steering stand; 2) conning tower steering wheel; 3) main supply manifold; 4) main return manifold; 5) Waterbury A-end pump; 6) control cylinder; 7) main steering manifold; 8) ram; 9) connecting rod; 10) guide; 11) crosshead; 12) rudder.

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