

CHAPTER 8

PIPING SYSTEMS

Aboard ship the various units of machinery and equipment are connected by miles of piping. Each piping system consists of sections of piping or tubing, fittings for joining the sections, and valves for controlling the flow of fluid. Most piping systems also include other fittings and accessories such as vents, drains, traps, strainers, relief valves, and various gages and instruments. This chapter covers information dealing with the care of piping systems, piping repairs, maintenance of valves, and appliances for piping systems.

PIPING CARE AND MAINTENANCE

REASONABLE CARE must be given the various piping assemblies, as well as the machinery connected by the piping. All joints, valves, and cocks in the lines must be examined frequently, and kept tight. The piping on any ship should not be subjected to strains by being used for handholds or footholds, by having chain falls secured to them, or by being used for supporting weights.

Where piping passes through decks or bulkheads, and a possibility exists for movement of one with respect to the other, stuffing boxes or flexible bulkhead connections are provided—if expansion bends or other offsets are not provided in the piping—to take up the movement. The external surfaces of uncovered and ungalvanized steel or iron piping should be kept properly painted and free of moisture. Copper and brass piping is seldom painted.

PIPE THREAD LEAKS should be promptly corrected. Leaky screwed joints which cannot be tightened with a reasonable amount of pullup should be taken apart, cleaned, examined for bad thread conditions, recoated with the appropriate compound, and carefully reassembled, to avoid any other thread damage. Poorly cut

threads are a constant source of trouble with threaded pipe joints. The proper use and care of pipe cutters will prevent such pipe troubles as shaved thread, wavy thread, and poor shoulders.

When a ship is in operative status, piping should be tested at the frequency and test pressure specified in BuShips Technical Manual. These tests must be carried on for a period of time long enough to disclose any leaks or other defects in the system.

Where technical manuals are available for piping systems and associated equipment, they should be followed. However, if the manufacturer's instructions or manuals are not available, BuShips Technical Manual should be referred to for details of piping maintenance.

TESTS AND INSPECTIONS

Maintaining the operational reliability of ships requires that all piping systems be in good operating condition; therefore, early detection and correction of piping defects are of the utmost importance. Fresh water, lube oil, fuel oil, aviation gas, jet fuel, and refrigerant gas are critical items—and any unnecessary loss of them must be avoided. Early correction of leaks, such as repair of faulty seats and disks, will reduce the amount of work, time, and material required for repairs. The following items are of extreme importance for the proper operation of valves and piping systems.

1. Piping systems should be inspected at regular intervals in order to detect and correct leaks as soon as they develop.

2. BuShips Technical Manual and the manufacturer's technical manuals for component systems should be referred to for specific information on a particular piping system or component.

3. If specific instructions are not available, all piping in an operating status aboard ship should be tested quarterly under full working pressure. In addition, a periodic hydrostatic test of 150 percent of the system designed pressure shall be applied to piping. The period between tests shall not exceed a maximum of 5 years; the test should be conducted prior to or during a scheduled major overhaul on the ship.

4. On ships in the reserve fleet, all piping not in use shall be kept thoroughly drained and should not be put under pressure for test purposes.

5. Drain holes which are provided in some systems to permit continuous drainage, should be checked periodically to guard against their becoming plugged with dirt or other foreign matter.

6. Before pressurizing any portion of a piping system for operation or for test purposes, operate all valves except those which would pressurize the system from another source.

7. Ensure that all valves and equipment in, or connected to, the part of the piping system being tested are in the required position or condition. Admitting steam to an open boiler and opening injection or overboard valves to an open condenser are to be particularly guarded against.

8. Sudden stoppage or changes in the flow, velocity, or direction of liquids in piping will generate high pressure (water ram) and may possibly damage equipment. Pumps should not be started when the discharge valve is open to a closed piping system, since the air present will be compressed and could result in damage to equipment.

9. Sudden temperature changes in a piping system can cause uneven contraction and expansion and can develop stresses which may cause material damage or failure. Excessive temperature changes are the primary cause of gasket failure.

MARINE GROWTH

Rapid fouling of the firemain has been experienced on many ships, especially ships operating in tropical waters. Figure 8-1 illustrates a firemain fouled by marine growth. To minimize fouling of the firemain and to

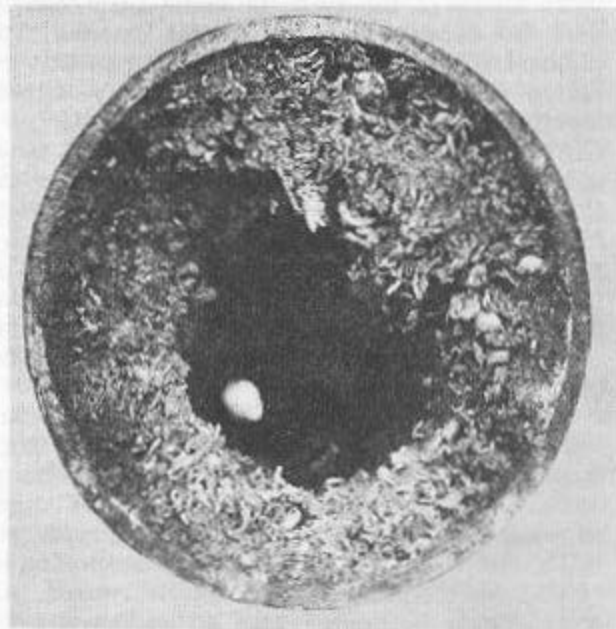
prevent valves from being stuck open or closed, the following procedure is recommended:

1. Once each quarter, flush the firemain under full pressure. High velocity flow must be used to remove marine growth. The firemain system may be lined up to direct the flow of water from more than one pump in one end of the ship, through a section of the system, while discharging through an adequate number of weather deck fireplugs. This procedure may be changed to reverse the flow through the piping. Flushing should be accomplished in areas where the sea water is clean.

2. The Naval Ship Systems Command has approved a procedure for acid cleaning of firemain piping to remove scale and marine growth. This type cleaning can be accomplished by a naval shipyard or by an approved contractor. Acid cleaning is satisfactory and is economical because it can be done without dismantling the piping.

GASKETS

It is possible to achieve a tight seal between flanges of a flanged joint; however, this requires perfect mating of machined or ground



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Figure 8-1.—Firemain fouled by marine growth.

surfaces. Hence this method is costly, impractical, and generally unsatisfactory. To eliminate the necessity for producing and maintaining perfect joint-contact surfaces, relatively inexpensive and easily replaceable gaskets are used as the sealing element. The seal is obtained by causing the gasket material to yield, or flow into the grooves or irregularities on the joint-contact surfaces.

For any flange, the type of gasket to be used will depend on several considerations: operating conditions, operating pressures, and mechanical features (bolting, shape of flange) of the flanged assembly. Chapter 9950 (95) of BuShips Technical Manual contains information on selecting the proper gasket for a specific flange.

Much of the trouble experienced with leaky joints in piping is due to poor alignment or to improper allowance for expansion. Either of these faults will throw excessive strain on joints. When the joints do not line up, the piping should be realigned so that the flanges or unions meet properly without being forced. In aligning piping, you must check the pipe supports adjacent to the joint to be made up to determine that the hangers are properly supporting the line. Correcting improper hanger support can be accomplished by loosening up on the supports and then adjusting them to carry their share of the load. In some instances, it may be necessary to reface the flanges. The piping sections must be in alignment so that the flange bolts can be inserted freely without forcing either the bolts or piping.

The most practical way to cut a full-faced gasket is to lay the sheet packing over the flange and mark the cutting limits by light blows with a ball-peen hammer. The bolt holes must be cut slightly larger than the bolts so that any tendency for the gasket to bulge along the bolt circle is eliminated. A gasket cutter should be used to cut gaskets that fit inside the bolt circle.

Before making up a gasketed joint, all bearing and sealing surfaces must be cleaned thoroughly. Surfaces must be checked for signs of damage from erosion or steam cutting. Flanges showing damage must be refaced or replaced. Bolts and nuts that show signs of corrosion or other imperfections should not be reused. All bolts should be coated with an approved anti-seize compound.

The first time a remade joint is put under pressure, it should be carefully inspected. If

any sign of leakage is evident, all bolts should be tightened in small increments. If leakage continues after a new gasket has been used, an investigation for other possible causes should be made.

THREADED CONNECTIONS

Threaded connections have been used in piping systems in the past, to a considerable extent. Experience has proven that these connections are susceptible to shock damage and may become loose due to vibration. In present new ship construction, the use of threaded connections is not permitted in piping systems, except in a few special cases.

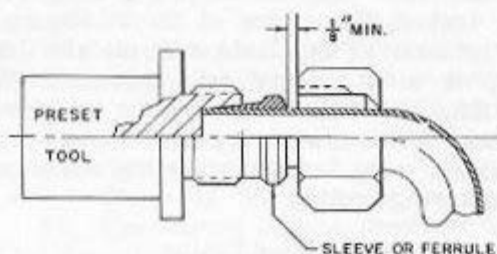
UNIONS

Unions are designed to seal against leakage under operating conditions; they have a ground joint, metal-to-metal surface, or for high-pressure air and oxygen service, they have an O-ring seal. The threaded union nut is required only to furnish mechanical strength for the joint, and does not have any of the fluid in the line acting on it. With a union joint, there is no reduction in pipe-wall thickness as there is with a threaded pipe joint.

When installing new lines of silver-brazed piping, not over 2 inches in diameter, sufficient union fittings and union fitting valves should be installed to facilitate repairs or alterations. Union joints may become loose due to vibration, and they should be checked for leakage at regular intervals.

FLARELESS FITTINGS

Flareless fittings (fig. 8-2) are suitable for use in hydraulic service and air service at a maximum operating pressure of 3000 psi and 250°F. Flareless fittings are installed where their use will conserve space, reduce weight, and reduce installation time and system cleaning time. Flareless fittings should not be used where there is insufficient space for proper tightening of the nuts, or where any equipment or piping must be removed for access to the fittings. One exception to this rule is a gage-board that is designed so that it may be removed as a unit for repairs or alterations. Flareless fittings should not be used where piping cannot be deflected easily to permit assembly and disassembly.



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Figure 8-2.—Typical flareless fitting.

Before assembly, the tubing end must be square, concentric, and free of burrs. In order for the fitting to be effective, the cutting edge of the sleeve or ferrule must bite into the periphery of the tube; this is accomplished by presetting the ferrule on the tube using either the fitting body intended for installation, or a presetting tool which has the same dimensions as the fitting body, and which is obtained from the manufacturer. The manufacturer's instructions should be referred to for the proper method of fitting and installing flareless fittings.

CARE OF SALT WATER SYSTEMS

Cast iron spools have given satisfactory service and protection against corrosion of tinned or bare copper and brass tubing; however, such spools have proved too vulnerable to shock and are not approved for service aboard combatant ships. These spools, as well as the zinc boxes formerly found in piping systems, have been completely eliminated. A spool of copper or brass, with a steel or iron waste sleeve inserted, may be used. The waste sleeve gives the same protection against galvanic corrosion as would be obtained from the use of cast iron spools, and also provides a source of waste material which is not a strength member of the piping system.

Piping 10 inches in size and smaller, used for salt-water service, should be of copper-nickel alloy tubing. Where bends are necessary they should be made by cold bending. Braze tube fittings are used with this tubing.

All tubing for salt-water service piping above 10 inches in size should be of copper. This tubing should be coated on the inside with wiping solder, grade D. This application should be made after all forming and fabricating operations have been completed. Both the inside and the outside of the tube must be cleaned thoroughly before

the solder coat is applied. Particular care should be taken to ensure that the solder coat is of uniform thickness and that there is positive adhesion between the solder and the tube in the vicinity of the bends, branches, and irregular shapes. Suitable holes may be cut in the piping at convenient locations to provide access for the necessary tools. These openings should be patched, subsequently, and the solder coat made intact with a flush surface on the inside.

In ferrous and nonferrous piping systems, replacement should be made in kind; that is, using the same material and protective coating as found in the remainder of the system, with the following exceptions:

1. When maintenance work becomes excessive on wrought iron piping in flushing systems, replacements may be made with copper-nickel tubing.

2. Replacements of machinery salt-water service piping, 2 inches and smaller, may be made with copper-nickel tubing when maintenance becomes excessive.

3. Individual sections of salt-water piping may be replaced with copper-nickel tubing, by repair ships or tenders, when specifically authorized by the force commander.

The life of SALT WATER PIPING may be lengthened by operating the systems with minimum practical water velocities; by eliminating grounds from electrical systems, especially d-c circuits; by eliminating air from the salt water systems; by promptly correcting any leaks; by insulating with sheet rubber the hangers which support piping other than that made of wrought iron or steel; and by eliminating wire-drawing, by fully opening valves where throttling is unnecessary.

PIPING REPAIRS

Most naval ships have all-welded main steam and feed piping. Welding-neck flanges with broad raised faces are used in this type of installation. A lap joint nipple is often used with smaller piping. The flange on a lap joint nipple swivels freely, facilitating lining up. Slip-on flanges are used with small piping involving low pressures and temperatures. These flanges are usually fillet-welded.

Brass fittings and valves suitable for naval piping are often supplied with a silver brazing alloy insert in the open end. When used with copper-nickel alloys and brass or copper pipes, the recessed openings are bored within close

tolerances to maintain predetermined clearances. These tolerances provide a small clearance area between the pipe and the fitting which will be entirely filled with silver brazing alloy upon completion of the brazed joint.

Slip-on brass fittings not provided with alloy inserts or threads are brazed to nonferrous pipe with the stick feed method. The operator must be skillful in manipulating the torch flame to ensure that the heat is applied at the proper point to cause the alloy to flow from the cooler to the hotter sections.

Temporary Repairs

Temporary Repairs may be made by simply securing a patch over the leak. The material used for the patch depends upon the purpose for which the piping is used. A good general rule is to make the patch from the same material that is used for flange gaskets in the piping. The patch is backed up with a piece of sheet metal and secured to the piping with bolted metal band clamps.

Red lead putty wrapped with canvas and served with marlin or friction tape makes an excellent, easily applied patch for low-pressure salt-water piping. A small leak in this type of piping often may be stopped by driving in a soft pine plug. The moisture will cause the wood to swell and remain in place.

Portland cement patches can be cast in place and secured by the band method. Iron cement can be used effectively on iron or steel piping carrying low pressures.

Figure 8-3 shows the details of a soft-patch device which can speedily be applied to remedy a defect in practically any size of piping to be repaired. This device has been tested on various piping sizes and has successfully withstood pressures up to 300 psi.

Semipermanent Repairs

Semipermanent repairs of leaky piping sections may be accomplished by serving the piping with wire drawn on tightly, soldering or brazing it as it is applied. Several layers of wire securely bonded provide a strong, tight repair.

A casting of soft metal may be formed around the piping. The section of piping should be removed and the leaks stopped with soft solder. The piping should be placed in a vertical position and filled with water above the level of the leaks. A sheet metal mold made

tight with fire clay should be placed completely around the piping at the leaks, and a molten mixture of available soft metals (lead, babbitt, or zinc) poured into the mold. The piping must be filled with water to prevent expansion when heated by the casting, and then pulling away from the casting when contracting during cooling.

Reshaping Dented Copper Piping

Copper piping sections that have been badly twisted or mangled may be brought back to normal roundness and shape by the following procedure: First, weld or rough patch all breaks or cracks and anneal the complete section. Then mount the piping on supports and close the ends with blank flanges. Fill the piping with water under pressure of 100 to 800 psi. While the piping is under pressure rough out the high spots with a mallet or forming hammer until the rounded or finished state has been achieved. This method may also be used on large seamed piping.

PIPING SAFETY PRECAUTIONS

The following safety precautions should be taken whenever you work on steam or hot water lines.

1. To prevent water rams, drain steam piping of water before admitting steam.
2. Before opening large steam valves, open bypasses to warm lines and equalize pressures; if bypasses are lacking, "crack" the valves.

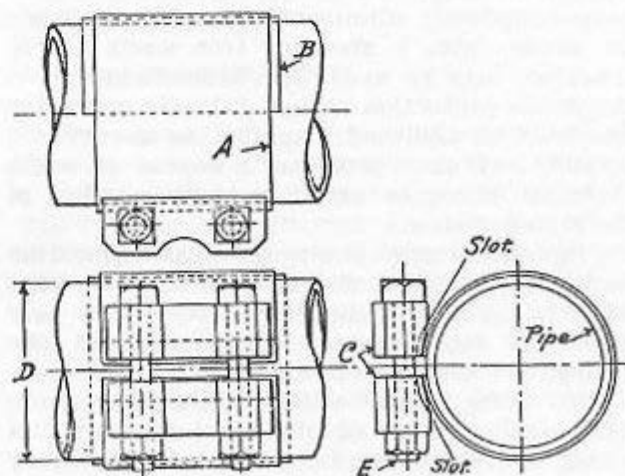


Figure 8-3.—Soft patch for emergency repair of leaking piping.

3. Open trap bypasses when admitting steam to piping.

4. When breaking a flange joint, particularly in steam and hot water lines or in those salt water lines which have a possibility of direct connection with the sea, special precautions should be taken to ensure that:

(a) There is no pressure on the line.

(b) The valves cutting pressure off the part of the line undergoing repair are secured in such a manner that they cannot be accidentally opened.

(c) The line is completely drained.

(d) Two of the flange-securing nuts (diametrically opposite if possible) remain in place while the others are being removed. The two remaining nuts should then be slacked sufficiently to allow breaking the joint. If the line is clear, all the nuts may be removed. This precaution is necessary to prevent accidents such as scalding personnel or flooding compartments.

5. After remaking a steam joint, tighten up on the nuts according to prescribed methods.

6. Do not use piping for handholds or foot-holds.

7. Secure copper and brass piping free from contact with bilges. The brackets should be lined with electrical insulating material to prevent direct contact between piping and any of the ship's structure.

8. Take all appropriate precautions to prevent fire and explosion when cutting into lines or breaking joints in systems that have contained flammable fluids.

REPAIRING INSULATION

Piping, machinery, and associated equipment should be inspected periodically for signs of broken, loose, or damaged insulation. The insulating materials to be used and the methods of application vary according to the service requirements. The following information concerning the application and maintenance of insulation is general in nature; for more specific details, see chapter 9390 (39), Bureau of Ships Technical Manual.

When replacing insulation after making repairs to a piping system, use the same kind of insulation that was used in the original installation.

Insulate all flanges and fittings with forms of insulation that are easily removable.

Fill and seal all air pockets and cracks in insulating material. Insulating cement is generally used for this purpose.

Seal the ends of insulation and taper them off to make smooth, airtight joints. At joint ends and at other places where insulation is likely to be damaged, use sheet metal lagging. (NOTE: Lagging serves to protect the piping and personnel from warm lines and acts as an insulation for that piping.)

Do not allow insulation or lagging to become damp. Moisture reduces the effectiveness of insulating material and may cause it to deteriorate.

VALVES

Valves are usually made of bronze, brass, cast or malleable iron, or steel. Steel valves are either cast or forged, and are made of either plain steel or alloy steel. Alloy steel valves are used in high-pressure, high-temperature systems; the disks and seats of these valves are usually surfaced with a chromium-cobalt alloy known as Stellite. This material is extremely hard.

Brass and bronze valves are never used where temperature exceeds 550°F. Steel valves are used for all services above 550°F, and in lower-temperature systems where internal or external conditions of high pressure, vibration, or shock would be too severe for valves made of brass or iron. Bronze valves are used almost exclusively in systems carrying salt-water. The seats and disks of these valves are usually made of Monel, a metal which has excellent corrosion-and erosion-resistant qualities.

TYPES OF VALVES

Globe valves are so called because of the globular shape of their bodies. A true globe valve is a stop valve. The disk, which is attached to the valve stem, seats against a ring or seating surface and thus shuts off the flow of fluid. When the disk is raised, fluid can pass through the valve. Globe valves may be used partially opened as well as fully opened or fully closed.

Globe valve inlet and outlet openings are arranged in several ways and are used to suit the requirement of flow. In the straight type, the fluid inlet and outlet openings are in line with each other. In the angle-type, the inlet and outlet openings are at an angle to each other. Angle-type globe valves are most commonly used where it is necessary to make a 90° turn in a line. The cross-type of globe valve has three openings. It

is frequently used in connection with bypass piping.

Globe valves may be installed so that the pressure is either above or below the disk. Figure 8-4 (A and B) shows pressure and temperature above the disk, and pressure under the disk. The method of installation is governed, in each case, by consideration of the service condition. Globe valves must be installed as specified on the appropriate blueprint.

Gate valves are used when a straight-line flow of fluid is desired. These valves operate on somewhat the same principle as globe valves, but have a wedge-shaped gate instead of a disk. Gate valves should never be used as throttling valves, since the flow of fluid against a partially opened gate can cause extensive damage to the valve.

The body of a plug valve is shaped like a hollow cylinder. Holes or ports in the cylinder wall line up with the pipe in which the valve is mounted. A solid cylindrical plug or, in some cases, a plug shaped like a truncated cone, fits snugly in the hollow cylinder. The plug is attached to a handle, with which the plug can be turned within the cylinder. A passage is bored through the plug. When the valve is in the open position, the passage in the plug lines up with the inlet and outlet port of the hollow cylinder, and fluid is thus permitted to flow through the valve. When the plug is turned crosswise in the cylinder, the solid part of the plug blocks the port and stops the flow of liquid. Three- and four-way cocks which allow selection of the routing of a fluid are usually variations of the plug valve.

A piston valve is a stop valve which may be thought of as a combination of a gate valve and a plug valve. The piston valve consists essentially of a cylindrical piston operating in a hollow cylinder. The piston is attached to the valve

stem, and the valve stem is attached to a handwheel. When the handwheel is turned, the piston is raised or lowered within the hollow cylinder. The hollow cylinder has ports in its wall. When the piston is raised, the ports are uncovered and the fluid is allowed to pass through the valve.

The tightness of this type of valve depends on the closeness of the fit between the piston and the inside of the cylinder. Some piston valves have metal rings on the piston; other types have fiber rings either on the piston or in the wall of the hollow cylinder. The fiber ring can be compressed by an external take-up device, so that it expands and thus prevents leakage.

Needle valves are stop valves that are used for making relatively fine adjustments in the amount of fluid allowed to pass through an opening. A needle valve has a point with a long taper at the end of the valve stem. This needle acts as a disk. The longer part of the needle is smaller than the orifice in the valve seat, and therefore passes through it before the needle seats. This arrangement permits a very gradual increase or decrease in the size of the opening, and thus allows more precise control of flow than can be obtained with an ordinary globe valve.

Check valves are used where it is necessary to permit fluid to flow in only one direction. A check valve opens when the pressure on the inlet side is greater than the pressure on the outlet side, and closes when the pressure on the inlet side is less than the pressure on the outlet side. Check valves usually open and close automatically although they may sometimes have a handle or a handwheel which may be used to lock the valve in a closed position or to limit the size of the valve opening.

Some valves function either as stop valves or as check valves, depending upon the position of

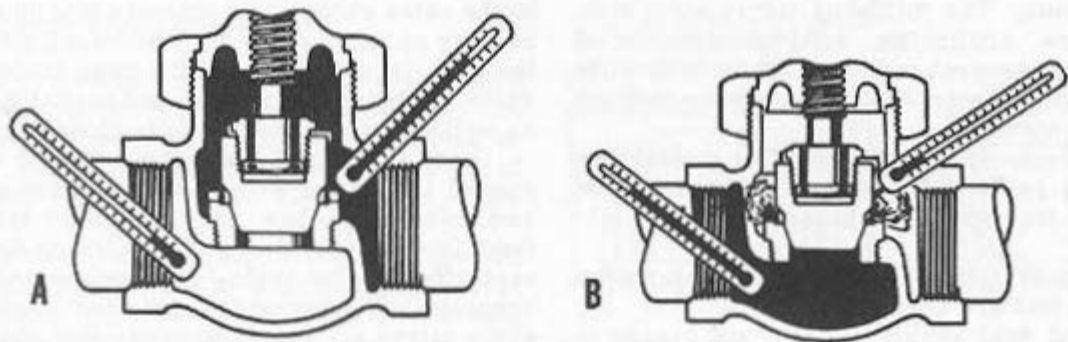


Figure 8-4.—(A) Pressure and temperature above the disk. (B) Pressure under the disk.

the valve stem. These valves are known as stop-check valves. The valve stem is long enough, in a stop-check valve, so that when it is screwed all the way down it holds the disk firmly against the seat, thus preventing any flow of fluid. In this position, the valve acts as a stop valve. When the stem is raised, the disk can be opened by pressure on the inlet side. In this position the valve acts as a check valve to allow the flow of fluid in only one direction. The amount of the opening is controlled by the position of the valve stem, and the amount of fluid allowed to pass through the valve is thereby regulated.

Relief valves are spring-loaded valves which may be set to open at a predetermined pressure.

Reducing valves are automatic valves which are used to provide a steady pressure lower than the supplied pressure. Reducing valves are used

on gland seal lines, galley steam lines, heating system lines, and on many other reduced pressure lines. A reducing valve can be set for any desired discharge pressure within the limit of the design of the valve. After the valve is set, the reduced pressure will be maintained regardless of changes in the supply pressure (as long as the supply pressure is at least as high as the desired delivery pressure) and regardless of the amount of reduced pressure steam that is used. Two general types of reducing valves are in common use: the spring-loaded reducing valve, and the pneumatic-pressure controlled (or gas-loaded) reducing valve.

The principal parts of a spring-loaded reducing valve (fig. 8-5) are (1) the main valve, an upward-seating valve which has a piston on top of its valve stem; (2) an upward-seating auxiliary

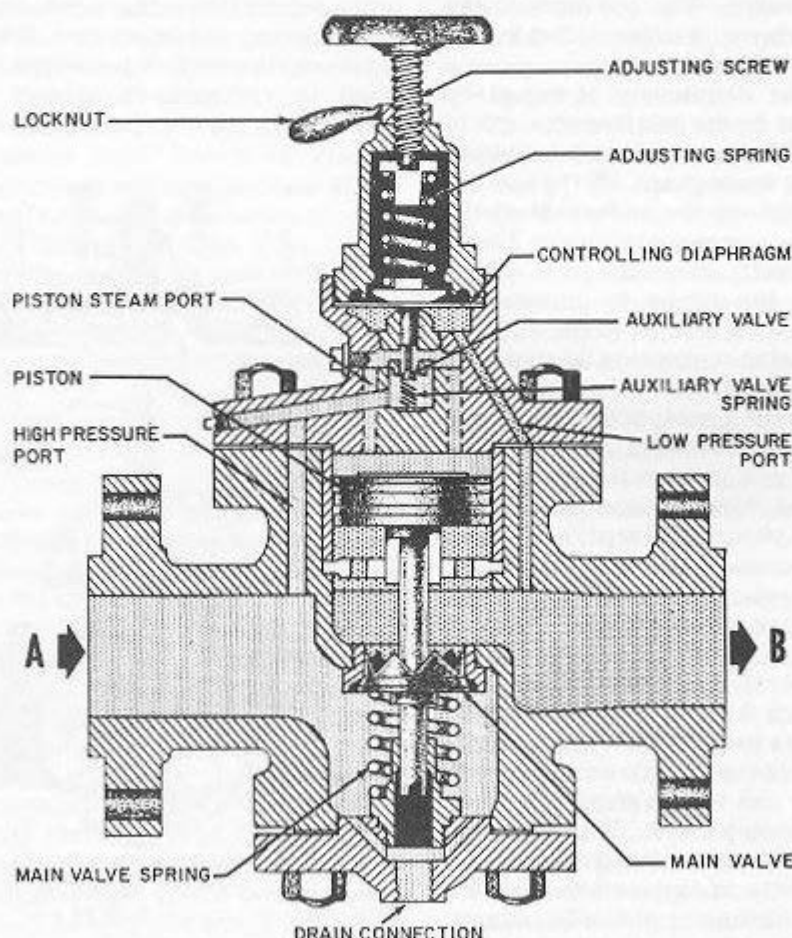


Figure 8-5.—Spring-loaded reducing valve, showing fluid flow.

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(or controlling) valve; (3) a controlling diaphragm; and (4) an adjusting spring.

High-pressure steam enters the valve on the inlet side and acts against the main valve disk, tending to close the main valve. However, high-pressure steam is also led through a port to the auxiliary valve which controls the admission of high-pressure steam to the top of the main valve piston. The piston has a larger surface area than the main valve disk; therefore, a relatively small amount of high-pressure steam acting on the top of the main valve piston will tend to open the main valve and allow steam at reduced pressure to flow out the discharge side.

The controlling diaphragm transmits a pressure downward upon the auxiliary valve stem and thus tends to open the valve. However, reduced pressure steam is led back to the chamber beneath the diaphragm; this steam exerts a pressure upward on the diaphragm which tends to close the auxiliary valve. The position of the auxiliary valve, therefore, is determined by the position of the controlling diaphragm.

The position of the diaphragm at any given moment is determined by the relative strength of two opposing forces: (1) the downward force exerted by the adjusting spring; and (2) the upward force which is exerted on the underside of the diaphragm by the reduced pressure steam. These two forces are continually seeking a state of balance; because of this, the discharge pressure of the steam is kept constant as long as the demand for reduced steam used is kept within the capacity of the valve.

Figure 8-6 shows the construction and indicates the manner of operation of a pneumatic-pressure-controlled reducing valve. A rubber diaphragm is installed in the middle of the dome. The bottom of the diaphragm is separated from the bottom half of the dome by a fixed-seal plate. The area immediately above the diaphragm communicates with the upper part of the dome through holes in the shrouding. The upper half of the dome carries a level of water for sealing; the lower half of the dome carries a level of glycerine for sealing. The area above the glycerine is charged with air which exerts a downward pressure on the glycerine and forces some of it to go up the tube toward the diaphragm. This pressure causes the diaphragm to move upward, and since the steam of the valve is in contact with the diaphragm, the upward movement of the diaphragm causes the valve to open. When the valve is open, steam can pass through.

From the outlet connection, an actuating line

leads back to the upper part of the dome, in the manner shown in figure 8-6. Steam at the reduced pressure is thus allowed to exert a force on the top of the water seal; this force is transmitted through the water and tends to move the diaphragm downward. When the pressure of steam from the actuating line exceeds the loading air pressure in the lower half of the dome, the diaphragm moves downward sufficiently to close the valve. The closing of the valve reduces the pressure of the steam on the discharge side of the valve. When the pressure on the outlet side of the valve is equal to the air pressure in the lower half of the dome, the valve takes a balanced position which allows the passage of sufficient steam to maintain that pressure.

If the steam load increases, tending to take more steam away from the valve, the outlet pressure will be momentarily reduced. Thus, the pressure of steam on top of the diaphragm becomes less than the pressure of air below the diaphragm, and the valve then opens wider to restore the outlet pressure to normal. If the load is reduced, it causes a momentary increase in outlet pressure, and this in turn

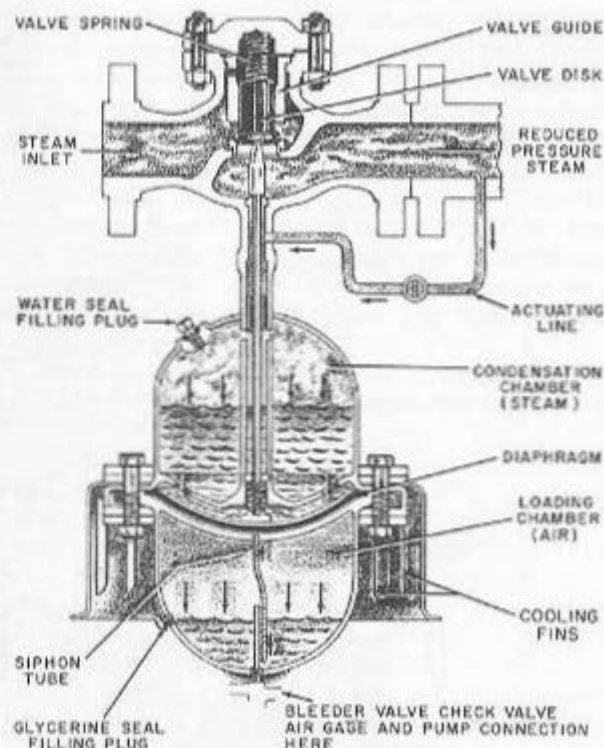


Figure 8-6.—Pneumatic-pressure-controlled reducing valve.

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increases the pressure on top of the diaphragm above that of the air pressure below it, causing the diaphragm to be displaced downward. The outlet pressure is again restored.

Thus, theoretically, the valve should deliver a steam pressure equal to the air pressure pumped into the lower half of the dome. However, since the valve itself has weight and is equipped with a light spring which tends to close the valve, it is necessary to introduce slightly more air pressure than is theoretically required. For the higher pressure valve, about 10 psi additional air pressure is required. If air is pumped in when the valve is cold, slightly less air pressure will be needed because the air pressure will increase slightly when the valve is warmed up.

The copper shroud extending outside the dome from the center flange appears only on the high-pressure valve. It is installed to allow for transmission of heat from the upper half of the dome to the atmosphere and to keep heat from passing into the lower half, where it may cause an excessive rise in the air pressure.

When the reducing valve is being put into operation, the discharge valve should be opened first. Then if the proper air pressure is in the dome, the inlet valve should be opened slowly, allowing the valve to heat up. The valve in the actuating line must be opened. It will be difficult to get these valves on the line unless some steam is being bled away from the discharge. It is desirable to have some steam leaving the valve when cutting it in.

Constant-pressure pump governors operate on much the same principle as spring-loaded reducing valves. There is, however, one important difference between the pump governor and the regular reducing valve. In the reducing valve, the reduced-pressure steam on the discharge side is used to exert an upward pressure on the diaphragm and so maintains a constant reduced pressure in the discharge line. In the constant-pressure pump governor, the discharge pressure of the pump (rather than the discharge pressure of the steam) performs this function. The pump discharge pressure is therefore kept constant, because this pressure regulates the flow of steam to the pump turbine. It is important to note that the pressure of the steam on the discharge side of the governor is not constant, but varies as necessary to keep the pump discharge pressure constant.

A constant-pressure pump governor for a lubricating oil service pump is shown in figure

8-7. The governors used on fuel oil service pumps and on main feed pumps are of the same type, except that the size of the upper diaphragm and the amount of spring tension differ on governors used for different services.

The adjusting spring exerts pressure downward on the upper diaphragm through a crosshead and mushroom arrangement. When there is no pump discharge pressure, the spring forces the upper diaphragm and the upper crosshead down. A pair of rods connects the upper crosshead with the lower crosshead so that the lower crosshead is moved down with the upper. When this happens, the lower diaphragm is pressed downward by the lower mushroom and the auxiliary valve disk is forced open. The auxiliary valve is always supplied with steam from the inlet side of the governor, and when the auxiliary valve is open, steam passes through a port to the top of the operating piston. The steam pressure on the top of the operating piston forces it downward and opens the main valve, thereby admitting more steam to the pump and increasing the speed of the turbine.

The increased speed of the turbine is reflected in an increased discharge pressure from the pump. This pressure is exerted against the underside of the upper diaphragm through an actuating line. When the force below the diaphragm is greater than the force represented by the tension of the adjusting spring, the diaphragm is forced upward. This causes a reduction in the size of the auxiliary valve opening and allows a spring to start closing the main valve against the now reduced pressure on the operating piston. When the main valve starts to close, the steam supply to the turbine is reduced, the pump is slowed, and the discharge pressure is decreased.

Steam from the main valve outlet is led through ports to chambers above and below the sealing diaphragm. A needle valve and a surge chamber are used to delay and minimize the effects of the main valve outlet pressure changes upon the pressure above the sealing diaphragm, thus serving to dampen excessive reactions of the auxiliary valve to variations in pump discharge pressure.

With the unit under constant-load conditions, the operating piston takes a position which holds the main valve open by the required amount. A change in load conditions results in momentary hunting by the governor, until it finds the new position required to maintain pressure at the new load.

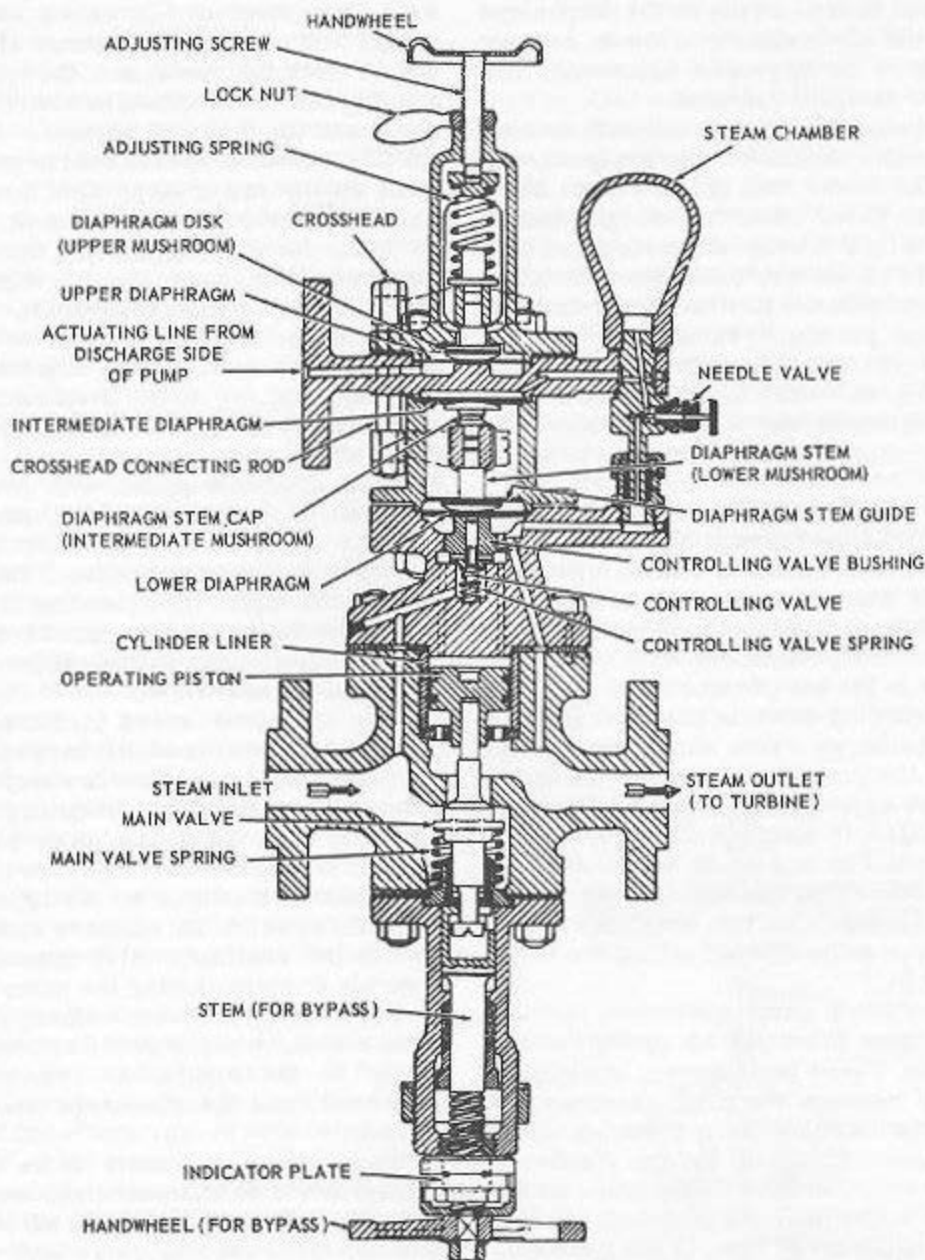


Figure 8-7.—Constant-pressure pump governor.

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Two adjustments are required on the constant-pressure pump governor: (1) the adjusting screw must be set to regulate the discharge pressure of the pump; and (2) the needle valve must be set to minimize hunting. The adjustments of the needle valve should be made while the pump is operating under a light load at normal discharge pressure.

The constant-pressure pump governor may be set for either automatic control or manual control. Under normal operating conditions, the automatic setting is used. When it is desired to control the pump manually, the valve stem below the main valve must be set to hold the main valve fully open. In this position, the valve allows a full flow of steam to the turbine, and control of

turbine speed must, therefore, be achieved by means of hand throttling.

MAINTENANCE OF VALVES

Valves, like other units of equipment, require proper care and maintenance. Valve troubles should be corrected as soon as possible.

Internal valve leakage is generally a result of the disk and the seat failing to make a tight joint; and this failure may be due to one of the following causes:

1. Foreign substances (scale, dirt, waste, or heavy grease) are lodged on the seat in such a way that the disk cannot be seated. If the obstructing material cannot be blown through, the valve will have to be opened and cleaned out.

2. Scoring of the seat or disk has been caused by attempts to close the valve on scale or dirt, or by corrosion. If the damage is slight, the valve may be made tight by grinding the disk together with the seat; if the damage is extensive, a cut will have to be made on the disk, and the valve seat ring may have to be renewed before it is ground.

3. The disk may not seat properly because of a bent spindle guide, or a bent valve stem.

4. The valve body or disk may be too weak for the purpose for which it is used, causing distortion of the valve seat or disk under pressure.

5. In bronze valves fitted with seat rings, leakage through the valve may occur as the result of leakage around the threads of the seat rings. To correct this defect, remove the seat rings, clean the threads, and remake the joint. It may be necessary to recut the threads in the valve and to renew the seat ring to secure tightness.

6. Leakage may be caused by a loose valve disk. When a valve disk comes loose from its stem, the cause is either failure of the securing device or corrosion through the stem. The first cause is infrequent in valves of good construction, and recurrence of the failure can be prevented by minor adjustments or by greater care in reassembling valve parts.

Corrosion of the valve stems occurs mostly to valves installed in salt water lines. Stems which have shown signs of corrosion should be inspected periodically so that replacement can be made before failure occurs. Replacements should be made with rolled Monel-metal stems. In order to prevent failure caused by corrosion,

split pins used in valve disks in the waterlines should be of nickel-copper alloy instead of iron, steel, or brass.

When a valve is disassembled for repairs, there are several steps that must be taken to ensure that the valve will be in proper condition when it is reassembled.

During disassembly every precaution should be taken to prevent damage to gasket surfaces and each part of the valve. When the valve is disassembled, all parts should be thoroughly cleaned and inspected for excessive wear. Seating surfaces should be inspected to determine whether lapping, grinding, or machining is required to restore them to a tight fit. Gasket surfaces may be corroded or steam cut. The stem must be carefully checked (1) for straightness, (2) where the packing fits, and (3) at the threaded section.

If the seating surface has become badly corroded or is so deeply scored that excessive lapping would be required to remove the damaged areas, machining will be necessary. A reseating machine may be used. The proper size cutter must be used in the reseating machine and light cuts must be taken until the damaged areas are removed. If the seating surface is made from a metal that is too hard for a reseating machine to cut, the work will have to be done in a lathe.

After the machining is completed, the seat should be lapped to ensure that it will have the smoothest possible finish. The lap must be of the exact same size and shape as the valve disk so that the valve seating surface will be true. For more information on lapping valve seating surfaces, refer to the manufacturer's technical manual for the specific unit.

An inspection should be made of the disk seating surface to determine whether lapping or machining will be required for reconditioning. If machining is required, light cuts should be taken until the damaged areas are removed. If excessive wear or severe pitting has taken place, the machining required to remove the damage may be extensive enough to warrant installing a new disk.

Reassemble the valve using new gaskets and packing. Be sure that all parts move freely as assembly progresses. Do not tighten the packing nut more than is necessary to prevent excessive leakage.

In any instance where new parts are required for a valve, the material must be the same as was in the original parts.

Pressure Reducing Valves

There are several types of pressure reducing valves installed on Navy ships. The most common types are the pneumatic reducing valves and the spring-loaded reducing valves. Some of the maintenance procedures for these valves are discussed in the following paragraphs.

PNEUMATIC REDUCING VALVES.—The most probable causes of erratic operation of the pneumatic reducing valves are incorrect pressure in the loading dome or an accumulation of dirt or other foreign matter on the surface of the moving parts. The condition of improper loading pressure is easily remedied by increasing or decreasing the pressure of the gas or air to maintain the proper outlet pressure.

If the cause of improper operation is the presence of dirt or other foreign matter, the only remedy is to disassemble the valve and clean all parts. The valve may be disassembled in place, or removed from the piping and disassembled. When the valve is disassembled, clean all parts with an approved solvent and a bristle brush or soft cloth. **NEVER USE AN ABRASIVE MATERIAL TO CLEAN VALVE PARTS.** If the usual cleaning methods will not remove hardened deposits of oil or other foreign matter, the part may be cleaned by scraping with a sharp tool; extreme caution is necessary to prevent damage to the surface finishes. Particular attention must be given to cleaning all guide surfaces, to ensure that all moving parts will move freely without binding.

Another possible source of trouble is leakage around the seating surfaces of the disk and seat ring and the joint between the seat ring and the body. If leakage occurs at these points the valve will not operate properly. A careful inspection must be made of these surfaces and if leakage is present, the seat ring and disk may be reconditioned by lapping or grinding. If the joint between the seat ring and the body is leaking, a new seat ring must be installed.

All parts must be inspected for excessive wear; pay particular attention to the valve spring and the diaphragm spring. If either is broken or permanently set, a new spring must be installed.

When the valve is reassembled and installed, it should be tested by opening the outlet valve and cracking the inlet valve to thoroughly warm up the valve. The dome should be pressurized with air or gas to about 10 psig more than the desired outlet pressure.

SPRING-LOADED REDUCING VALVES.—

Failure of the spring-loaded reducing valve can usually be traced to one or more of the following causes:

1. Ruptured diaphragm.
2. Leakage through the disk seat or seat ring threads.
3. Ports stopped up with dirt or other foreign matter.
4. Grooves in the bore of the sleeve.
5. Cup leather leaking.

In the event the diaphragm ruptures, there will be no control over the flow of liquid through the valve. The diaphragm can be renewed without removing the valve from the piping system.

All tension must be taken off the adjusting spring, and then the diaphragm nuts can be removed from their bolts. Next the spring chamber can be lifted off the valve body. This provides access to the diaphragm, which can be removed, then a new one can be installed and the valve reassembled. The diaphragm should always be renewed when there is indication of deterioration.

At any time that disassembly of the valve is necessary, all parts of the valve should be cleaned and inspected for excessive wear. Cleaning should be done with an approved solvent and a soft brush.

Particular attention should be given to cleaning the guide surfaces between the seat ring and wing guides and to the guide surfaces of the sleeve.

The seating surface of the seat ring should need little repair but in the event it is scored or otherwise damaged, it should be lapped in, using the same process as described for other valves. If the damage to the seating area is excessive or the bore is badly worn, a new seat ring should be installed.

If there are signs of deterioration of the disk seat, it should be renewed. If a new disk seat is not available, turning the seat over will provide a new seating surface; however, this should be considered as a temporary repair, and a new disk seat should be installed as soon as it is available.

If the cup leather shows signs of leaking or deterioration, it should be renewed. The bore of the sleeve should be inspected for excessive wear or corrosion. If there is excessive damage to the sleeve, it should be renewed. If the

sleeve is only slightly damaged, the damage can be corrected by machining the surface in a lathe. Use extreme care to ensure that the bore is concentric, has a smooth finish, and is not enlarged to the extent that leakage will occur when the cup is installed.

Relief Valves

Relief valves are installed on piping and units of machinery where excessive pressure may build up and damage equipment or endanger personnel. Relief valves are set to lift at the proper pressure by increasing or decreasing the tension on the spring.

Failure of the valve to function properly is usually due to an incorrect setting of the spring, leakage between the disk and seat, leakage around the threads of the seat ring, cocking of the disk or stem, or an accumulation of dirt or other foreign matter around the working parts.

In most instances, relief valves may be disassembled in place or they can be removed from the piping, when repairs are necessary. The first step in disassembling a relief valve is to release all tension on the adjusting spring. This is accomplished by loosening the locknut and then loosening the adjusting nut. (Some relief valves are fitted with a test lever which must be removed before the spring tension can be released.) The top assembly can be removed by either removing the nuts on the yoke bolts or by unscrewing the top assembly from the body of the valve (depending on the construction of the valve). The disk can then be removed and the seating surfaces can be inspected. The seating surfaces can be reconditioned by lapping, grinding, or machining in the same manner as would be done with a globe valve.

All surfaces used for guide purposes should be inspected for burrs or other defects which may interfere with the free movement of the working parts. Parts which are worn excessively, are bent, or are in any way unfit for further service must be replaced. When it is necessary to replace parts, those supplied by the manufacturer should be used, if obtainable.

When a relief valve has been overhauled, it is generally tested for leaks before installing it in the piping system or on a unit of machinery. It is far more practical to mount the valve on a test stand (if available) and conduct a hydrostatic test and then set the relieving pressure at the desired amount, than it is to test it after installation.

On some relief valves, an adjusting ring has been provided so that blowdown (reseating pressure) as well as the relieving pressure can be adjusted. The position of the ring may be raised or lowered in relation to the disk, by removing the adjusting ring setscrew and moving the ring to the desired position. Raising the ring will increase the blowdown period and lowering the ring will decrease the blowdown period.

Constant Pressure Governor Maintenance

The following paragraphs deal with maintenance of constant pressure governors. For more complete details on operation and maintenance of these governors, consult the manufacturer's technical manual.

The most common cause of improper operation of these governors is dirt or other foreign matter being carried into the governor and interfering with the operation of the moving parts. The only remedy is to disassemble the governor and thoroughly clean all parts.

Failure of the governor to properly regulate the pump discharge pressure may also be caused by one or more of the following reasons:

1. Leakage around the seating surfaces of the control valve, the main valve, or the threads of their respective seat rings.
2. A main valve spring or a controlling valve spring that is broken, is weak, or that has taken a permanent set.
3. A broken, cracked, or excessively deformed diaphragm.
4. Improper adjustment of the needle valve.
5. Too little or too great a clearance between the control valve and its diaphragm.
6. Clogged ports in the diaphragm chamber.
7. Binding of any moving parts.

This is not a complete list of reasons for failure of constant pressure governors, but it does cover the most common causes.

REMOVING FOREIGN MATTER.—When a constant pressure governor acts sluggishly or erratically because dirt or other foreign matter is interfering with the free movement of working parts, the governor must be completely disassembled, and all parts cleaned. The manufacturer's technical manual gives a step-by-step procedure for disassembly. Extreme care must be taken in the removal of all parts, and in the

cleaning. The parts may be cleaned with an approved solvent and a soft brush. If this cleaning method fails to remove hardened deposits, a sharpened tool may be used with extreme caution.

CYLINDER LINER.—Particular attention should be given to cleaning the seat for the cylinder liner. The cylinder liner must fit properly to prevent it from projecting above the body flange. The bore of the main valve guide must also be carefully cleaned. As each part is cleaned, it should be carefully inspected for excessive wear. If it is necessary to renew parts, use only parts furnished by the manufacturer.

CONTROL AND MAIN VALVES.—If there is leakage through the control valve or its bushing, steam will flow to the top of the main valve, and hold it open, even though there is no tension on the adjusting spring. The main valve must be able to close off completely or else the governor cannot operate properly. The only remedy for this situation is to disassemble the governor and stop the steam leakage. In most instances, the control valve must be renewed. If the leakage is through the bottom of the bushing and its seat, the seat must be lapped. A cast iron lap is best for this type of work.

The lap should be rotated through a small angle of rotation, lifted from the work occasionally, and moved to a new position as the work progresses. This will ensure that the lap will slowly and gradually rotate around the entire seat circle. Do not bear down heavily on the handle of the lap, and take particular care not to bear sideways on the lap. Replace the compound often, using only clean compound. If the lap should develop a groove or cut, redress the lap. Lapping should never be continued longer than is necessary to remove all damaged areas.

When you are installing the control valve and its bushing, remember that the joint between the bottom of the bushing and its seat is a metal-to-metal contact. The bushing must be installed tightly; and when it is all the way down, the wrench should be tapped lightly with a hammer, to ensure a steamtight joint.

When the controlling valve is installed, the clearance between the top of the valve stem and the diaphragm must be checked. It is absolutely mandatory that this clearance be between .001 and .002 inch (fig. 8-8). If the clearance is less than .001 inch, the diaphragm will hold

the control valve open, allowing steam to flow to the main valve at any time the throttle valve is open. If the clearance is more than .002 inch, the diaphragm will not fully open the control valve—which means that the main valve cannot open fully, and the unit cannot be brought up to full speed and capacity.

In the event the main valve seating area is damaged, it must be lapped in by the same process. ALWAYS lap in the main valve with the piston in the cylinder liner to ensure perfect centering.

If the damage to the seating surfaces is excessive, new parts must be installed; use only parts supplied by the manufacturer, if available.

TOP CAP.—In the event the top flange of the top cap becomes damaged, extreme care must be taken in machining it. The manufacturer's technical manual must be consulted for the correct clearances. (See fig. 8-8.) All seating surfaces must be square with the axis of the control valve seat threads and must have the smoothest possible finish. Before the reassembly is started, all ports in the top cap and diaphragm chamber must be free of dirt or other foreign matter. A check should be made to ensure that the piston rings are free in their grooves. The cylinder liner must be smooth and free of grooves, pits, or rust.

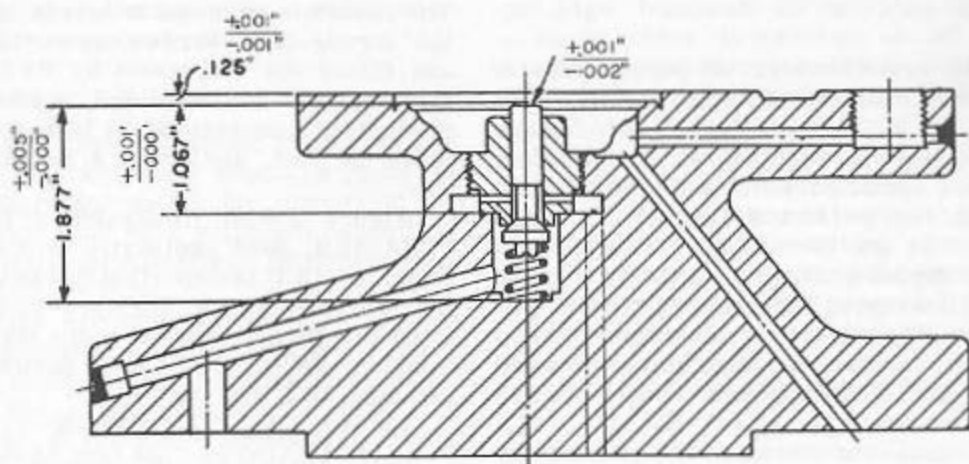
When installing the cylinder liner, make certain that the top of the liner does not extend above the top of the valve body. The piston must work freely in the liner; if there is binding, the governor will not operate satisfactorily. The controlling valve spring and the main valve spring should be renewed if they are weak, broken, or corroded, or if they have taken a permanent set. If necessary, renew all diaphragms; if the old diaphragms are used, they should be reversed.

The instructions in the manufacturer's technical manual should be followed in reassembling the governor. All clearances must be as designed if the governor is to operate satisfactorily. Each moving part must be carefully checked to ensure freedom of movement.

When the governor is reassembled, it should be tested as soon as possible so that corrections, if necessary, can be made.

Inspection of Sea Valves in Drydock

When a ship is in drydock, the engineer officer should see that all outboard valves are



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Figure 8-8.—Important points in cleaning and reassembling a top cap assembly.

inspected and entries made in the engineering log. The inspection must include the following: yoke, yoke rods, securing bolts, and internal valve parts (stem, disk, disk securing device, tightness of valve, and the threads of the valve stems of the main injection and overboard discharge gate valves).

On each outboard valve, at least two of the bolts holding the valve to the sea stool should be removed and inspected. The other bolts should be sounded with a hammer. If any bolt is defective, all the bolts of that valve must be removed for inspection. In addition, the gaskets should be inspected, and renewed if necessary.

When sea gate valves are assembled, the gate should be in the half-open position before the bonnet bolts are tightened. This ensures that the guides in the valve bonnet align properly with the guides in the valve body.

REMOTE-CONTROL OPERATING GEAR

Remote-control operating mechanisms for emergency purposes are installed at various control points outside the space where the valves are located. In addition, there are remote-control mechanisms for other than emergency purposes; these mechanisms are generally located at operating stations. On board ship, there are generally three types of remote operation: (1) manual, (2) hydraulic, and (3) pneumatic.

Remote operating gear is installed to permit operation of valves from remote control points when the compartments within which the valves

are installed are untenable. For this reason it is imperative that these valves and their operating gear be kept in the best possible mechanical condition.

All remote operating gear should be lubricated and valves operated through their full travel from remote control points at least once each week. This inspection, if not already included, should be incorporated in the weekly test and inspection sheet.

Flood valve and steam smothering system control valve operating gear should be inspected in accordance with specific instructions.

Steam smothering system control valve operating gear should be operated through the full valve travel at the same time that the steam smothering system is undergoing its periodic test.

If the remote control gear jams as a result of structural damage, an immediate inspection should be made of the installation, to determine the advisability of disconnecting the gear at the valve. Any deficiencies located during this inspection should be corrected as soon as possible.

APPLIANCES FOR PIPING SYSTEMS

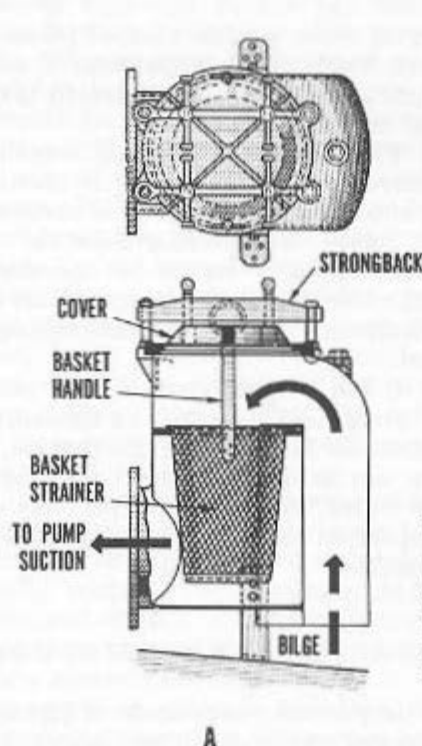
Important components of piping systems, not covered previously in the chapter, are: strainers, steam traps and drains, meters, expansion points, and steam whistles. Information concerning maintenance and repair of such appliances is given in the paragraphs which follow.

STRAINERS

Strainers are fitted in all piping lines to prevent passage of foreign matter which may obstruct pump or throttle valves, or damage machinery parts to which piping is connected. Strainers are installed so that the flow is into and through the perforated basket. In some places, such as the forced lubrication and fuel oil lines, a duplex strainer is fitted so that the flow is not interrupted when closing one strainer for cleaning. The valves or plug cocks should be marked to indicate the direction of flow and arranged so that both strainers cannot be closed off at the same time.

The installation of strainers in suction lines to the main lubricating oil pumps and the fuel oil service pumps has been discontinued in new installations.

Figure 8-9(A) illustrates a common BILGE SUCTION STRAINER. This strainer is located in the bilge pump suction line between suction manifold and pump. Any debris which enters the piping will collect in the strainer basket.



The basket is removed for cleaning by loosening the strong-back screws, removing the cover, and lifting out the basket by its handle. These strainers should be cleaned, in accordance with prescribed instructions, at least every 24 hours while in port, and every 4 hours while under way.

Figure 8-9(B) illustrates a DUPLEX OIL STRAINER, used ordinarily in fuel or lube oil lines, where it is important that an uninterrupted flow be maintained. The flow may be diverted from one strainer basket to the other, while one is being cleaned. The shutoff device works on the principle of a four-way cock.

Figure 8-9(C) illustrates a MANIFOLD STEAM STRAINER. This type of strainer is desirable where space is limited, since it eliminates the use of separate strainers and their fittings. The cover is located so that the strainer basket can be easily removed for cleaning.

A clean SPARE STRAINER basket of correct size (plainly marked or tagged) should be kept convenient to each strainer location. If the removed basket is heavily encrusted with foreign

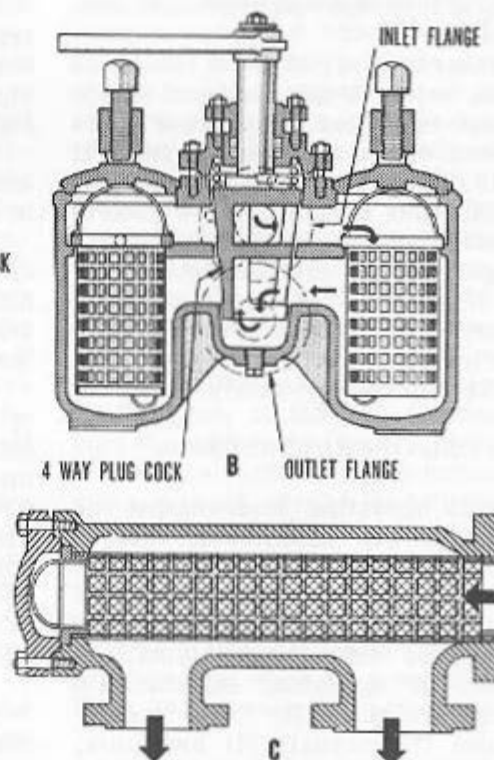


Figure 8-9.—(A) Bilge suction strainer. (B) Duplex oil strainer. (C) Manifold steam strainer.

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matter, clean the strainer with a steam jet or boil in a boiler compound solution.

STEAM TRAPS AND DRAINS

Steam traps must be located below the lowest point to be drained and should be placed so as to be easily accessible for inspection and repair. A trap must have sufficient capacity to handle the maximum quantity of condensate that will reach it at any time.

Steam traps are installed in steam lines to remove condensate. All steam traps consist of a valve and some device or arrangement which will cause the valve to open and close, as necessary, to drain the condensate from the line without allowing the escape of steam. A trap that has been functioning properly can be overloaded if additional drains are led to it as a result of piping alterations.

Types of Traps

The four types of traps used on naval ships are: (1) thermostatic traps, (2) ball-float or open-bucket traps, (3) impulse traps, and (4) continuous flow traps (without moving parts).

THERMOSTATIC TRAPS. These are lightweight types of traps of compact design. The discharge through the thermostatic trap is controlled by expansion of vapor from a volatile liquid enclosed in a bellows-type element. These traps are primarily used for draining heating systems and auxiliary exhaust drain lines. Use is limited to pressures under 100

psi gage. Inasmuch as this type trap requires a temperature differential of 10° to 30°F, a length of pipe is required for cooling, between the unit drained and the trap. A thermostatic steam trap is shown in figure 8-10.

BALL-FLOAT OR OPEN-BUCKET TRAPS. Compared with the thermostatic or pulsating types, these traps are larger, weigh more, and have additional working parts. The ball-float trap is occasionally used where the working pressures do not exceed 100 psi. The inverted bucket traps are suitable for all services and pressures.

IMPULSE TRAPS. These traps are suitable for all services where the discharge pressure is not more than 25 percent of the line pressure. They are very compact but have a definite steam leak when the condensate increases.

CONTINUOUS FLOW TRAPS (WITHOUT MOVING PARTS). These traps are suitable where condensate formation is continuous and relatively constant. With a large reduction in condensate, the steam leakage may be too great for the system. These traps should not be used where slugs of water are developed.

A strainer, installed ahead of each steam trap, must be kept clean and in good condition to prevent scale or other foreign matter from getting into the trap itself. If the trap valve does not open or close properly, the difficulty is probably due to scale clogging the control orifice, the orifice in the valve seat, or the space between the flange and the cylinder.

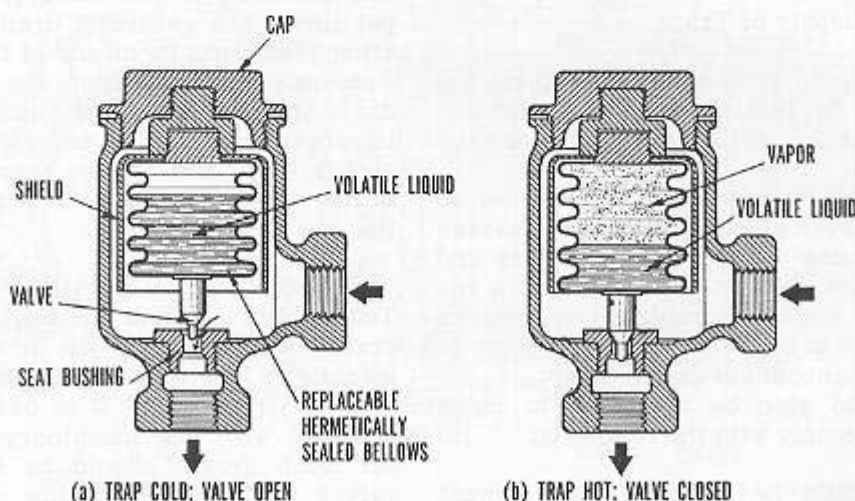


Figure 8-10.—Thermostatic steam trap.

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If either the cylinder or the disk is damaged, the complete unit should be replaced. Replacement of either part separately might result in improper clearance between the flange and the cylinder.

Inefficient Operation of Traps

The principal causes of faulty operation, and the remedies, are:

1. **PUNCTURED FLOAT OR BUCKET.** Remedy: Repair leak.
2. **WORKING PARTS ADRIFT.** Remedy: Secure the parts in place with additional securing devices to prevent repetition of the trouble.
3. **VALVE DOES NOT SEAT PROPERLY:**
 - (a) Remedy: Use the hand tripping device, if provided, to dislodge any dirt or scale caught under the valve.
 - (b) Remedy: Break the trap down and clean it.
4. **AIR-BOUND.** Remedy: Relieve by opening the air cock. When a cold trap is to be operated, leave the air valve open until steam or water issues from it.
5. **SEDIMENT IN BOTTOM OF TRAP.** This condition may prevent proper operation. Remedy: Blow out if possible; otherwise, break the trap down and clean it.
6. **OPEN OR LEAKY BYPASS VALVES.** Remedy: Close or tighten the valve.

Inspection and Repair of Traps

All traps should be inspected quarterly and those found to be leaking should be repaired immediately. Leaky traps waste an enormous amount of steam.

Traps should be adjusted, if possible, so that steam is never discharged, as the passage of steam produces erosion. Trap valves and valve seats which have given trouble as a result of erosion should be replaced with valves and seats made of nickel-copper alloy, or of steel faced with chromium-cobalt alloy.

Traps should also be inspected to make sure that they comply with the following:

1. They should be located at the lowest point to be drained.
2. They should be placed where they are accessible for inspection and repair.

3. They should not be subjected to pressures higher than designed pressure.

4. They should not be subjected to a discharge head pressure of more than 1 foot of water for each 2 pounds of pressure within the trap.

Every trap other than thermostatic is normally fitted with a small atmospheric test valve installed in the discharge line between the trap and the trap discharge cutout valve. To test the operation, close the discharge cutout valve and open the test valve. The trap should then be tripped and it should be noted whether or not the trap shuts off properly. Some steam will accompany the discharged condensate because of reevaporation of a portion of the condensate at a temperature of 212°F, and atmospheric pressure. However, a sizzle of steam after the trap shuts off indicates a leak. Impulse traps require about 3 percent of full condensate capacity to prevent the discharge of live steam. If the cutout valve leaks, a false indication will be given when the drain line is under pressure from some other leaky trap. To determine the source of leakage, close the trap inlet valve. If the sizzle stops, the trap is leaking; if it continues, the discharge cutout valve is leaking.

Principal Drain Systems

All steam systems are drained through a closed system. On the newer ships, the main and auxiliary steam lines, including the 150-psi lines, are generally drained to the deaerating feed tanks by means of the impulse traps. For underway operation the pressure in the drain line for main and auxiliary steam lines is approximately 35 psi gage. Whistles and sirens, also drained by impulse traps, drain to the same tank, but through an independent line.

FRESH-WATER DRAIN COLLECTING SYSTEM.—This system consists of atmospheric drains leading from the lowest point of all machinery parts where fresh water may collect and from which it is desirable to remove drainage when the machinery is not operating. All such drains should be fitted with drain valves and open sight-flow devices (funnels) arranged to prevent the entrance of foreign matter into the system. Any atmospheric drain from a closed fireroom discharging to this

system should be fitted with a water seal (U-bend or equivalent) which will prevent leakage of air from the fireroom when the latter is under an air pressure up to 1 1/4 times the maximum specified for the particular ship.

SALT-WATER AND OTHER CONTAMINATED LEAKAGE DRAIN COLLECTING SYSTEM.—This system is installed to collect salt-water drainage and oil leakage from machinery which normally operates with leakage; its purpose is to keep the bilges dry. The system carries this leakage to the bilge sump tank, and it is then pumped to a contaminated oil tank, where the oil is allowed to settle out and the water remaining is pumped overboard.

METERS

Meters become unreliable from friction, leakage, or erosion, and should be overhauled and tested when they fail to register properly. To prevent rapid wear, meters should never be operated at maximum capacity for prolonged periods of continuous flow. One-half the capacity is recommended.

All meters, except fueling meters, are considered satisfactory if they show errors of less than three percent. Fueling meters should not show in excess of a two percent error.

The ordinary type of meter can be opened at the bolted flange without disconnecting the meter from the line. Any troubles can usually be located in the submerged parts and can be rectified by cleaning the parts and removing any foreign matter. If the meter is equipped with a hard-rubber disk and the disk is found to be warped or swelled, it must be renewed. If a meter is consistently inaccurate, the matter should be referred to the Naval Ship Systems Command.

EXPANSION JOINTS

Expansion joints of various types are installed at suitable intervals in long steam lines, because of the expansion and contraction of metal subjected to a wide range of temperature. The types include the slip joint, expansion bends, corrugated joints, and bellows joints.

The **SLIP JOINT** (fig. 8-11) is used for low pressures, such as auxiliary exhaust piping. A slip joint consists of a stuffing box, packing gland, male sliding tube, female receptacle tube, and stop bolts (to prevent separation of male and female sections of the joint).

EXPANSION BENDS are employed for high pressure and high temperature steam piping in preference to the slip joint. Expansion bends are merely loops of piping of proper length and configuration to take up the changes in pipe length caused by temperature changes. The expansion

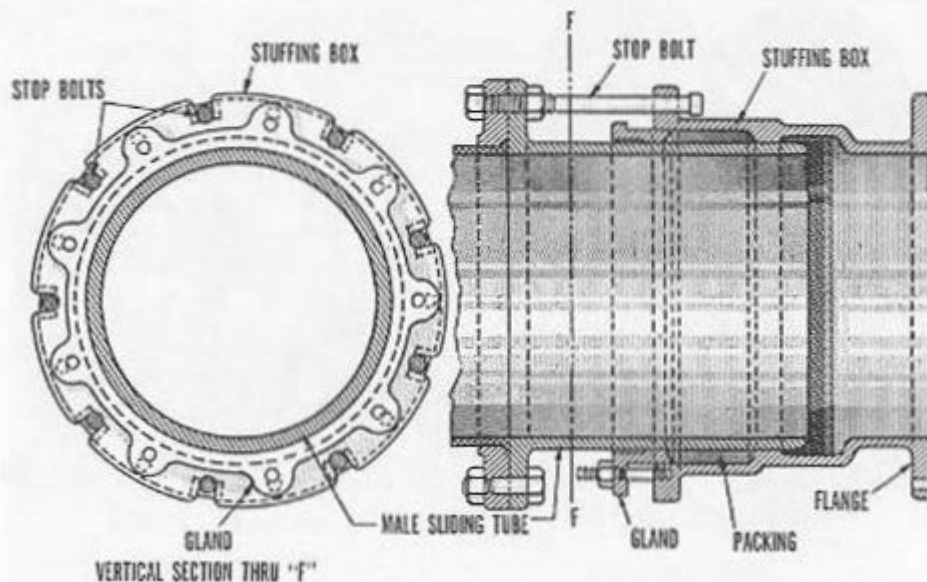


Figure 8-11.—Slip type expansion joints.

bends take many shapes—most common are the U-bend, Z-bend and L-bend.

The CORRUGATED and BELLOWS TYPES of expansion joints (fig. 8-12) are used for both medium and high pressures and temperatures. The principle of these joints is obvious: the expansion-contraction movement is absorbed by the changing curvature of the corrugations or bellows (as with an accordion). The internal sleeves, free to slide axially in these joints, serve to prevent excessive turbulence and erosion of the expansion parts. Figure 8-13 illustrates a corrugated BULKHEAD EXPANSION JOINT, which is designed to provide for both radial and axial movement of piping, with respect to the bulkhead.

Expansion joints must be kept in effective working condition. Indications should be fitted on expansion joints so that it can readily be seen whether or not the joints are working properly.

Expansion joint bodies must be anchored securely so that movement is confined to the part designed to slip. The limiting bolts must be kept adjusted to allow maximum expansion and contraction without danger of the joints pulling apart.

STEAM WHISTLES

The diaphragm type of steam whistle (Fig. 8-14) is typical of the type used on modern

ships. Before testing the whistle, remove the diaphragm leaves by unscrewing the back cover, and turn on the steam at least 30 minutes, with all drains open and traps operating. With the diaphragm removed, operate the whistle valve several times in order to blow out the pipe lines thoroughly. Replace the proper number of leaves and tighten the back cover before testing. The leaves are marked so that they may be installed properly; all leaves must have the high side facing towards the nozzle.

If water comes out through the horn or around the stem of the operating valve while the whistle is being tested, or if the note is not clear from the beginning of the first blast, immediately check all associated traps. If the traps are not functioning properly, they should be bypassed until put into working order.

The diaphragm of a steam whistle must be inspected and cleaned every three months. Damaged leaves must be removed and replaced. After the leaves have been cleaned and positioned properly, the whistle must be retested.

The operating valve should also be checked when the diaphragm is examined. If the operating valve is leaking, it should be removed and ground in to obtain a good clean seat. The seat is generally locked in place with a setscrew and can be removed only with a proper wrench and after the setscrew has been loosened.

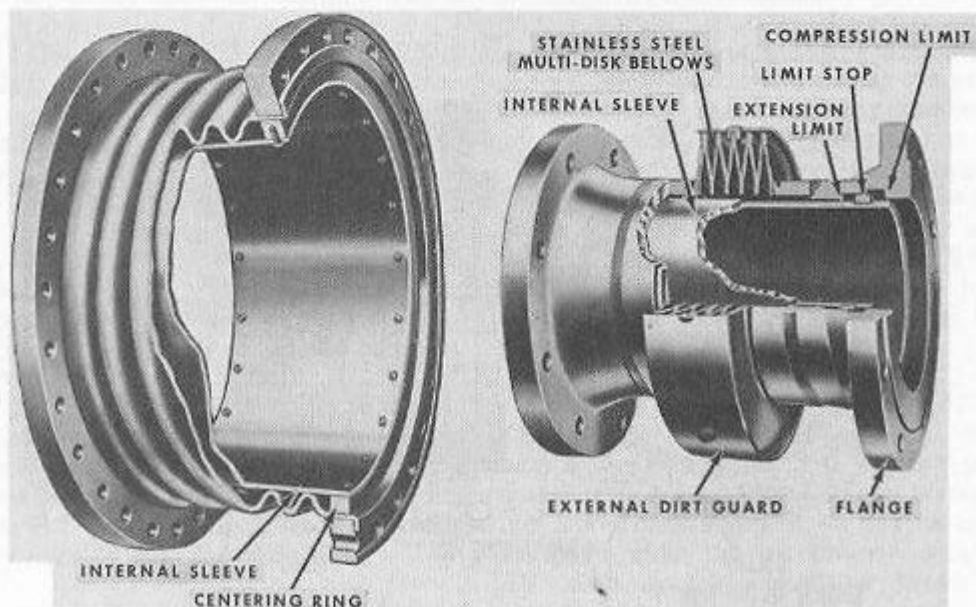


Figure 8-12.—Corrugated type and bellows type expansion joints.

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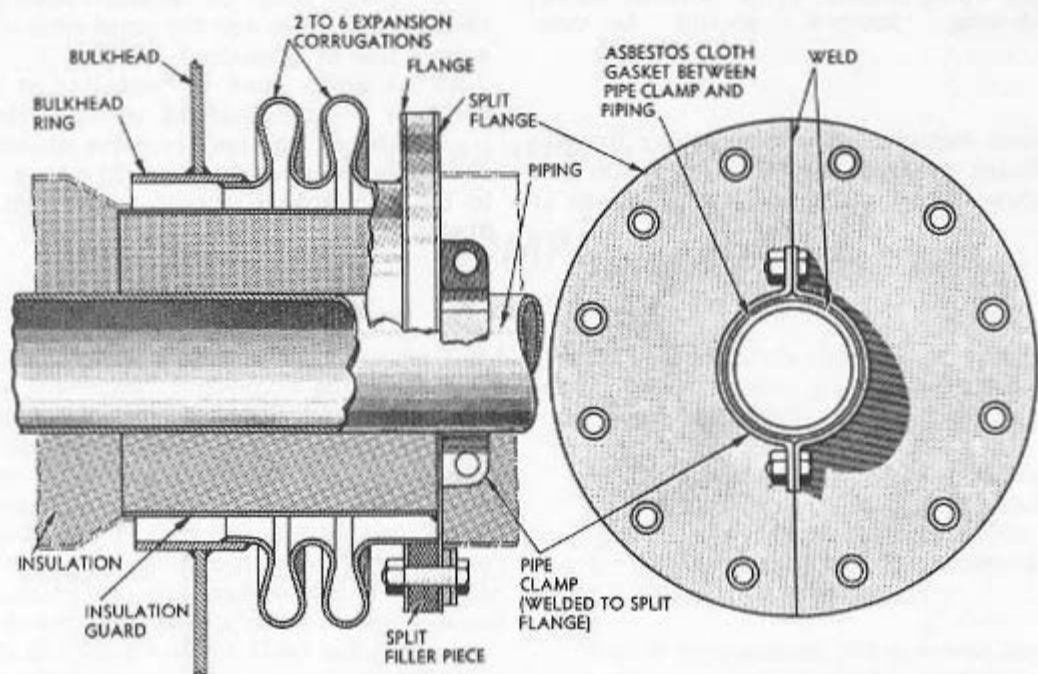


Figure 8-13.—Corrugated bulkhead expansion joint, showing details of installation.

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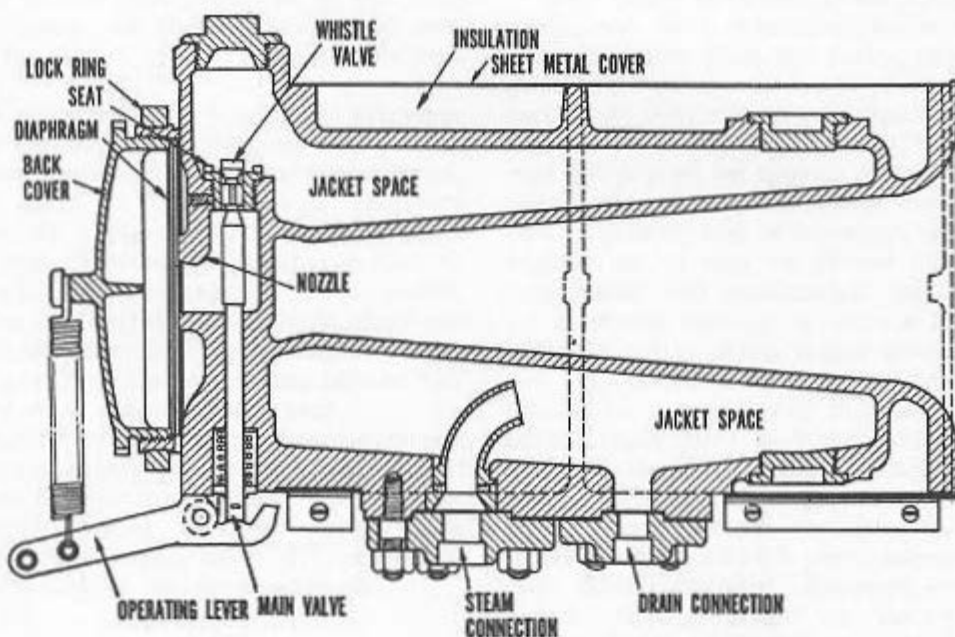


Figure 8-14.—Sectional view of a diaphragm type steam whistle.

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On the installation of a whistle valve, the following factors should be considered:

1. Steam supply must be taken either directly from a boiler or from a point on a steam line where there is a continuous flow of steam at all times.

2. There must be no horizontal piping between the whistle and the point where the steam supply line is connected.

3. A drain must be installed at the lowest point of a long lead of piping below decks.

4. The drain line from the whistle must be connected to a continuous flow trap connected to the atmosphere (never to the high-pressure drains).

CHAPTER 9

PUMPS

The purpose of a pump is to move fluid from one point and deliver it to another, by pulling, pushing, throwing, or a combination of these methods. Every pump has a power end which may be a steam turbine, a reciprocating steam engine, a steam jet, or an electric motor. Each pump also has a fluid end, where the fluid enters (suction) and leaves (discharges) the pump; this fluid end may be called the liquid end, the water end, the oil end, or the gas end to indicate the nature of the fluid being pumped.

The suction head of a pump refers to the pressure measured at the pump suction and is the difference in the level of fluid with respect to the pump suction plus any pressure exerted on the fluid from an external means. The discharge head means the pressure of the fluid leaving the pump, or the level of fluid with respect to the level of the pump on the discharge side.

On board ship, pumps are used for a number of essential services. Pumps feed water to the boilers, draw condensate from the condensers, supply sea water to the firemain, circulate cooling water for coolers and condensers, empty the bilges, transfer fuel oil, discharge fuel oil to the burners, and serve many other purposes. The operation of the ship's propulsion plant and of almost all auxiliary machinery depends upon the proper operation of pumps. Pump failure may cause failure of an entire power plant.

This chapter deals with reciprocating pumps, variable stroke pumps, centrifugal pumps, and rotary pumps. For information on other types of pumps, consult either the Bureau of Ships Technical Manual, chapter 9470 (47), or appropriate manufacturers' technical manuals.

RECIPROCATING PUMPS

The reciprocating pump moves water or other liquid by means of a piston or plunger

which reciprocates (goes back and forth or up and down) within a cylinder. Reciprocating pumps are usually classified as:

1. Direct-acting or indirect-acting
2. Simplex (single) or duplex (double)
3. Single-acting or double-acting
4. High pressure or low pressure
5. Vertical or horizontal

The reciprocating pump shown in figure 9-1 is a direct-acting, simplex, double-acting, high pressure, vertical pump. An explanation of what all these terms mean, with reference to the pump illustrated, is given in the paragraphs which follow.

The pump is **DIRECT-ACTING**, because the pump rod is a direct extension of the piston rod; and, therefore, the piston in the power end is directly connected to the plunger in the liquid end. Most reciprocating pumps used in the Navy are direct-acting. An **INDIRECT-ACTING** pump may be driven by means of a beam or linkage which is connected to and motivated by the steam piston rod of a separate reciprocating engine; or it may be driven by a crank-and-connecting rod mechanism which is operated by a steam turbine or an electric motor. An indirect-acting pump might appear to have only one end—that is, the pump end. However, it should be remembered that this pump, like all others, must have a power end as well. The separate engine, turbine, or motor which drives the pump is the actual power end of the pump.

The pump shown in figure 9-1 is called a **SINGLE OR SIMPLEX** pump because it has only one liquid cylinder. Simplex pumps may be either direct-acting or indirect-acting. A **DOUBLE OR DUPLEX** pump is an assembly of two single pumps, placed side by side on the same foundation; the two steam cylinders are cast in a single block, and the two liquid cylinders are cast in another block. Duplex

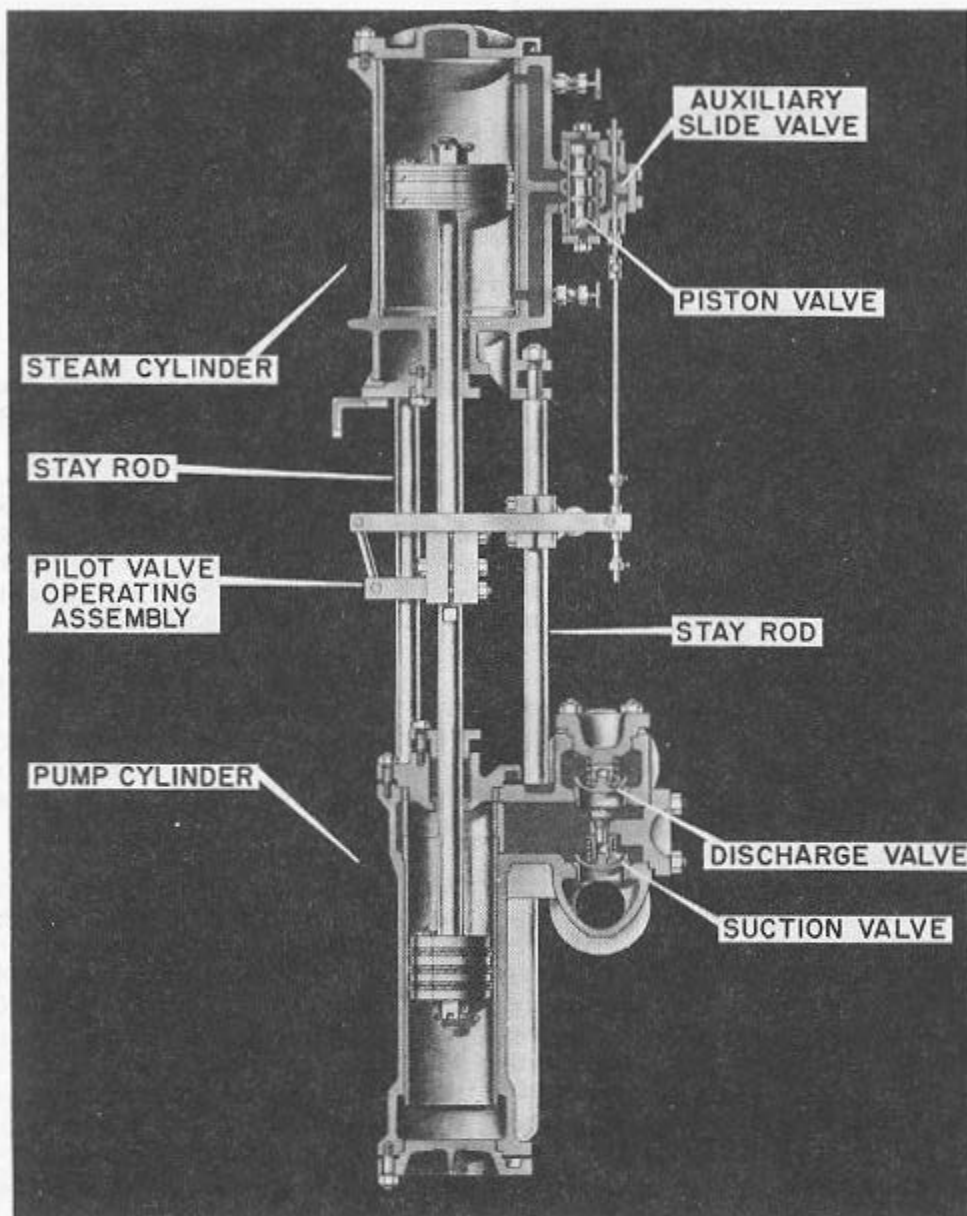


Figure 9-1.—Reciprocating pump.

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reciprocating pumps are seldom found in modern combatant ships but were commonly used in older ships.

In a **SINGLE-ACTING** pump, the liquid is drawn into the liquid cylinder on the first or **SUCTION STROKE** and is forced out of the cylinder on the return or **DISCHARGE STROKE**. In a **DOUBLE-ACTING** pump, each stroke serves both to draw in liquid and to discharge liquid. As one end of the cylinder is filled, the other

end is emptied; on the return stroke, the end which was just emptied is filled and the end which was just filled is emptied. The pump shown in figure 9-1 is double-acting, as are most of the reciprocating pumps used in the Navy.

The pump shown in figure 9-1 is designed to operate with a discharge pressure which is higher than the pressure of the steam operating the piston in the steam cylinder. In other words,

this is a **HIGH PRESSURE** pump. In a high pressure pump, the steam piston is larger in diameter than the plunger in the liquid cylinder. Since the area of the steam piston is greater than the area of the plunger in the liquid cylinder, the total force exerted by the steam against the steam piston is concentrated on the smaller working area of the plunger in the liquid cylinder; and, therefore, the pressure per square inch is greater in the liquid cylinder than in the steam cylinder. A high pressure pump discharges a comparatively small volume of liquid against a high pressure. A **LOW PRESSURE** pump, on the other hand, has a comparatively low discharge pressure but a larger volume of discharge. In a low pressure pump the steam piston is smaller than the plunger in the liquid cylinder.

The standard way of designating the size of a reciprocating pump is by giving three dimensions, in the following order: (1) the diameter of the steam piston; (2) the diameter of the pump plunger; and (3) the length of the stroke. For example, a 12" x 11" x 18" reciprocating pump has a steam piston which is 12 inches in diameter, a pump plunger which is 11 inches in diameter, and a stroke of 18 inches. This designation enables one to tell immediately whether the pump is a high pressure or a low pressure pump.

Finally, the pump shown in figure 9-1 is classified as **VERTICAL** because the steam piston and the pump plunger move up and down. Most reciprocating pumps in naval use are vertical; however, a **HORIZONTAL** pump, in which the piston moves back and forth rather than up and down, may be found aboard some ships.

The following discussion of reciprocating pumps is generally concerned with direct-acting, simplex, double-acting, vertical pumps, since most reciprocating pumps used in the Navy are of this type.

The power end of a reciprocating pump consists of a bored cylinder in which the steam piston reciprocates. The steam cylinder is fitted with heads at each end; one head has an opening to accommodate the piston rod. Steam inlet and exhaust ports connect each end of the steam cylinder with the steam chest. Drain valves are installed in the steam cylinder so that water resulting from condensation may be drained off.

Some reciprocating pumps have cushioning valves at each end of the steam cylinder. These

valves can be adjusted to trap a certain amount of steam at the end of the cylinder; thus, when the piston reaches the end of its stroke, it is cushioned by the steam and prevented from hitting the end of the cylinder. When the pump is operating at high speeds, the cushioning valves should be nearly closed so that a considerable amount of steam will be trapped at each end of the cylinder; at low speeds, the cushioning valves should be almost open. (The steam cylinder shown in figure 9-2 does not have cushioning valves.)

Automatic timing of the admission and release of steam to and from each end of the steam cylinder is accomplished by various types of valve arrangements. Figure 9-2 shows the piston-type valve gear commonly used for this purpose; it consists of a main piston-type slide valve and a pilot slide valve. Since the rod from the pilot valve is connected to the pump rod by a valve-operating assembly, the position of the pilot valve is controlled by the position of the piston in the steam cylinder. The pilot valve furnishes actuating steam to the main piston-type valve, which, in turn, admits steam to the top or the bottom of the steam cylinder at the proper time.

The valve-operating assembly which connects the pilot valve operating rod and the pump rod is shown in figure 9-3. As the cross-head arm (sometimes called the rocker arm) is moved up and down by the movement of the pump rod, the moving tappet slides up and down on the pilot valve operating rod. The tappet collars are adjusted so that the pump will make the full designed stroke.

The liquid end of a reciprocating pump has a piston and cylinder assembly similar to that of the power or steam end. The piston in the liquid end is often called a **PLUNGER**. A **VALVE CHEST**, sometimes called a **WATER CHEST**, is attached to the liquid cylinder; it contains two sets of suction and discharge valves, one set to serve the upper end of the liquid cylinder and one to serve the lower end. The valves are so arranged that the pump takes suction from the suction chamber and discharges through the discharge chamber on both the up and down strokes.

An adjustable relief valve is fitted to the discharge chamber, to protect the pump and the piping against excessive pressure.

Some reciprocating pumps have an air chamber and a snifter valve installed in the liquid end. The upper part of the air chamber contains

air; the lower part contains liquid. On each stroke, the air in the chamber is compressed by the pressure exerted by the plunger. When the plunger stops at the end of a stroke, the air in the chamber expands and allows a gradual rather than sudden, drop in the discharge pressure. The air chamber, therefore, smooths out the discharge flow, absorbs shock, and prevents pounding. The snifter valve, if installed, allows a small quantity of air to be drawn in

and compressed with each stroke. If no snifter valve is installed, some provision is usually made for charging the air chamber with compressed air.

USAGE IN NAVAL SERVICE

Reciprocating pumps are used for two main purposes in the main machinery spaces: (1) as fire and bilge pumps; and (2) as emergency feed

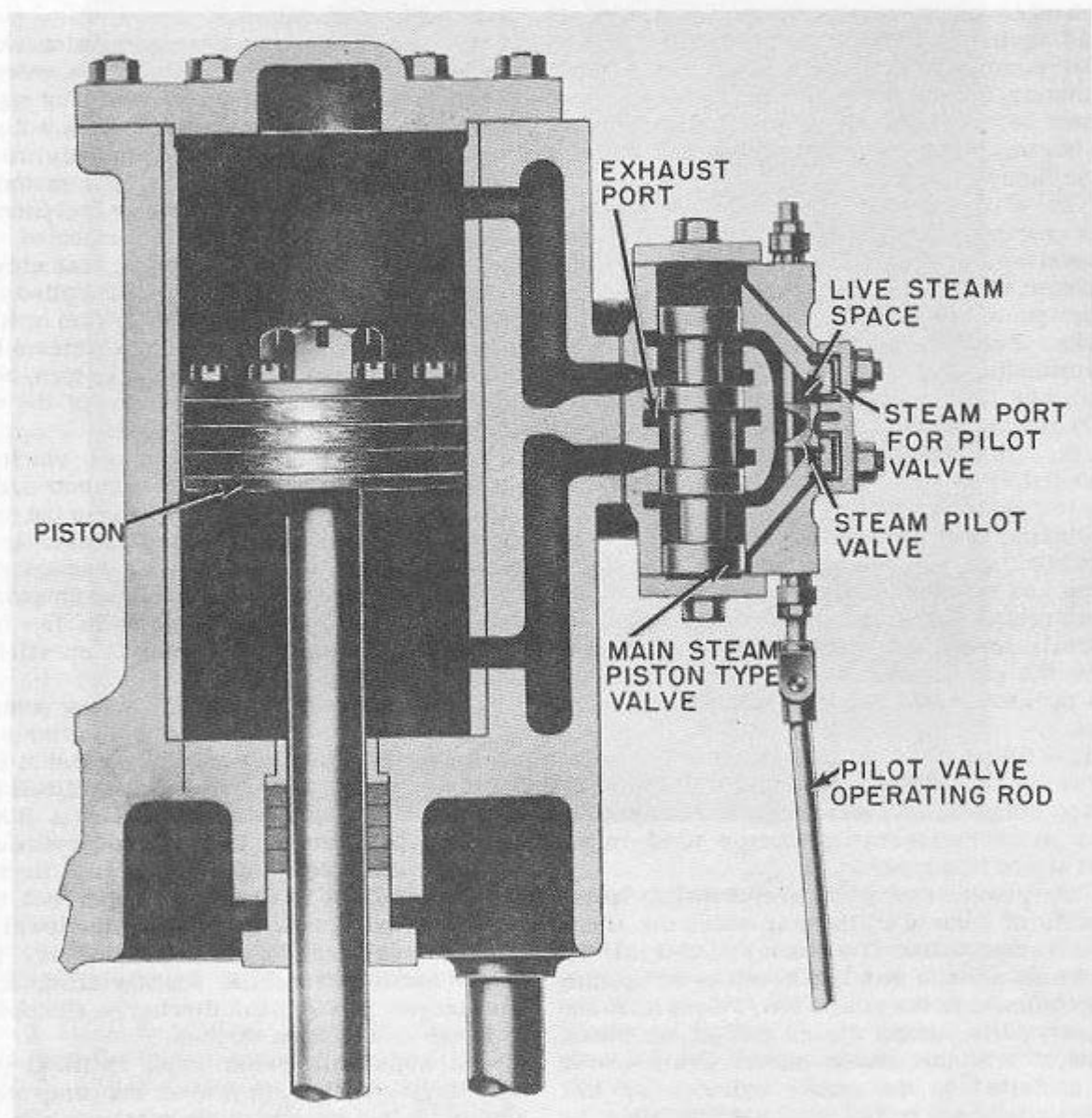
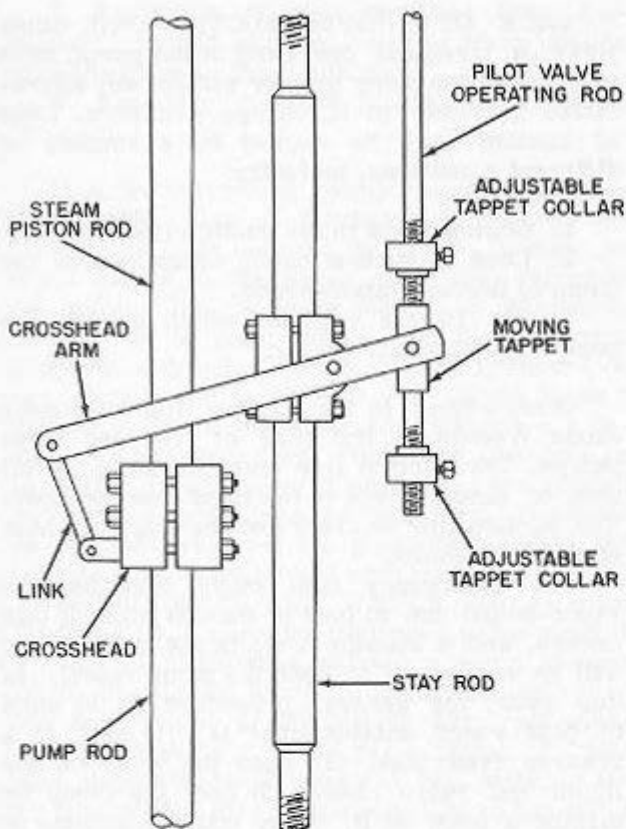


Figure 9-2.—Piston-type valve gear for steam end of reciprocating pump.



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Figure 9-3.—Valve operating gear.

pumps. Reciprocating pumps are very good for emergency use because they are relatively simple, reliable, and easy to start and operate under cold conditions.

The FIRE AND BILGE PUMP is sometimes called the STANDBY FIRE PUMP. In emergency, it is used as a fire and flushing pump. The fire and bilge pump is designed to operate on relatively low pressure steam (usually about 150 psi or a little higher).

Procedures for the operation, maintenance, and repair of the fire and bilge pump are, in general, the same as for any other reciprocating pumps. With the fire and bilge pump, however, special precautions must be taken to see that the suction strainers are kept clean. Clogged suction strainers and the presence of foreign matter in the water chest suction and discharge valves are the most frequent causes of trouble in the liquid end of the fire and bilge pump.

The EMERGENCY FEED PUMP is a direct-acting, simplex, double-acting, high pressure, vertical pump of the type shown in figure 9-1.

The pump is operated from the auxiliary steam line. It is used for filling idle boilers, for transferring reserve feed water, for applying pressure to boilers undergoing hydrostatic test, and in some cases for regular boiler feed service for in-port (auxiliary) steaming. This pump does not have sufficient capacity for high firing rates, and its use is therefore limited to emergency or auxiliary service.

It should be noted that the main feed pump is almost always of the centrifugal type (discussed later in the chapter), requiring a positive suction head. If the feed booster pump fails, therefore, the main feed pump cannot operate. Reciprocating pumps, on the other hand, do not require a positive suction head and are therefore capable of taking suction directly from reserve feed tanks. It is primarily for this reason that all emergency feed pumps are of the reciprocating type.

The emergency feed pump must be kept in a standby condition whenever the fireroom is steaming. Some emergency feed pumps are provided with a discharge check valve so that the discharge valve may be kept open while the pump is in standby condition.

When an emergency feed pump is used for in-port steaming, another pump must always be used for standby. This precaution is necessary in order to avoid a serious engineering casualty, in the event of failure of the emergency feed pump.

The emergency feed pump is also used to add boiler compound to the water in the boiler, and an open suction connection is provided for this purpose. After the compound has been taken in, enough additional water must be pumped to ensure that all the boiler compound is carried through the pump and the lines to the boiler. CAUTION: If the emergency feed pump has been taking a hot suction, it must be cooled down before it is used to pump boiler compound into the boiler.

OPERATION AND OPERATING TROUBLES

The general procedure for starting a reciprocating pump is as follows:

1. Check to be sure that the steam cylinder and steam chest drain valves are open. (They should always be opened when the pump is shut down.)
2. Oil the pins of the steam valve operating gear and set up on any grease cups which may

be fitted. (Some modern reciprocating pumps do not have grease cups.)

3. Open the liquid end suction and discharge valves.

4. Open the exhaust and steam line root valves.

5. Open the steam exhaust valve at the pump.

6. Crack the steam throttle valve and admit steam SLOWLY so that the steam cylinder will warm up gradually.

7. Close the steam cylinder drains after the pump has made a few strokes. Do not close these drains until the steam cylinder is clear of water.

8. Open the throttle valve slowly to bring the pump up to the desired operating speed or discharge pressure.

In general, the steps to be followed in stopping and securing a reciprocating pump are:

1. Close the steam throttle valve.
2. Close the steam exhaust valve at the pump.
3. Open the steam cylinder drains.
4. Close the liquid end suction and discharge valves.
5. Close the steam and exhaust root valves.

Sometimes the pump may not kick over when it is being lined up and the throttle valve is cracked open. If the throttle valve is opened wider and nothing happens, the starting procedure should be repeated to ascertain that everything has been done correctly. If the pump still doesn't run, it is necessary to:

1. Follow the approved securing procedure.
2. Examine the discharge line and the exhaust line. The trouble may be a closed valve, or a valve in which the disk has become detached from the stem.
3. Check the rod packing glands at the steam end and at the water end; if someone has set up on them too tightly, the pump may be locked so that it cannot move.
4. If the trouble cannot be located, report the fact to the proper authority.

From time to time operating troubles with reciprocating pumps are likely to occur. Some of the most common causes of trouble, together with their symptoms and remedies, are described in the paragraphs which follow.

LACK OF PROPER SUCTION will cause jerky or irregular operation of the pump, or it may cause the pump to race without any appreciable increase in discharge pressure. Loss of suction may be caused by a number of different conditions, including:

1. Obstructions in the suction line.
2. Loss of suction head, which causes the pump to become vapor-bound.
3. Air in the system, which causes the pump to become air-bound.

Obstructions in the suction line frequently cause trouble in the case of fire and bilge pumps. The suction line must be clear and all stop or check valves in the lines must be open. The suction line strainer and the bilge strainer should be cleaned.

The emergency feed pump may become vapor-bound due to loss of suction head. If this occurs, and a standby pump is not available, it will be necessary to cool the pump rapidly. In this case, the general procedure is to shift to cold water suction—that is, (1) shift to a reserve feed tank, (2) open the vents on the liquid end valve chest, (3) cool the pump by turning a hose on it, or by pouring buckets of cold water over it, (4) continue cooling measures until a steady flow of water comes from the vents, and (5) continue feeding cold water until the head pressure is restored.

A pump can lose suction by becoming air-bound—that is, by having air trapped in the system. The remedy for this condition is to open the aircocks and vents on the liquid end valve chest and to leave them open until water flows out.

Insufficient prime often causes loss of suction in pumps which have a considerable suction lift. The fire and bilge pump can usually be primed from the sea by opening the sea suction valve for a short time.

LOSS OF DISCHARGE PRESSURE and **LOSS OF CAPACITY** are closely related operating troubles. They may be caused by various conditions, including:

1. Low steam pressure.
2. High exhaust back pressure.
3. Insufficient speed of the pump.
4. Excessive suction lift.
5. Air leakage into the pump.
6. Entrained vapors in the pumped liquid.

7. Excessive friction resulting from improperly packed stuffing boxes or from binding of the packing in the liquid end.

8. Excessive wear of packing on the pump plunger.

If a reciprocating pump races without an appreciable loss of discharge pressure, the trouble may be caused by leaky, broken, or stuck valves in the water end; leaky valves in the suction line; a leaky piston; or other conditions. If a pump which has been running properly suddenly loses discharge pressure on one stroke, the trouble is very likely to be a broken valve in the water end. Whenever a reciprocating pump loses discharge pressure or capacity, or whenever it begins to race without increasing the discharge pressure, it should be stopped as soon as possible so that the trouble may be found and corrected.

POUNDING IN THE WATER END is most likely to be caused by improper adjustment of the steam cushioning valves; a pump plunger which is slightly loose on the rod; a rod which has come loose at the crosshead; loose water chest valves or a loose valve plate; or loose zinc plates. Water hammer or ram effect in the suction piping may cause pounding in the water end of a pump which has a considerable suction lift; this pounding will usually stop when the pump is run at a slower speed. Pounding in the liquid end may also be caused by insufficient charging of the air chamber (if installed). If pounding occurs in the liquid end of a pump which is not fitted with an air chamber, the installation of a snifter valve may take care of the trouble. However, snifter valves or air chambers must NEVER be installed on the emergency feed pump, since these devices would tend to draw air into the feed water.

GROANING IN THE WATER END is most often caused by packing that is too tight. Other causes include misalignment of the pump, a broken or damaged follower plate, and other broken parts. The pump should be stopped at once and the trouble should be found and corrected. Continued operation of a pump which has any of these defects may cause a scored cylinder or even more serious damage.

KNOCKING IN THE STEAM END may be caused by too long a stroke, by the presence of water in the steam cylinder, by loose piston rings, by a loose piston assembly, by the piston being loose on the rod, or by some difficulty in the piston-type valve gear. The pump should

be stopped at once and the trouble should be found and corrected.

GROANING IN THE STEAM END may indicate that the packing is too tight; that the piston or a piston ring is broken, that rust has formed in the cylinder, or that the pump is out of alignment. The pump should be stopped so that the difficulty may be found and corrected.

MAINTENANCE AND REPAIR

Reciprocating pumps require a certain amount of routine maintenance and, upon occasion, some repair work. All the pertinent blueprints, drawings, and available data should be examined before a pump is repaired. These drawings and data furnish the required clearances, measurements and information regarding materials to be used. In addition, the complete history of the pump being repaired should be available so that it can be determined what has been done previously, when repairs were made, and what kind of trouble has been encountered with this particular pump.

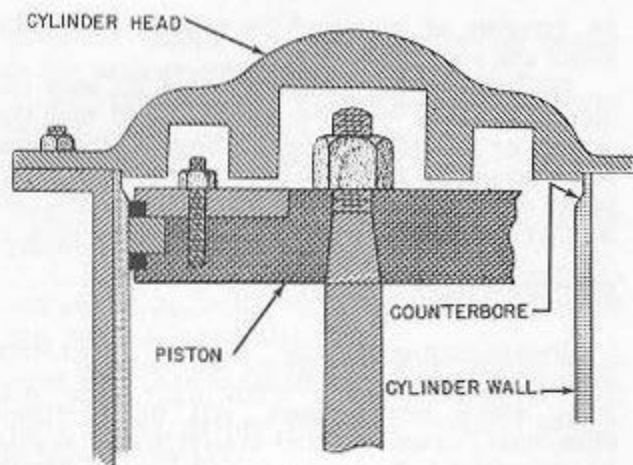
Whenever reciprocating pumps are opened for repairs, micrometer or caliper measurements should be taken of the main cylinders and the valve chest cylinders. These measurements are made on the fore and aft and athwartships diameters at the top, middle, and bottom. The results should be recorded, with an accompanying diagrammatic sketch showing the measurements obtained and the date on which they were made.

The steam end of a reciprocating pump should NOT be dismantled until a thorough check reveals that the water end is satisfactory. Most reciprocating pump troubles result from fouled water cylinders, worn valves, or from faulty conditions in the pipe connections external to the pump.

Some of the most important factors concerning the maintenance and repair of pumps are discussed in the sections which follow. Additional information can be obtained from either the Bureau of Ships Technical Manual, chapter 9470(47), or applicable manufacturers' technical manuals.

Adjustment Of Stroke

In order for a steam-driven reciprocating pump to operate properly, the steam piston must travel a little beyond counterbore (fig. 9-4); this means that the pump must operate with a full



38.101

Figure 9-4.—Piston at upper end of stroke.

stroke. A full stroke will result in more even wear throughout the cylinder.

The length of the stroke is adjusted by moving the two adjustable tappet collars on the threaded portion of the valve rod link. The tappet moves between the tappet collars as the lever is moved by the action of the piston rod.

The stroke of the pump is shortened by turning the tappet collar in the direction that moves it toward the tappet. The stroke of the pump is lengthened by turning the tappet collar in the direction that moves it away from the tappet. Once the tappet collars have been set properly, they should be left alone. If it becomes necessary to adjust the tappet collars frequently while the pump is operating, the pump should be stopped and disassembled as soon as possible. The trouble may be in the operating linkage, the auxiliary piston valve, or the main piston valve.

Properly adjusted tappet collars will ensure a full stroke for the various pump loads and speeds. Refer to manufacturer's drawings and technical manuals for detailed information as to the method to be followed for specific types of valve gear. The following method may be used for a general guide if the appropriate information is not available. Place the steam piston and auxiliary piston valve on the center or half stroke. Then move each tappet collar so that it will be one-half the width of the steam port away from the tappet. Next start the pump. If the stroke is too short, move the tappet collars further apart. If the stroke is too long, move the tappet collars closer together. Make certain that the tappets are moved an equal amount, or the stroke will be longer on one end than on the

other. When final adjustment has been made, lock the tappet collars securely in place.

Run the pump slowly, with the throttle cracked, against little or no pressure, and with the cushioning valves wide open. The piston should be striking on the cylinder heads (if it does not, there is friction at some point). Close down on the cushioning valves until the pump is running at full stroke and with smooth reversal and no striking. If it is impossible to obtain smoothness of reversal, it may be necessary to adjust the tappet collars.

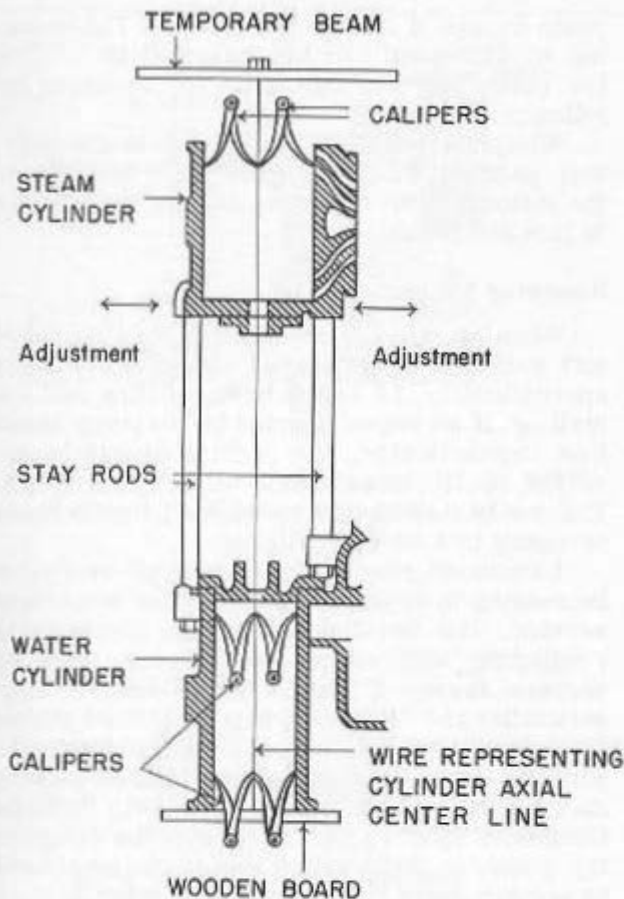
Pump Alignment

Improper alignment is one of the most frequent sources of trouble with pumps. Pumps with mountings secured to a bulkhead are more subject to misalignment than those with independent bases. A pump may have been properly aligned in the shop and then pulled out of line when bolted to the bulkhead mounting; or after the pump mounting was secured, the ship may have changed shape sufficiently to warp the bulkhead and cause misalignment.

Operation of an improperly aligned pump usually scores the rod and cylinders, and breaks the followers. The alignment of pumps should be tested occasionally by removing the piston and plunger and running a line through the steam and water cylinders. This should be performed as a routine test within the first year after a ship is commissioned; and also for a pump that is scoring rods or cylinders, or breaking followers.

Before a line is run through the cylinder or any adjustments are made, the foundation must be lined up and the centerline must be determined. The centerline must divide each cylinder equally (see fig. 9-5). Fasten one end of the line to a temporary beam at the end of one of the cylinders. In figure 9-5 the beam is rigged above the steam cylinder. Run the line down the center of both cylinders, and center it at the top and bottom of the steam cylinder, so that it becomes the axis of that cylinder. Then align the water cylinder with the steam cylinder. If realignment is necessary, the water cylinder may be moved and centered on the line without affecting the centering of the line on the steam cylinder.

To make a rough check of alignment of a pump, pull the steam and liquid end rod packing and check the clearances between the piston rods and the cylinder throat bushings. Make this check with the pistons in each of three positions—top, center, and bottom of the stroke. If clearance is



96.14

Figure 9-5.—Centering a line through two cylinders.

not uniform, realign the pump as soon as possible.

In some cases, when steam cylinder foundation pad bolts are slacked off, the cylinder pads pull away from the foundation as much as 1/2 inch, indicating settling of foundations and bulkheads. Correct this by fitting shims between the foundation and the pump.

A frequent cause of misalignment is the piping. The piping should line up naturally with the pump connections and should not be forced into position. Provision must be made in steam and exhaust lines to allow for expansion. All piping should be supported independently of the pump. Improperly installed piping puts a strain on the pump and forces it out of alignment. Special care should be taken to avoid vapor pockets when installing suction piping.

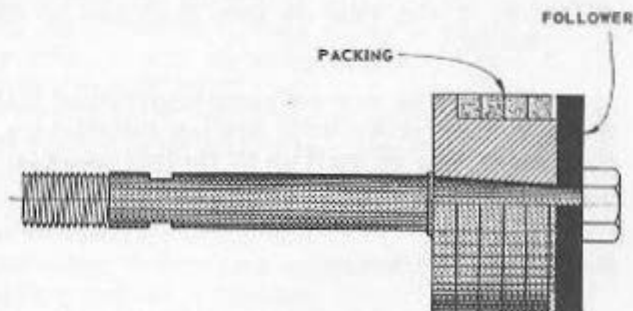
Gland Leakage

Care should be exercised when setting up on the glands. If the two sides are set up unequally, the gland becomes tilted and scores the rod, and sometimes breaks the gland itself. If a gland is set up too hard, the packing will probably score the rod. If a gland continues to leak after the nuts have been given a few turns, it will be best to leave it alone until the pump can be shut down. Then an examination should be made to see if the bushing is too large, possibly because the rod has been turned down, or if a new packing is required. Particular attention should be given to packing for cylinders operating at low pressure, or below atmospheric pressure, to prevent not only loss of vacuum, but the admission of grease into the cylinder and air into the feed system.

Loose Pistons

Pistons in the water end of pumps (fig. 9-6) are generally constructed of bronze and are of the body and follower type. The piston itself is not a tight fit, but depends upon several rings of packing to prevent leakage. These rings of packing are placed between a shoulder at one end of the piston and a follower plate at the other end.

Loose water pistons and steam pistons are sometimes a source of trouble in reciprocating pumps. A piston should always be properly refitted after it has been removed from the rod. The tapered part of the rod and the opening in the piston must be free of foreign matter before the piston is fitted. Even a small amount of foreign matter will prevent the piston from giving the proper bearing surface to the tapered part of the rod. The piston should be



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Figure 9-6.—Liquid end piston, rod, packing, and follower.

fitted onto the tapered part of the rod and the securing nut should be set up handtight. There should be a uniform clearance of $1/32$ to $1/8$ of an inch between the piston and the rod shoulder, the size of the clearance depending on the amount of taper of the rod. After the piston is properly placed, the securing nut should be tightened to force the piston tightly against the shoulder of the rod. Piston trouble will usually disappear when the piston is properly refitted to the rod.

If a lock nut or split pin is not fitted, one should be installed. Pump rods are sometimes screwed into the plunger and secured by a lock nut, with a flat plate secured on the top of the plunger to prevent the nut from backing off. However, this arrangement will still allow the nut and the plunger to turn together, permitting the plunger to back off and carry away. This condition is corrected by securing the nut to the rod with a setscrew.

Piston Too Small

Pistons may be built up by flowing on metal by the oxyacetylene method or by electric welding. The piston is then machined to the proper fit.

It sometimes happens that in reboring a water cylinder so much clearance is introduced that the piston and follower require renewal. Until a new piston and follower can be obtained, one of the following procedures may be employed:

1. Install upper and lower rings of metal packing and insert soft packing between the rings.

2. The piston and the follower may be turned down and threaded, and a ring with the same thread screwed on tightly. The outside diameter of the ring is then machined to fit the cylinder.

If the pistons are so much undersized that the preceding procedures are not satisfactory, the pistons may be built up by flowing on metal, and then turned to the correct diameter.

Breaking of Followers

The breaking of followers and bolts may result from misalignment, but is generally caused by a weak follower. A new and heavier follower, or one of better material, should be tried on a

pump to see if it stops the trouble. The breaking of followers can be prevented by drilling the piston for through bolts for securing the follower.

When the follower is too small in diameter, soft packing will frequently roll up between the piston and the cylinder, causing the follower to jam and break.

Renewing Packing

When packing a pump with flax or other soft packing, the packing is soaked in hot water approximately 12 hours before fitting and installing. If an urgent demand for the pump makes this impracticable, the packing should be inserted to fit loosely and allow for swelling. Failure to do this will cause the pump to groan or result in a scored cylinder.

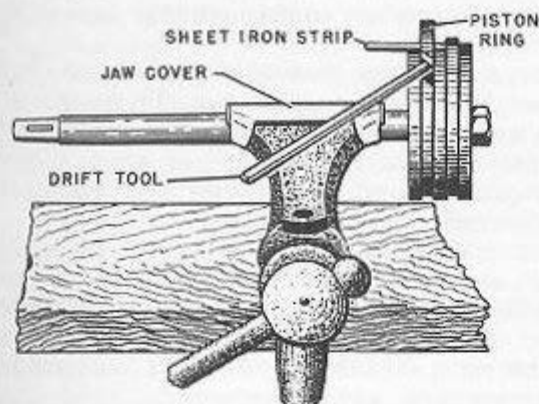
Laminated phenolic packing type rings are increasing in usage, particularly for boiler feed service. The Naval Ship Systems Command is conducting laboratory and service tests on various types of pumps to determine their suitability and to develop data as to their proper application and installation. The use of laminated phenolic rings as a substitute for soft packing may be authorized by the Naval Ship Systems Command upon request, provided the design of the piston is satisfactory for or can be altered to accommodate the phenolic type rings.

Metal rings are sometimes very narrow and cut the cylinder. If wider rings are fitted, the trouble generally stops. Sharp edges of rings should be rounded with a file. The use of white metal rings is considered obsolete and unsatisfactory.

Worn or Broken Piston Rings

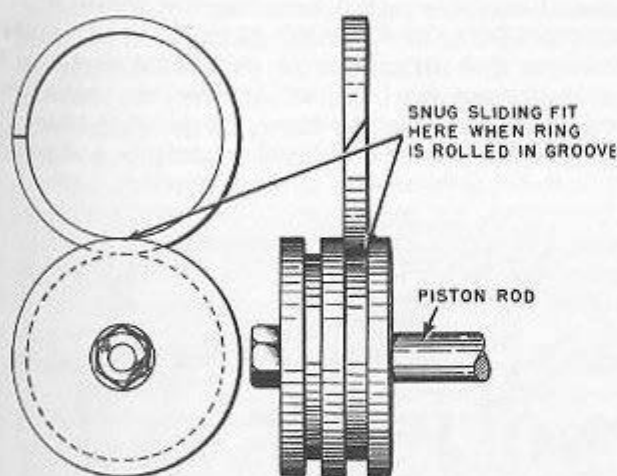
Troubles in the steam cylinder result mainly from faulty piston rings. Wearing of piston rings can cause a pump to lose power, and even, in some cases, to stop. If a pump stops, while operating slowly, in the middle of a stroke, the trouble may be due to worn rings. In this case, the pump should be secured and the condition of the rings and the cylinder checked. Piston rings must be renewed when necessary.

Figure 9-7 shows a steam piston assembly of a reciprocating pump. The piston rings are cast iron. If the piston rings are broken or worn or have been poorly fitted so that there is excessive leakage by the piston, new rings must be installed. Figure 9-8 illustrates the fitting of piston rings.



47.52

Figure 9-7.—Removing piston rings.



47.53

Figure 9-8.—Fitting piston rings.

Overhauling Water End Valves

All valves in the water end of the pump must be kept tight to ensure satisfactory and economical pump operation. Valves may be faced in a lathe and then ground in on their seats by a simple device which consists of a length of rod slotted to fit a piece of metal which seats across the top of the valve.

It is sometimes desirable to take a cut off the valve seat without removing it. A simple cutter can be made with an extension for a bit-stock, similar to the grinding-in device. When flat valves are fitted, the seats may be trued up by using a small surface plate and spotting-in the section on the surface plate.

After the valves have been ground in, the valves can be tested by closing the suction valve,

opening the discharge valve, starting the pump, and noting the vacuum that the pump is capable of attaining.

At each examination, all metal valve disks should be checked with a straightedge to see if they are true. The life of rubber valves can be lengthened by trimming and turning the valves and by inserting brass backings.

Tension on the valve springs should be great enough to ensure a quick closing of the valve, but not so great that the valve cannot be lifted easily by hand. The springs should be secured by split pins, and the valves adjusted to give the proper lift. Lift should be such that the circumferential opening is slightly greater than the clear opening through the seat, but NOT greater than $1/4$ the diameter of the clear opening.

Valves must be kept clean. A light mineral oil makes a good cleaner, and a lye or soda solution is satisfactory for removing caked or gummed oil from the valves.

In pumps having valve seats secured only by a taper fit, the seats should be forced home by a jack resting on the end of a reseater which in turn rests on the face of the valve seat. If the seat works loose, the edge of the seat should be peened slightly. In pumps that have the valve seats screwed into the pump diaphragm, the valve seats must be inserted with white lead; otherwise it will be difficult to remove them.

In some pumps, discharge valve seats in the water end are secured to the pump diaphragm by shoulders on the valve stems, where the stems screw into the suction seats. These seats have small flanges under which gaskets are fitted. Rubber gaskets supplied by the manufacturer are soon squeezed out, causing the seats to leak. Hard sheet packing will give better performance than rubber; and if cold water is to be pumped, sheet lead will give the best performance. When flanges cause a great deal of trouble, it will be necessary to fit new seats with a ground joint.

Frequently, valve stems shear off. This can be remedied by cutting the stem off the valve and turning a groove in the top of the valve for the spring to rest in. The stem is pinned to the guard at a sufficient height to allow proper opening of the valve; it then acts merely as a guide for the spring and as a limiting device for the valve. It will be necessary to fit a new stem because the old one will not be large enough to make a close fit in the guard.

Extreme care should be taken in assembling pumps after overhaul. Valves, valve seats,

stems, and springs must be marked before removal, to make it easier to replace them in the proper order.

SAFETY PRECAUTIONS

The following safety precautions must be observed in connection with reciprocating pumps:

1. Never attempt to move a reciprocating pump by hand while the steam valve to the pump is open.
2. Do not use the emergency feed pump for purposes other than those connected with the service of boilers or the use of feed water, except in emergency.
3. Before opening a steam cylinder or a steam chest, be sure that all drains are open and the steam and exhaust root valves are wired closed.
4. Before opening the water cylinder or the valve chest of a pump handling water at a temperature higher than 212°F, be sure that the suction and discharge valves are wired closed and that the cylinder and valve chest are drained.
5. Always open the steam cylinder drain valves and the steam chest drain valves when the pump is shut down; leave them open until the pump is again in operation and has been cleared of condensate.

VARIABLE STROKE PUMPS

Aboard ship, variable stroke pumps are used primarily on electrohydraulic steering gear, elevators, cranes, and anchor windlasses. In these applications, the variable stroke pump is referred to as the A-end of the drive system; and the hydraulic motor which is driven by the A-end is referred to as the B-end. By controlling the pumping action of the A-end, the motor can be operated in either direction and the speed varied from zero to the maximum rate.

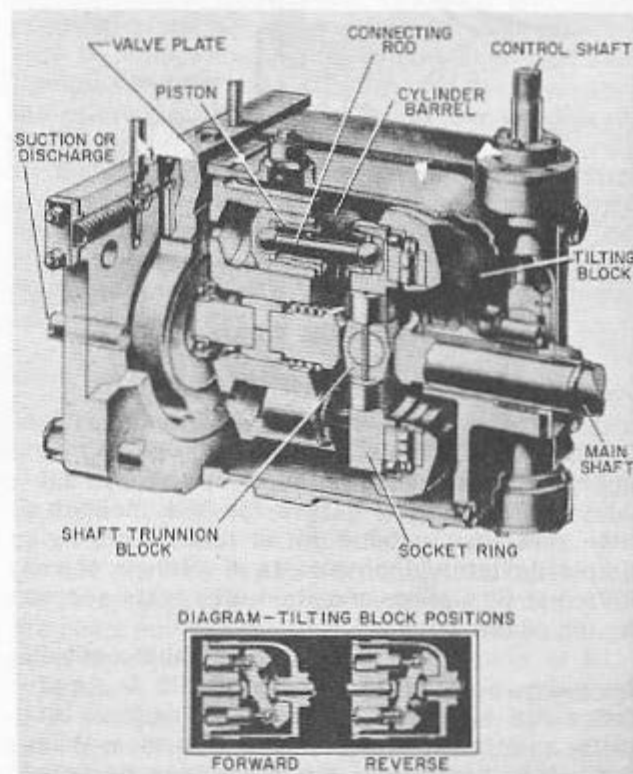
Variable stroke pumps are also used on some ships as in-port or cruising fuel oil service pumps. Although they are often classified as rotary pumps, variable stroke pumps are actually reciprocating pumps. Variable stroke pumps operate on a principle similar to that of a single-acting reciprocating pump. A rotary motion is imparted to a cylinder barrel or cylinder block in the pump by means of a constant-speed electric motor. But the actual pumping is done by a set of pistons reciprocating inside

cylindrical openings in the cylinder barrel or cylinder block.

There are two general types of variable stroke pumps in common use. In the axial-piston type, the pistons are arranged parallel to each other and to the pump shaft; in the radial-piston type, the pistons are arranged radially from the shaft.

The AXIAL-PISTON VARIABLE STROKE PUMP, shown in figure 9-9 usually has either seven or nine single-acting pistons which are evenly spaced around a cylinder barrel. (Note that the term CYLINDER BARREL, as used in this connection, actually refers to a cylinder BLOCK which holds all the cylinders.) The piston rods make a ball-and-socket connection with a socket ring. The socket ring rides on a thrust bearing carried by a casting called the TILTING BOX OR TILTING BLOCK.

When the tilting box is at a right angle to the shaft, and the pump is rotating, the pistons do not reciprocate; therefore, no pumping takes place. When the box is tilted away from a right



38.103
Figure 9-9.—Axial-piston variable stroke pump.

angle, however, the pistons reciprocate and the liquid is pumped.

If the tilting box is designed to be moved in only one direction, the liquid can flow in only one direction. In some pumps, however, the tilting box is so arranged that it may be tilted in either direction, thus allowing the liquid to be pumped in either direction. The position of the tilting box controls both the direction of flow and the amount of flow.

The RADIAL-PISTON VARIABLE STROKE PUMP is similar in general principle to the axial-piston type just described, but the arrangement of component parts is different. In the radial-piston pump, the cylinders are arranged radially in a cylinder body which rotates around a nonrotating central cylindrical valve. Each cylinder communicates with horizontal ports in the central cylindrical valve. Plungers or pistons, which extend outward from each cylinder, are pinned at their outer ends to slip-rings which slide around the inside of a rotating floating ring or housing.

The floating ring is so constructed that it can be shifted off center from the pump shaft. When it is centered, or in the neutral position, the pistons do not reciprocate and the pump does not function, even though the electric motor is still causing the pump to rotate. If the floating ring is forced off center to one side, the pistons reciprocate and the pump operates. If the floating ring is forced off center to the other side of the pump shaft, the pump also operates but the direction of flow is reversed. Thus it can be seen that the direction of flow and the amount of flow are both determined by the position of the cylinder body relative to the position of the floating ring.

The shipboard application of reversible type variable stroke pumps is found in such hydraulic transmission gear as steering mechanisms. For information on these mechanisms, refer to chapter 15 of this publication.

When used for fuel oil service, variable stroke pumps are designed to be nonreversing. They operate at constant speed, with a constant discharge pressure, but with varying capacity. Spring tension is often used to control the position of the tilting box or the floating ring, and so to maintain constant pressure while varying the amount of liquid which is pumped. When this type of constant pressure control is fitted, it is usually adjustable from 150 to 300 psi. Most variable stroke pumps have, in addition, a hand-operated capacity control device which can be

used instead of the spring tension to adjust the capacity of the pump.

Variable stroke pumps require very little maintenance. When they are properly installed and correctly operated, they may run for years with practically no trouble. The most common causes of trouble with variable stroke pumps are (1) air in the system, which may cause jerky or irregular operation, and (2) impurities in the pumped liquid, which may cause damage to the pump parts.

If foreign matter scores the valve plates, pistons, or cylinders, these parts may need to be reground or replaced. The cause of the scoring must, of course, be found and corrected or the entire repair job will be wasted. If pistons are improperly fitted, they may seize; replacing or regrinding the pistons may be required.

When a variable stroke pump is disassembled, each piece should be carefully marked so that the pump can be reassembled correctly. It is particularly important to mark the pistons. The designed clearances are so small that the pistons will work properly only if they are replaced in the right cylinders.

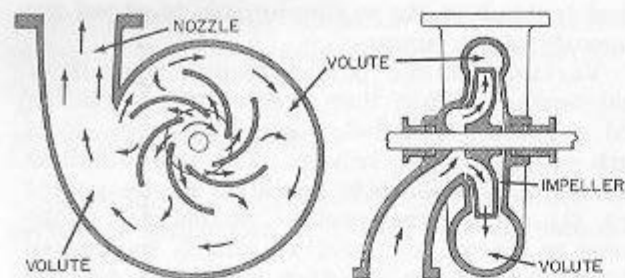
CENTRIFUGAL PUMPS

There are many types of centrifugal pumps, but all operate on the same principle. The operation of centrifugal pumps depends upon centrifugal force (which imparts a high velocity to the liquid pumped) produced by the rotation of the impeller at high speed. The liquid is sucked in at the center or EYE of the impeller and discharged at the outer rim of the impeller.

By the time the liquid leaves the impeller, it has acquired a high velocity—and its potential energy has been changed to kinetic energy. The liquid is slowed down by being led through a volute or through diffusion vanes. As the velocity of the liquid decreases, its pressure increases; in this way the kinetic energy of the liquid is changed to potential energy.

The two types of centrifugal pumps generally found aboard ship are the volute pump and the volute turbine pump.

In the VOLUTE PUMP, shown in figure 9-10, the impeller discharges into a volute—that is, a gradually widening channel in the pump casing. As the liquid passes through the volute and into the discharge nozzle, a considerable portion of its kinetic energy is converted into potential energy.



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Figure 9-10.—Simple volute pump.

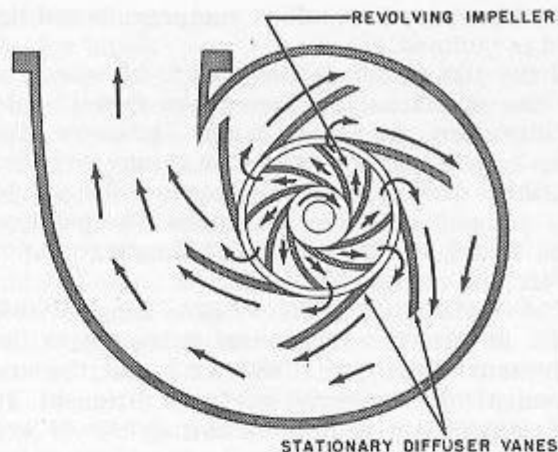
In the **VOLUTE TURBINE PUMP**, shown in figure 9-11, the liquid leaving the impeller is first slowed down by the stationary vanes which surround the impeller. The liquid is forced through the gradually expanding passages of the diffuser ring before entering the volute. Since both the diffuser vanes and the volute reduce the velocity of the liquid in the volute turbine pump, practically all the kinetic energy is converted to potential energy.

Centrifugal pumps may be classified in several ways. For example, they may be either **SINGLE STAGE** or **MULTISTAGE**. A single-stage pump has only one impeller. A multi-stage pump has several impellers housed together in one casing; each impeller functions separately, discharging to the suction of the next stage impeller. Centrifugal pumps are also classified as **HORIZONTAL** or **VERTICAL**, depending upon the position of the pump shaft.

The impellers used on centrifugal pumps may be classified as **SINGLE SUCTION** or **DOUBLE SUCTION**. The single-suction impeller allows liquid to enter the eye from one direction only; the double-suction type allows liquid to enter the eye from two directions. Impellers are also classified as **CLOSED** or **OPEN**. Closed impellers have side walls which extend from the eye to the outer edge of the vane tips; open impellers do not have these side walls. Most centrifugal pumps used by the Navy have closed impellers.

USAGE IN NAVAL SERVICE

Centrifugal and axial flow pumps are used for most nonviscous liquid services on naval ships. They have largely supplanted direct-acting steam pumps for such services. The advantages of centrifugal pumps include simplicity, compactness, weight saving, and adaptability to a high-speed prime mover. Centrifugal pumps, however, have the disadvantage of a lack of suc-



23.19

Figure 9-11.—Volute turbine pump.

tion power and must be primed to operate on a suction lift. They are also sensitive to variations in the head and in the speed. They are usually designed for a specific set of operating conditions and may give unsatisfactory performance when subjected to operation at great variance with the designed rating.

Centrifugal pumps may be arranged to operate in series when the required pressure exceeds that of one available pump. They may also be installed to operate in parallel when several smaller units to handle varying capacity demands over a wide range are desired, so when a maximum reliability is required. For satisfactory operation in parallel, pumps should have a constantly rising head from rated capacity to shut off. Where pumps of different capacity ratings are to operate in parallel, the shut off head of the smaller pump should be slightly in excess of the shut off head of the larger pump. This is essential; otherwise, the smaller units would be blocked off the line by the higher pressure developed by one of the larger pumps.

Boiler feed pumps are of the high speed, multistage type and are usually driven by a steam turbine. The main feed pump, shown in figure 9-12, may be installed either in the fireroom or in the engineroom. The feed pump requires recirculation from the discharge to the source of supply to prevent the fluid from turning to steam which causes the pump to cavitate when operating at low capacity. The main feed pump operates at a discharge pressure considerably above the maximum steam drum pressure; it operates at varying speeds

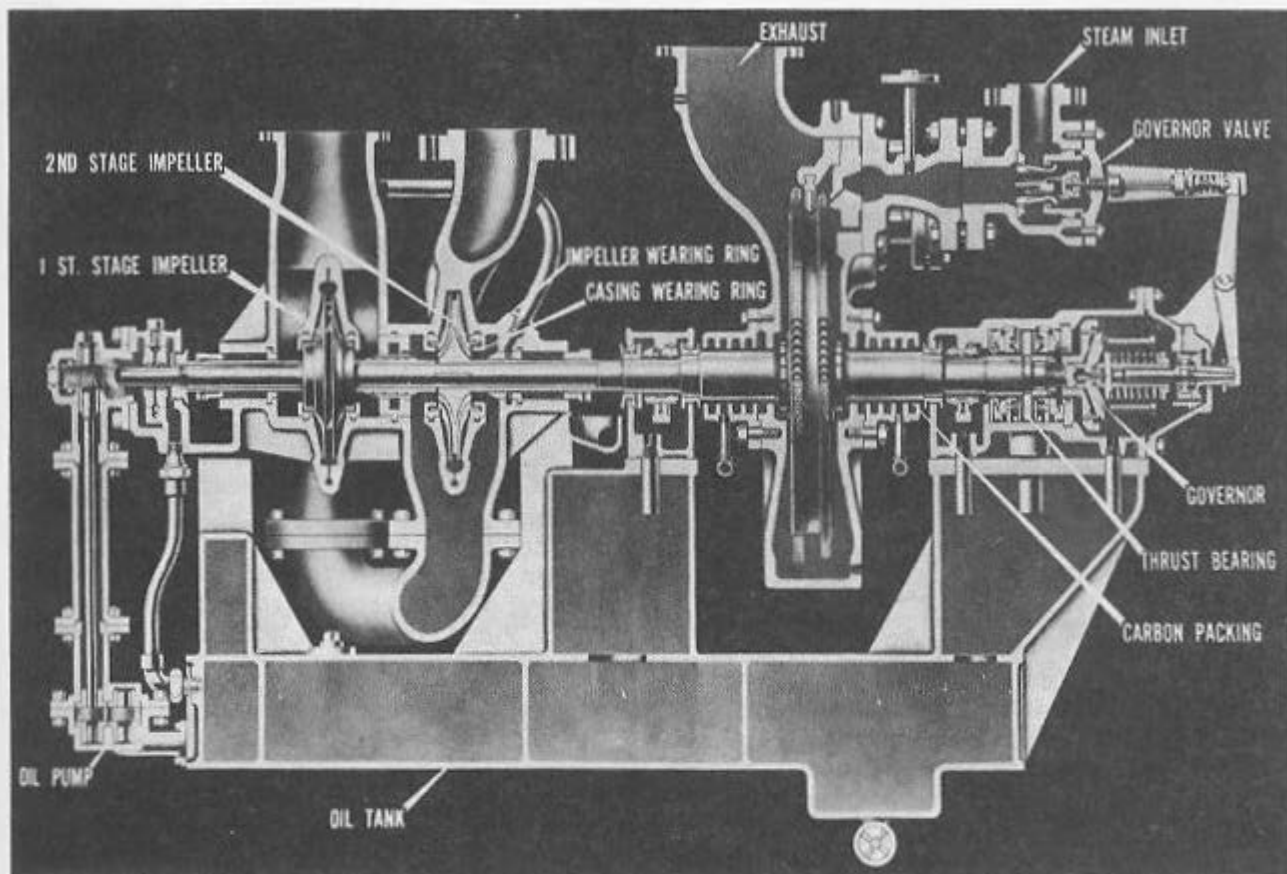


Figure 9-12.—Main feed pump.

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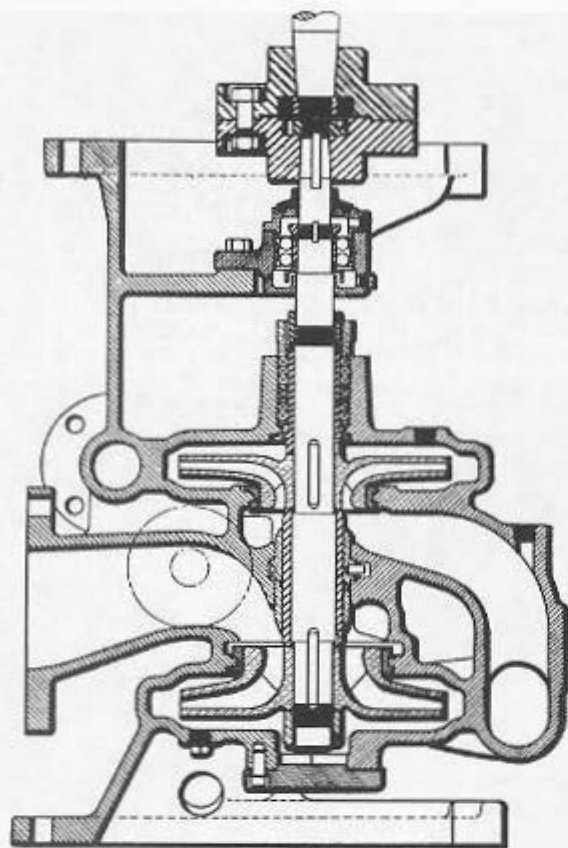
in order to maintain a constant discharge pressure under all conditions. Main feed pumps are fitted with constant-pressure pump governors.

Feed booster pumps are usually vertical, single- or two-stage pumps driven by a steam turbine or electric motor. Feed booster pumps, normally installed in the engine room, have low suction and impeller eye velocities and operate at low speeds because of the low suction heads available. These pumps should be fitted with suction vent connections and with a recirculation system. The recirculating line should be opened when starting or securing and when the pump is discharging to a reciprocating feed pump. At other times, the recirculation from the centrifugal main feed pump will provide sufficient protection against overheating of the booster pump at low capacities.

Main condensate pumps are vertical, one- or two-stage pumps driven by steam turbines or

electrical motors. Condensate pumps take suction under extremely low submergence from the hot well of the condenser. The first-stage impellers are usually of the single, top-suction type, and the suction nozzle and piping are so arranged that there is a continuous downward slope from the condenser to the impeller eye. The impeller must be submerged even at the maximum angle of the ship's roll or a severe water hammer may occur. Figure 9-13 shows a two-stage condensate pump.

Pumps for main circulating service on high-speed combatant ships are generally of the vertical propeller type and are driven by steam turbines. These pumps have capacities of from 10,000 to 40,000 gallons per minute at total head of approximately 30 feet. For such installations, circulating pumps are usually arranged to operate when maneuvering, backing, or going ahead at low speeds. At high speeds the scoop circulation



150.4

Figure 9-13.—Two-stage condensate pump.

is adequate. In auxiliary ships, the main circulating pumps are usually of the vertical, centrifugal, double-suction type and are driven by electric motors.

The majority of pumps for miscellaneous circulating and supply applications are of the single-inlet, centrifugal, volute type, and are close-coupled to the driving unit. Electric power is generally used as the motive force. Figure 9-14 illustrates this type of pump.

OPERATION AND OPERATING TROUBLES

The operating instructions for centrifugal pumps vary somewhat from one type to another. Before attempting to operate any pump, one should read the posted operating instructions and the valve labels, and check the piping markings.

If a centrifugal pump **DOES NOT DELIVER ANY LIQUID**, the trouble may be caused by (1) insufficient priming; (2) insufficient speed of the pump; (3) excessive discharge pressure, such as might be caused by a partially closed valve or some other obstruction in the discharge line; (4) excessive suction lift; (5) clogged impeller passages; (6) the wrong direction of rotation; (7) clogged suction screen (if used); (8) ruptured suction line; or (9) loss of suction pressure.

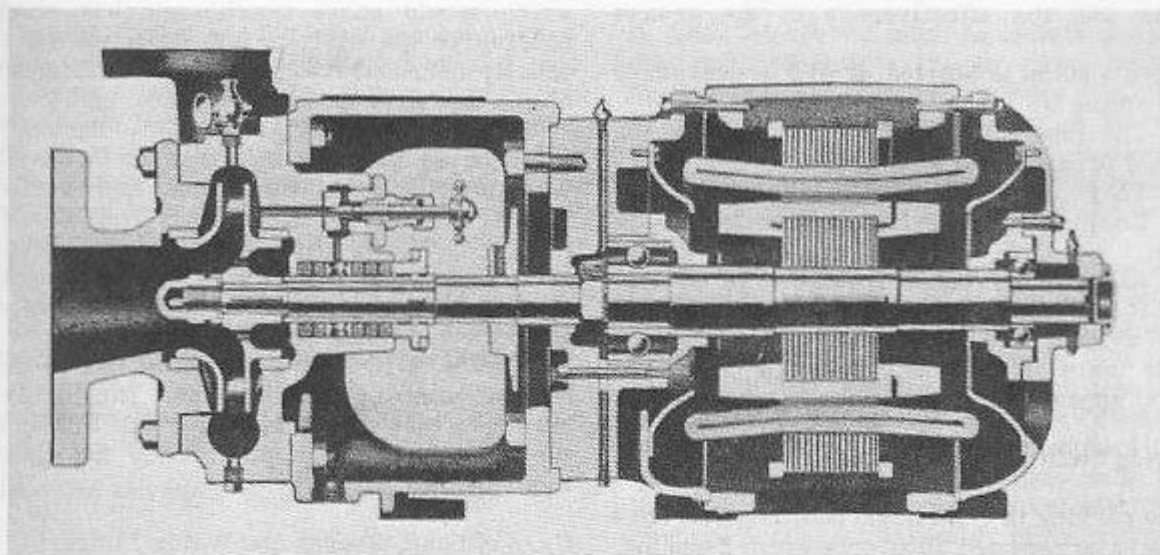
If a centrifugal pump delivers some liquid but operates at **INSUFFICIENT CAPACITY**, the trouble may be caused by (1) air leakage into the suction line; (2) air leakage into the stuffing boxes, in the case of pumps operating at less than atmospheric pressure; (3) insufficient speed of the pump; (4) excessive suction lift; (5) insufficient liquid on the suction side; (6) clogged impeller passages; (7) excessive discharge pressure; or (8) mechanical defects such as worn wearing rings, impellers, stuffing box packing, or sleeves.

If a pump **DOES NOT DEVELOP ENOUGH DISCHARGE PRESSURE**, the trouble may be caused by (1) insufficient speed of the pump; (2) air or gas in the liquid being pumped; or (3) mechanical defects such as worn wearing rings, impellers, stuffing box packing, or sleeves.

If a pump **WORKS FOR A WHILE AND THEN FAILS TO DELIVER LIQUID**, the trouble may be caused by (1) air leakage in the suction line; (2) air leakage in the stuffing boxes; (3) clogged water seal passages; (4) insufficient liquid on the suction side; or (5) excessive heat in the liquid being pumped.

If a motor-driven centrifugal pump **TAKES TOO MUCH POWER**, the trouble will probably be indicated by overheating of the motor. The basic cause of the difficulty may be (1) operation of the pump at excess capacity and insufficient discharge pressure; (2) excessively high viscosity or specific gravity of the liquid being pumped; or (3) misalignment, a bent shaft, excessively tight stuffing box packing, worn wearing rings, or other mechanical defects.

VIBRATION of a centrifugal pump is often caused by (1) misalignment; (2) a bent shaft; (3) a clogged, eroded, or otherwise unbalanced impeller; or (4) lack of rigidity in the foundation. Insufficient suction pressure may also cause vibration, as well as **NOISY OPERATION** and **FLUCTUATING DISCHARGE PRESSURE**, particularly in pumps handling hot or volatile liquids.



150.5

Figure 9-14.—Cross-section of a motor-driven centrifugal pump.

If the pump fails to build up pressure when the discharge valve is opened and the pump speed increased, it will be necessary to:

1. Secure the pump.
2. See that the pump is primed and that all air is expelled through the air cocks on the pump casing.
3. See that all valves on the pump suction line are open.
4. Start the pump again. If the discharge pressure is not normal when the pump is up to its proper speed, the suction line may be clogged, or an impeller broken. It is also possible that air is being drawn into the suction line or into the casing. If any of these conditions exist, stop the pump, try to find the source of the trouble, and correct it, if possible.

MAINTENANCE AND REPAIR

The following discussion of maintenance and repair applies in general to most centrifugal pumps aboard ship. However, a number of different designs of centrifugal pumps are in use; for specific information on any particular pump, study the manufacturer's technical manual furnished with the unit.

Inspections of Operating Pumps

As a routine maintenance procedure, frequent and regular inspections should be made

of each pump that is in operation. At least once an hour, it should be ascertained that all temperature and pressure gages are indicating proper conditions and that there is proper leakage from the stuffing boxes.

Lubricating Systems

Lack of lubrication or improper lubrication is a major cause of pump failure. Before a pump is started, the level of oil in the sump should be checked—not only for the amount of oil, but also for quality of oil it contains. If water is found in the oil sump, a check should be made for leakage from turbine glands, a leaky oil cooler, or any other possible source of water contamination. The oil filters or strainers must be checked frequently; in those with edge filtration (such as in the Cuno type filter), the sediment, which will collect in the bottom of the filter, must be cleaned out frequently. Housings of grease-lubricated bearings should be checked occasionally to ensure that they are free of water, dirt, and other foreign matter. If water is found in the bearing housing, it should be traced to its source. When water or other foreign matter is found in a lube oil system, the unit should not be operated until the system has been drained, cleaned, and filled with the proper quantity and quality of oil. The frequency with which grease is added to a bearing must be determined by the type of

service and the effectiveness of the grease seals.

When a pump is started, it will be necessary to determine if:

1. The lube oil pump is discharging at the designed pressure.
 2. There is oil flow to all bearings.
 3. Cooling water is flowing through the air cooler.
 4. All air is vented from the oil cooler.
 5. It is necessary to vent the lube oil system.
- If the system needs venting the vent at the highest point in the system should be opened until oil appears, and then closed.

Renewing Stuffing Box Packing

The packing in centrifugal pump stuffing boxes should be renewed about once every 2 months. When packing is replaced, the specified material and the correct size should be used. The joints in the packing rings must be staggered so that they will fall at different points around the shaft. The stuffing box should be packed loosely and set up lightly on the gland, allowing a liberal leakage. With the pump in operation, the gland should be tightened and the packing compressed gradually. It is important to do this gradually and evenly, in order to avoid excessive friction

which would cause overheating and possibly scoring of the shaft or the shaft sleeve. It is usually necessary to put in more packing rings after the first ones have been compressed.

On some centrifugal pumps, a lantern ring is inserted between the rings of the packing. When stuffing boxes on such pumps are replaced, the packing beyond the lantern ring should be replaced. The stuffing box should be packed in such a way that the packing will not block off the liquid seal connection to the lantern ring after the gland has been tightened.

Figure 9-15 shows a stuffing box on a centrifugal pump. Notice that the packing is so arranged that the lantern ring will line up with the liquid seal connection when the gland is tightened.

Care of Shaft Sleeves and Water Flingers

On most centrifugal pumps, the shaft is protected at the stuffing box by sleeves which are either screwed or keyed to the shaft. Sleeves should be examined whenever the pump is opened for inspection or repair. The sleeves must be properly fitted to the shaft to keep water from leaking between the shaft and the sleeves. If leakage does occur, a fiber or asbestos washer must be fitted between the

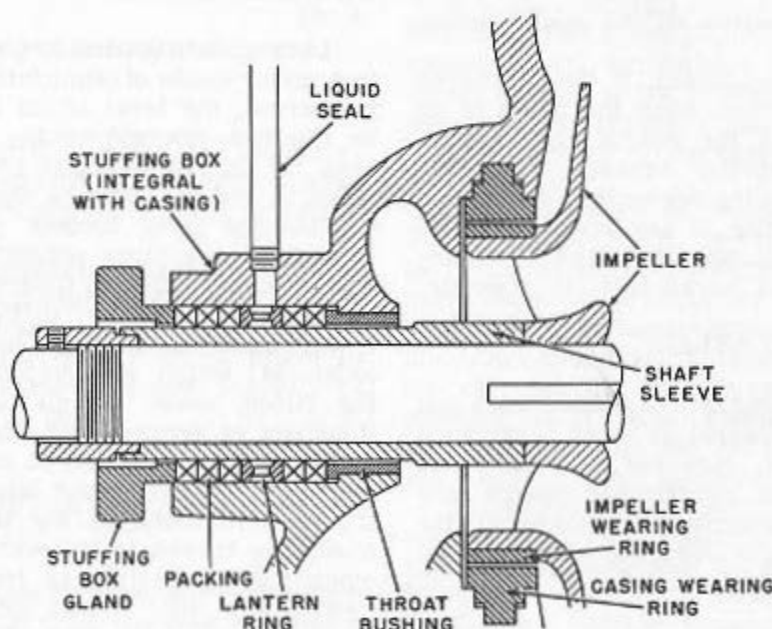


Figure 9-15.—Stuffing box on centrifugal pump.

end of the sleeve and the shaft shoulder and all clearances filled with white lead or red lead.

The outer surface of the sleeve must be kept smooth and free from scores, in order to prevent excessive wear of the packing. A sleeve which is only slightly worn or scored should be sent to the shop for a finishing cut to smooth the surface. A badly worn sleeve should be replaced.

Water flingers are fitted on shafts outboard of the stuffing box glands to prevent water from flowing along the shaft and entering the bearing housing. The water flingers must be tightly fitted to the shaft.

Inspection and Renewal of Wearing Rings

Most centrifugal pumps have both impeller wearing rings and casing wearing rings, similar to those shown in figure 9-16. The smaller ring fits over the hub of the impeller and turns with it; the larger ring is stationary, being attached to the casing and prevented from turning by the semicircular flange or shoulder on one side.

A close clearance must be maintained between the two wearing rings in order to prevent excessive leakage from the high pressure side to the low pressure side of the impeller. Some pumps have wearing rings only on the casing; in this design, the close clearance must be maintained between the impeller itself and the casing wearing ring.

Wearing ring clearance must be checked frequently and must be maintained within the specified tolerances. The allowable wear in these rings varies according to the type of pump and the service for which the pump is used. If it is necessary to replace wearing rings (when clearances exceed the specified figures) the manufacturer's instructions must be followed carefully. Improper fitting of the wearing rings or incorrect assembly of the pump can result in serious damage. On most ships, this job can be done by the ship's force but it requires the complete disassembly of the pump. All necessary information on disassembly of the unit, dimensions of the wearing rings, and reassembly of the pump can be found in the manufacturer's technical manual.

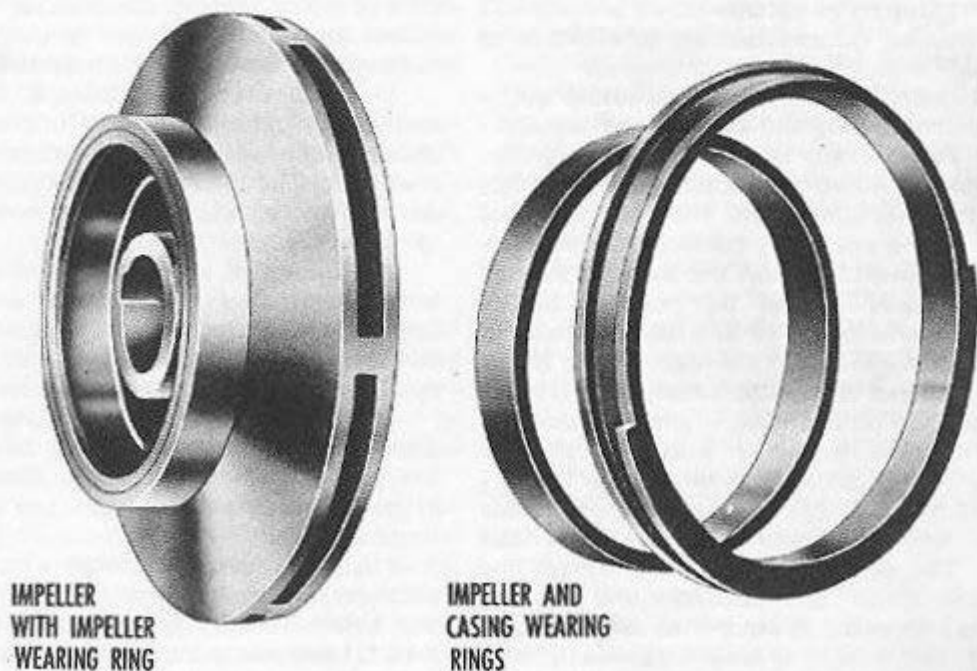


Figure 9-16.—Centrifugal pump impeller and wearing rings.

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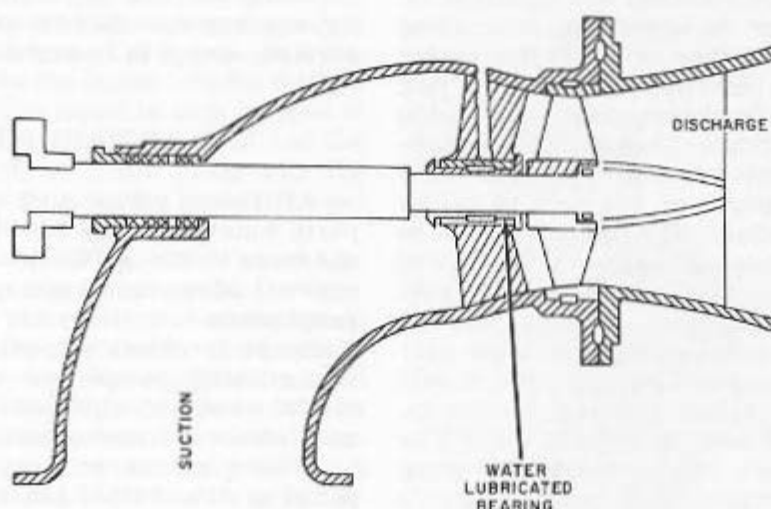


Figure 9-17.—Main condenser circulating pump, showing internal water-lubricated bearing.

96.15

than the oil film; however, lubrication still plays an important part in the operation because it dissipates heat and prevents corrosion. The oil film also helps prevent foreign matter from entering the bearing. Enough grease or oil should be supplied to provide a protective film over the bearing parts; using an excessive amount of lubricant will cause it to churn and the bearing will overheat.

When a roller or ball bearing fails in service, it must be renewed as it cannot be repaired. The replacement bearing must be carefully installed if it is to give satisfactory service.

Replacing Pump Rotors

Pumps, like all machinery, in time, will need overhauling. Much of the work on pumps involves removing the rotor from the casing. To renew wearing rings, bearings, packing, sleeves, or impellers, the casing must be removed and the rotor lifted out.

When the rotor parts are disassembled, the shaft should be checked carefully. The journal surfaces should be checked for burrs or nicks. If a lathe is available, the shaft can be swung in the lathe, and with a dial indicator, it can be determined whether the shaft is bent or the journals are out of round. The journal surfaces can be measured with an outside micrometer to determine whether there is wear. If the journals are worn or out of round, they can be

built up and machined to the designed diameter, at a repair activity. If the wearing rings are to be renewed, they will have to be fitted either in the ship's machine shop, or at a repair activity.

All parts of a rotor must be clean and free of burrs (especially the faces of the impeller and the sleeves) when the rotor is reassembled. The oil clearances of the journal and thrust bearings, the running clearance of the wearing rings, the clearance between the impeller and diaphragm bushing, and clearance between the shaft sleeve and stuffing box bushing should be within the limits indicated in the manufacturer's technical manual.

Before a rotor is lowered, it is necessary to roll in the lower half of the journal bearings and clean all foreign matter from the lower half of the casing. A new parting flange gasket should be used to avoid leaks, as internal leaks will lower the efficiency and maximum capacity of the pump. Then the lifting gear should be attached and the rotor lowered into the casing. A check should be made to see that all stationary rotor parts (diaphragms, casing rings, and stuffing box bushings) enter their respective fits in the casing without binding. If force has to be applied to the rotor parts so that they can enter the casing, the rotor should be removed and all parts checked for dirt and burrs.

When the rotor is in place, the upper half of the casing should be lowered. The casing must fit over the rotor easily. If it does not, the upper

casing half should be removed and examined for dirt and burrs. When the upper and lower casing halves contact each other properly, the casing dowels should be inserted. Next, the parting flange nuts should be tightened evenly by going over them several times. Then the thrust bearing should be assembled, the upper half of the bearing placed in position, and the two halves of each bolted together. The flingers should be adjusted so that they are close to the face of the bearings, however, they **MUST** not rub. Then the flinger setscrews are tightened, the bearings closed up by placing the caps over them, the bolts tightened, and a reading should be taken on the thrust bearing clearance.

The pump shaft and turbine shaft **MUST** be in correct alignment. For information on pump alignment, refer either to the manufacturer's technical manual for the specific pump or to the Bureau of Ships Technical Manual.

All water lines **MUST** be in place and tightened before attempting to align the unit, otherwise tightening the lines may cause misalignment of the unit. The stuffing boxes should be packed with the proper packing; then the unit is ready to be tested.

The pump should be rotated several times, by hand, before steam is cut into the driving unit. There must be no undue binding or friction. If all conditions are satisfactory after repairs have been completed, the pump should be brought up to operating speed and pressure. When the pump is used for the first time, it should be kept under close observation for several hours and should not be considered ready for unlimited operation until it has carried the required load with the ship underway.

SAFETY PRECAUTIONS

The following safety precautions must be observed in connection with the operation of centrifugal pumps:

1. See that all relief valves are tested at the appropriate intervals. Be sure that relief valves function at the designated pressures.
2. Never attempt to jack over a pump by hand while the steam valve to the pump is open or while the power is on.
3. Do not tie down the overspeed trip, the speed-limiting governor, or the speed-regulating governor. Do not in any way attempt to render these devices inoperable. Be sure that speed-limiting and speed-regulating governors are properly set.

4. Do not use any boiler feed system pump for any service other than boiler or feed water service, except in emergency.

ROTARY PUMPS

All rotary pumps work by means of rotating parts which trap the liquid at the suction side and force it through the discharge outlet. Gears, screws, lobes, vanes, and cam-and-plunger arrangements are commonly used as the rotating elements in rotary pumps. Rotary pumps, like reciprocating pumps, operate on the positive-displacement principle—that is, each rotation or each stroke delivers a definite quantity of liquid.

Rotary pumps are particularly useful for pumping oil and other heavy, viscous liquids. In the fireroom this type of pump is used for fuel oil service, fuel oil transfer, and lubricating oil service. Rotary pumps are also used for non-viscous liquids, such as water or gasoline, where the pumping problem involves a high suction lift.

The power end of a rotary pump is usually an electric motor or a steam-driven turbine. The main fuel oil service and transfer pumps are generally steam-driven. A smaller fuel oil service pump driven by an electric motor is often used for in-port steaming or for steaming at low firing rates. In addition, most firerooms have a hand-driven fuel oil service pump which can be used either for lighting off boilers in a completely cold plant or for emergency fuel oil service in the event of complete power failure of the ship. A hand-driven fuel oil service pump is shown in figure 9-18.

Rotary pumps are designed with very small clearances between rotating parts, and between rotating parts and stationary parts, in order to minimize slippage from the discharge side back to the suction side. Rotary pumps are designed to operate at relatively low speeds in order to maintain these clearances; operation at higher speeds would cause erosion and excessive wear, which would result in increased clearances.

Classification of rotary pumps is generally made according to the type of rotating element. In the following paragraphs we will discuss briefly the main features of gear pumps and screw pumps.

The **SIMPLE GEAR PUMP** has two spur gears which mesh together and revolve in opposite directions. One is the **DRIVING GEAR**, and the other is the **DRIVEN GEAR**. Clearances

between the gear teeth and the casing and between the gear faces and the casing are only a few thousandths of an inch. The action of the unmeshing gears draws the liquid into the suction side of the pump. The liquid is then trapped in the pockets formed by the gear teeth and the casing, so that it must follow along with the teeth. On the discharge side, the liquid is forced out by the meshing of the gears.

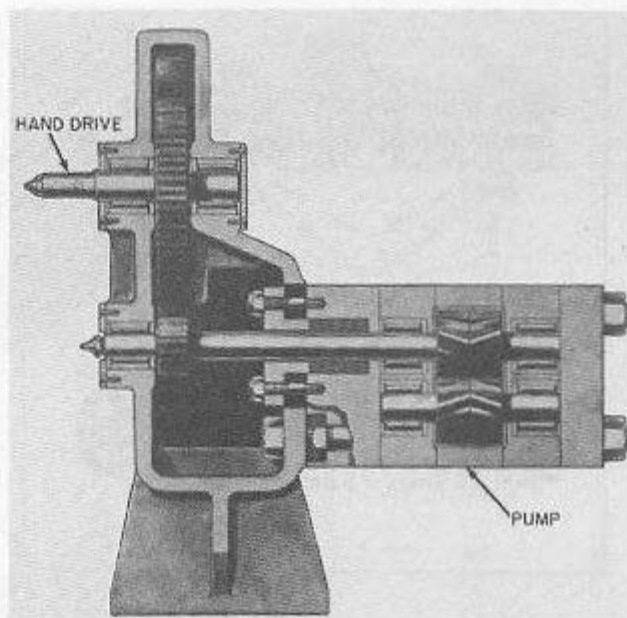
The **HERRINGBONE GEAR PUMP** is a modification of the simple gear pump. In the herringbone gear type, one gear type, one discharge phase begins before the previous discharge phase is entirely complete; and this overlapping tends to give a steadier discharge pressure than is found in the simple gear pump. The hand-driven fuel oil service pump shown in figure 9-18 is a herringbone gear pump. Power-driven pumps of this type are sometimes used for low-pressure fuel oil service, lubricating oil service, and Diesel oil service.

The **HELICAL GEAR PUMP** is still another modification of the simple gear pump. Because of the helical gear design, the overlapping of successive discharges from spaces between the teeth is even greater than it is in the herringbone gear pump; and the discharge flow is, accordingly, even smoother. Since the discharge flow is smooth in the helical gear pump, the gears can be designed with a small number of teeth, thus allowing increased capacity without sacrificing smoothness of flow.

The pumping gears in this type of pump are driven by a set of timing and driving gears, which also function to maintain the required close clearances while preventing actual metallic contact between the pumping gears. As a matter of fact, metallic contact between the teeth of the pumping gears would provide a tighter seal against slippage; but it would cause rapid wear of the teeth because foreign matter in the pumped liquid would be present on the contact surfaces.

Roller bearing at both ends of the gear shafts maintain proper alignment, and so minimize the friction loss in the transmission of power. Stuffing boxes are used to prevent leakage at the shafts. The helical gear pump is used to pump nonviscous liquids and light oils at high speed. It can also be used to pump heavy, viscous materials at lower speed.

The **LOBE-TYPE PUMP** is still another variation of the simple gear pump. The lobes are considerably larger than gear teeth, but there are only two or three lobes on each rotor. The rotors are driven by external spur gears on



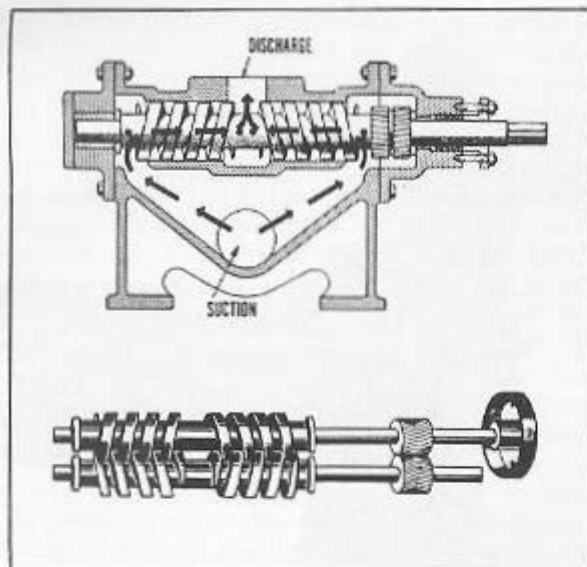
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Figure 9-18.—Hand-driven fuel oil service pump.

the rotor shafts. Some lobe pumps are made with replaceable inserts (gibs) at the extremities of the lobes. These inserts take up the wear which would otherwise be sustained by the ends of the lobes; and, in addition, they maintain a tight seal between the lobe ends and the casing. The inserts are usually seated on a spring, and are thus able to automatically compensate for considerable wear of both the gibbs and the casing. Replaceable cover plates (liner plates) are fitted at each end of the casing, where the lobe faces cause heavy wear.

There are several types of **SCREW PUMPS**. The main points of difference between the various types are the number of intermeshing screws and the pitch of the screws. A **DOUBLE-SCREW LOW-PITCH PUMP** is shown in figure 9-19. This type of pump is widely used on board ship as a fuel oil service pump. Figures 9-20, 9-21, and 9-22 show various views of a **TRIPLE-SCREW HIGH-PITCH PUMP**.

In the screw pump, the liquid is trapped and forced through the pump by the action of rotating screws. Screw pumps have few moving parts and no valves to get out of order. They may have two or three screws, and are divided into high- and low-pitch types.

The triple-screw, high-pitch pump has three screws or rotors that revolve within a close



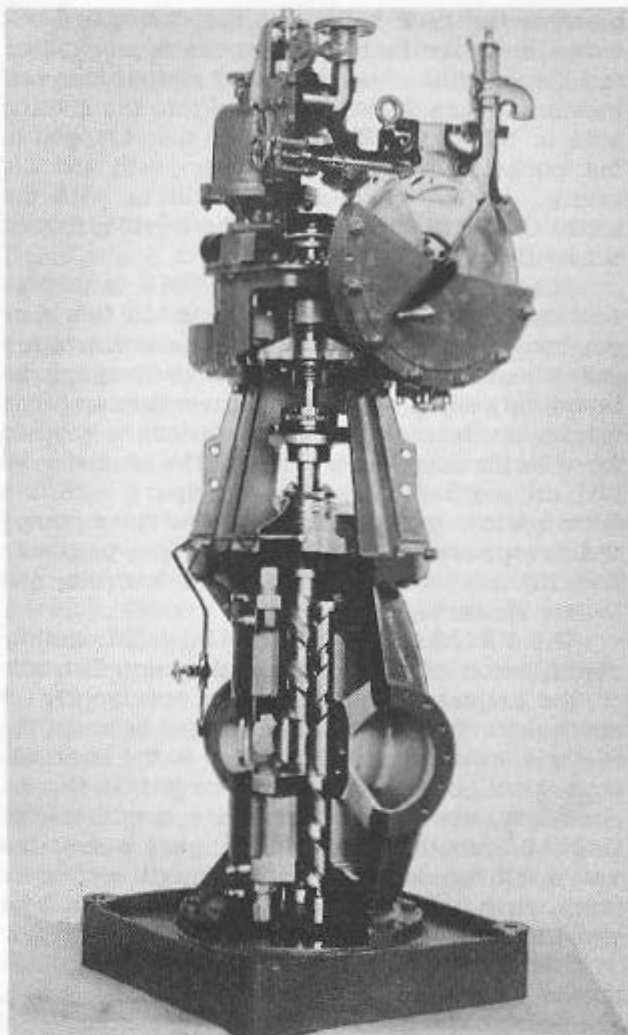
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Figure 9-19.—Double-screw low-pitch pump.

fitting housing. The power rotor, in the center, is in mesh with, and drives, the two idling rotors (idlers). As the rotor turns, the liquid flows in between the threads at the outer end of each pair of screws. The threads carry the liquid along within the housing to the center of the pump, where it is discharged.

ROTATING-PLUNGER PUMPS are used in the naval service for the following applications: fuel oil and Diesel oil service, fuel oil booster and transfer service, fuel oil tank drains and lubricating oil service.

Figure 9-23 illustrates the main operating parts of the rotating plunger pump (sometimes classified as a "cam-and-plunger" pump). The plunger is shown in three positions, (1) to (3), illustrating the pumping process. The main body of the pump is a cylinder with the suction port entering through the side, as shown, in the upper left-hand corner. The drive shaft, concentric with the pump cylinder, carries an eccentric strap which has a slightly smaller diameter than the pump cylinder. This eccentric strap operates as a piston or "plunger." The eccentric arm plus the radius of the plunger is equivalent to the radius of the cylinder less the necessary operating clearances. Therefore, with each revolution of the eccentric, the point of nearest contact of the plunger on the cylinder wall rotates completely around the cylinder. Motion of the plunger about its own center is



38.106

Figure 9-20.—Triple-screw high-pitch pump.

constrained by a hollow arm, or slide, which extends from the plunger through a slot in the top of the cylinder, and above that point, through a slotted pin carried in a bearing which seals the cylinder space from the discharge space.

Referring to (1) in figure 9-23 it may be seen that liquid trapped in the right side of the cylinder will be forced through the hollow arm to the discharge line as the eccentric rotates counterclockwise. View (2) shows the next phase with the space on the left side opening, thereby creating a vacuum which causes liquid to flow in from the suction line. The next stage, shown at (3), illustrates the discharge port, at the bottom of the hollow arm, beginning to close. The discharge port is closed by the slide pin,

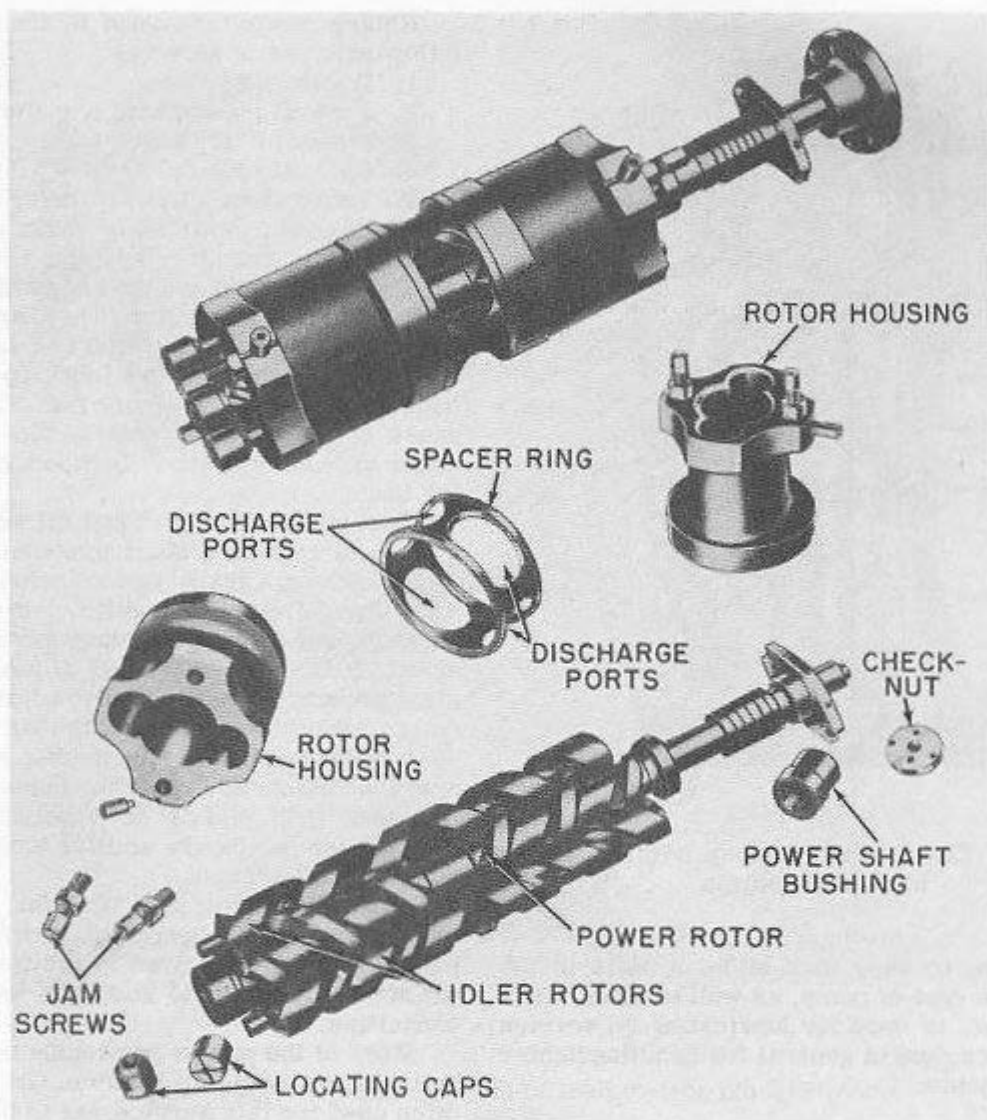


Figure 9-21.—Internal parts of a triple-screw high-pitch pump.

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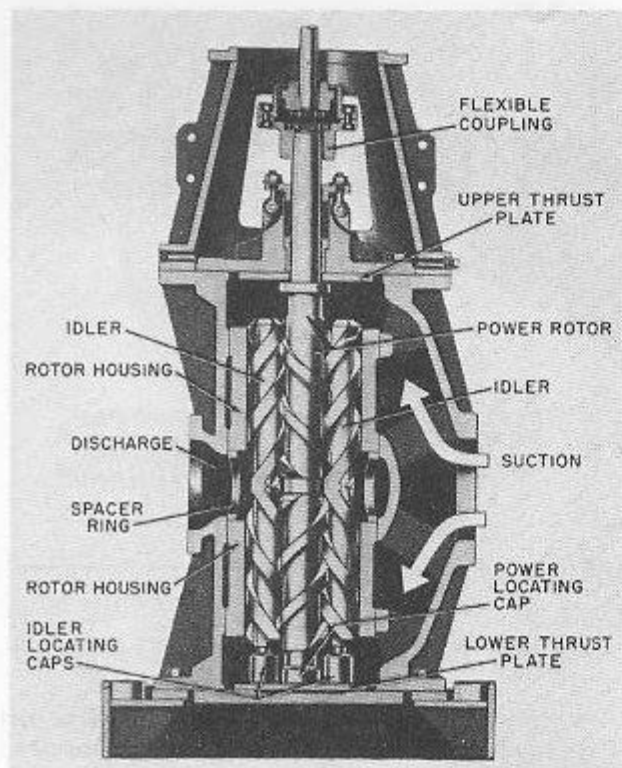
during the suction portion of the stroke. When the eccentric turns slightly further, the point of contact of the plunger on the cylinder will pass over the suction port and trap the new charge on the discharge side, as shown in view (1).

In order to reduce the tendency to pulsate, rotating-plunger pumps usually employ two plungers whose driving eccentrics are 180° apart on the shaft. The plungers are separated by a diaphragm through which the shaft extends.

The MOVING-VANE TYPE PUMP, illustrated in figure 9-24, consists of a cylindrically bored housing with a suction inlet on one side,

and a discharge outlet on the other side. A cylindrically shaped rotor of less diameter than the cylinder is driven about an axis placed above the center line of the cylinder so that clearance between the rotor and cylinder, at the top, is small, and is at a maximum at the bottom.

The rotor carries vanes which move in and out as it rotates to maintain sealed spaces between the rotor and the cylinder wall. The vanes trap liquid on the suction side and carry it to the discharge side where contraction of the space expels liquid through the discharge line. The vanes may swing on pivots, as shown in the



47.80

Figure 9-22.—Cutaway view of triple-screw high-pitch pump.

illustration, or they may slide in slots in the rotor. This type of pump, as well as other vane-type pumps, is used for lubricating oil service and transfer, and in general for handling lighter viscous liquids.

USAGE IN NAVAL SERVICE

Positive displacement rotary pumps have largely supplanted reciprocating pumps for pumping all viscous liquid. They are also used for gasoline or other low viscosity volatile liquid where a high suction lift is required. Rotary pumps are suitable for handling liquid over a wide range of viscosities. The power required increases with the viscosity due to the increased friction within the pump. The speed of the pump should be reduced when handling increased viscosities so that the rotors are allowed sufficient time to fill. Rotary pumps are not suitable for handling corrosive liquids or liquids containing abrasive solids.

Rotary pumps are used by the Navy for the following types of services:

1. Boiler fuel oil.
2. Fuel oil booster and transfer.
3. Diesel oil and transfer.
4. Fuel oil tank draining.
5. Lubricating oil and transfer.
6. Fuel oil, gasoline, or water cargo.
7. Cargo stripping.

The screw-type pumps are extensively used for boiler fuel oil service. The gear-type pumps are used for this application to a lesser extent. Other types, such as the lobe-type pump, are not suited for high pressure fuel oil service because of their larger rotors. The large rotors cause excessive shaft deflection and heavy bearing loads.

Two types of in port fuel oil service pumps are in current use. Most combatant ships have motor-driven, axial piston pumps installed. This type of pump is designed to operate with varying capacity at constant motor and pump speed. This is accomplished by means of a constant pressure governor which adjusts the stroke mechanism in response to the burner demand. This control is usually augmented by a manually operated capacity control. Some ships are equipped with pumps of a constant delivery type. These pumps are similar to those used for main fuel oil service.

Fuel oil booster and transfer pumps often encounter severe operating conditions. These pumps are usually driven by multispeed motors or steam turbines to ensure a wide range of capacities.

Most of the pumps previously described are suitable for diesel oil service. Gear pumps are often used for this service due to their economy of space and weight.

Main lubricating oil pumps for surface ships are subjected to severe operating conditions because of entrained air in the lubricating oil. This has been particularly noticeable in lubricating oil pumps which must run at their maximum capacity regardless of the operating conditions. The pumping of these air-oil mixtures results in pulsating discharge pressures and vibration of the pump and the piping. Screw-type rotary pumps are used for this service.

Pumps used for cargo stripping must maintain a suction lift, or act as a continuous priming pump for the centrifugal main cargo pumps. Vane pumps, similar to that illustrated in figure 9-24, are used for this service.

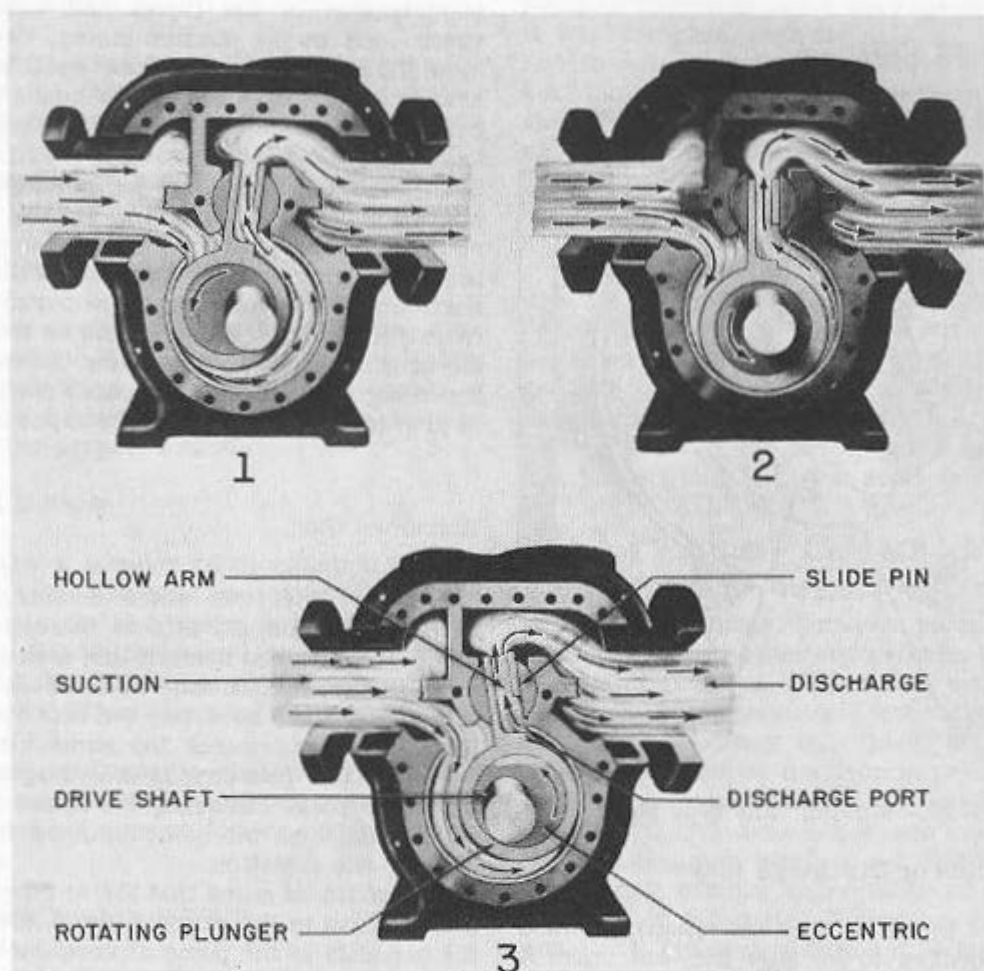


Figure 9-23.—Operating parts of the rotating plunger pump.

47.46

OPERATING TROUBLES

The operating instructions for rotary pumps can be obtained from either Chapter 9470 (47) of the Bureau of Ships Technical Manual or the manufacturer's technical manual for the specific unit. Some rotary pump operating troubles and causes are considered in the paragraphs which follow.

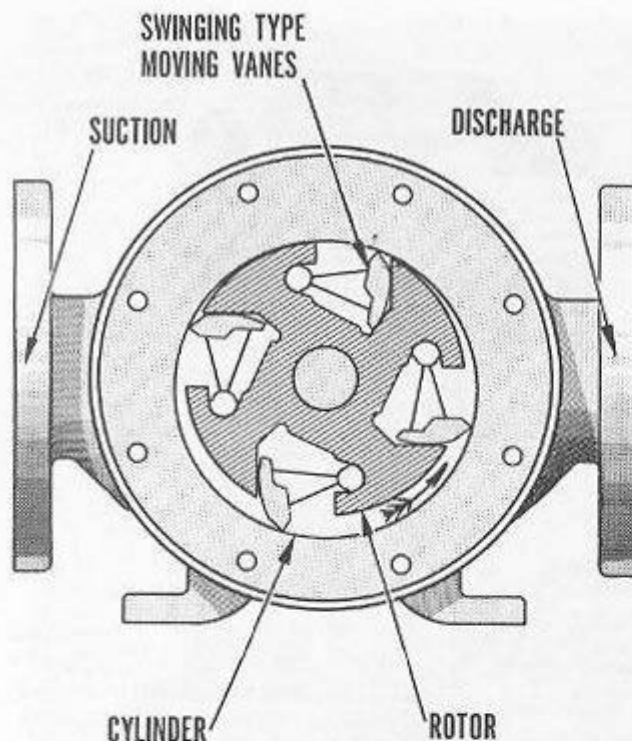
Pump Fails to Deliver Liquid

Sometimes a rotary pump fails to deliver liquid or delivers some liquid but is unable to reach the required capacity. A pump may deliver liquid for a while and then lose suction or

fail to deliver. Under some conditions, a rotary pump will require excessive power in order to operate at the proper capacity. If any of these troubles occur, or if the pump operates at adequate capacity but is noisy in operation, the pump should be stopped as soon as practicable and the source of the trouble located. Some common causes of faulty operation in rotary pumps are discussed here.

Insufficient Priming

Rotary pumps are generally self priming. However, a pump operating under a high suction lift may become air-bound or vapor-bound and may not be able to prime itself.



47.47

Figure 9-24.—Moving vane type pump.

Clogged Suction or Discharge Lines

All valves in the suction and discharge lines should be checked to be sure they are open. A check should be made to see if a broken valve spring or a detached or damaged valve disk is causing the trouble. The suction strainer (if fitted) should be checked to be sure it is not clogged.

Air Leakage

Air leakage into the suction side of the pump or into any part of the suction piping or the suction manifold will cause improper operation of the pump. The pump stuffing box and the packing on all valve stems in the suction line and suction manifold should be checked to ensure that air is not leaking into the suction side of the system. The end of the suction pipe must be properly submerged in the liquid supply.

Vapor Or Air Lock

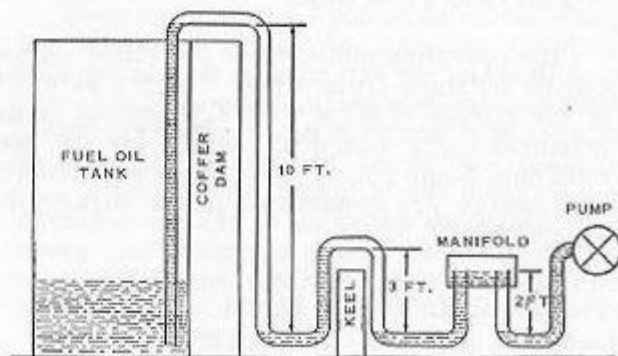
Excessive suction lift or excessive temperature of the pumped liquid may cause partial

vaporization of the liquid and thereby cause vapor lock in the suction piping. Vapor lock is most likely to occur in long suction lines that have a good many loops and bends (fig. 9-25), particularly if the pump is handling oil which has recently been taken on or oil which has been heated. Vapor lock is indicated by noisy operation and by pounding in the pump. To remedy this condition, another tank should be lined up, using another manifold if possible, and suction shifted. When the pump operates properly from this tank, a shift should be made back to the original tank, and the pump operated slowly. Reducing the speed of a rotary pump may help to prevent the development of vapor lock.

Entrained Gas

Air or other gas which is entrained in the liquid being pumped affects the capacity of the pump even at zero suction lift; and, as the pressure in the suction line decreases, the effects of entrained gas become even more pronounced. Entrained gas causes the same kind of noisy operation and pounding in the pump as is caused by vapor lock. Reducing the speed of the pump or heating the oil being pumped may help to remedy the situation.

It should be noted that air or other gas which is dissolved in the pumped liquid does not affect the capacity of the pump at zero suction lift. As the pressure in the suction line decreases, however, the dissolved gas is freed from the liquid and thereby becomes entrained.



104.5

Figure 9-25.—Type of piping arrangement likely to cause vapor lock.

Excessive Viscosity

If the liquid being pumped is too heavy or too viscous for the design of the pump, an excessive amount of power will be required to operate the unit. To correct this trouble, the viscosity of the pumped liquid should be reduced by heating and the speed of the pump should be reduced.

Improper Direction of Rotation

If a motor-driven pump fails to develop discharge pressure when it is first operated after major repairs have been made to the motor, a check should be made to see that the pump is rotating in the proper direction.

Mechanical Defects

There are a number of mechanical defects which may cause serious operating difficulties in rotary pumps. If a pump does not operate properly, it should be checked for misalignment, tight packing, binding of the rotors, a bent shaft, an improperly adjusted relief valve, and other defects.

Additional information concerning operating difficulties can be obtained from the manufacturer's technical manual for the specific pump installation.

MAINTENANCE AND REPAIR

The information in this section is supplementary to that given earlier in the chapter. For more detailed information concerning any particular unit, consult the manufacturer's technical manual.

Shaft Packing

The triple-screw high-pitch rotary pump, which is widely used in the Navy, has only one stuffing box. It is located in the upper casing head and is subject only to suction pressure. An external pipe connects the pump discharge and the stuffing box, allowing the pumped oil to seal the stuffing box and lubricate the bushing which forms the seat for the packing and acts as an upper bearing. A valve in the liquid seal line is factory adjusted to provide the correct amount of oil flow. The adjustment of this valve should NOT be changed. If the setting is disturbed, the valve should be reset so as to allow a slight leakoff from the gland when the

pump is operating under the conditions for which it was designed, with the packing in good shape and the gland stud nuts tightened just enough to seat the packing firmly. Under no circumstances should the pump be operated with this valve closed.

The procedure for repacking the stuffing box is the same as the procedure for repacking stuffing boxes on centrifugal pumps.

In addition to stuffing box type packing, the packing around the shafts of rotary pumps may be of the labyrinth type, the rotary seal type, or a combination of these types. If the shaft packing is not supplied with sealing and lubricating liquid, the packing will become hot from excessive friction, seriously damaging the packing, and scoring the shaft or sleeve.

Renewing Wearing Plates and Liners

The clearances between pump rotors and casing wearing plates and cylinder liners should be maintained as shown on manufacturers' plans. On a low pressure, low suction lift pump, such as lubricating oil, diesel oil supply, and tank drain pumps, the drop in pressure across the clearance spaces does not usually exceed 50 psi, and the clearance between parts, with this type pump, may wear to as much as 0.005 to 0.010 inch without appreciable effect upon the capacity of the pump. Therefore, wearing plate and liner renewal should not be undertaken for this type pump until wear or increased clearance has exceeded these figures, or in the case of fuel oil tank drain pumps, until the pump will not pull a vacuum of at least 16 inches mercury with the suction valve closed. The engineer officer should decide in each case whether or not the amount of wear of clearance parts dictates renewal. For boiler fuel oil service pumps, however, the effect of increased clearance makes itself felt by reduction in the efficiency and in the maximum capacity of the pump. For this class of service the wearing parts should be renewed when the clearances exceed the designed clearances shown on manufacturer's plans by about 100 percent.

Whenever the pump casing is opened, the clearance between the casing liners and plates, and various parts of the rotors and shaft, should be measured to see if excessive wear has taken place and if renewal is necessary. If the bearings are worn excessively, it will be necessary to renew the liners. However, they should not be

renewed unless the pump bearings, that may be down, are first restored to their original readings. The required oil clearances for bearings is usually given on the manufacturers' plans. In the absence of such data, the table of tolerances and clearances in the Bureau of Ships Manual should be followed.

Timing Gears

Timing, or synchronizing, gears are fitted to the rotor shafts to maintain correct clearances between the two pumping rotors during operation. To accomplish this, the gears must be securely locked to the rotor shaft in their exact position to maintain a clearance between the rotor elements as the shafts make a complete revolution. Therefore, no lost motion is permissible

in way of keys or pins holding the rotors and gears in position on the shafts.

SAFETY PRECAUTIONS

The following precautions must be observed in the operation of rotary pumps:

1. See that all relief valves are tested at the appropriate intervals. Be sure that relief valves function at the designated pressures.
2. Never attempt to jack over a pump by hand while the steam or power is on.
3. Do not tie down the overspeed trip, the speed-limiting governor, or the speed-regulating governor. Do not in any way render these devices inoperable.
4. Never operate a positive displacement rotary pump with the discharge valve closed, unless provision is made for adequate discharge.

CHAPTER 10

HEAT EXCHANGERS AND RELATED EQUIPMENT

Any device or apparatus designed to allow the transfer of heat from one fluid (liquid or gas) to another is a heat exchanger. Boilers, distilling plants, and deaerating feed tanks are primary examples of heat exchangers; however, these large and relatively complex pieces of equipment are seldom referred to as heat exchangers.

In order for heat to be transferred from one substance to another, a temperature difference is required. Heat flow or heat transfer can occur only from a substance that is at a higher temperature to a substance that is at a lower temperature. When two objects at different temperatures are placed in contact with each other, or near each other, heat will flow from the warmer object to the cooler one until both objects are at the same temperature. Heat transfer occurs at a faster rate when there is a large temperature difference than when there is only a slight temperature difference. As the temperature difference approaches zero, the rate of heat flow also approaches zero.

In some heat exchangers it is desired to **RAISE THE TEMPERATURE** of one fluid. Fuel oil heaters, combustion air preheaters, lube oil heaters, and many other heat exchangers used on board ship serve this function.

In some heat exchangers it is desired to **LOWER THE TEMPERATURE** of one fluid. Lube oil coolers, boiler water sample coolers, and desuperheaters are examples of this type of heat exchanger.

In condensers, **LATENT HEAT MUST BE REMOVED** from a fluid in order to make it change from a gas to a liquid. Very often, it is necessary to remove the latent heat without removing any sensible heat—that is, it is desired to change the state of the fluid but not to lower its temperature. For example, the purpose of the main condenser is to remove the latent heat from the turbine exhaust steam so that the steam will condense. In this process, however, it is

NOT desired to lower the temperature of the condensate. Since any heat removed from the condensate must be replaced in the deaerating feed tank or in the boilers, lowering the temperature of the condensate is wasteful of heat and therefore wasteful of fuel.

In some heat exchangers, **LATENT HEAT MUST BE ADDED** to a fluid in order to make it change from a liquid to a gas. The generating part of a boiler is a good example of this type of heat exchanger. Since it is impossible to raise the temperature of the steam as long as it is in contact with the water from which it is being generated, the steam does not increase in temperature until it has been drawn off into another heat exchanger (the superheater).

This chapter deals with the important heat exchangers and associated equipment located in the engine room. This group of equipment includes the main and auxiliary condensers, the air ejectors, and the deaerating feed tanks. Information concerning other heat exchangers may be obtained from either the manufacturer's technical manual or the Bureau of Ships Technical Manual.

CONDENSERS

Since the main condenser of a steam plant is one of the most important units in the plant, the operation of the main condenser is discussed here in some detail.

A typical main condenser system is illustrated in figure 10-1. There are two separate circuits involved in the condensation of steam in a condenser of this type. The first is the vapor-condensate circuit, in which the steam exhausted from the turbine enters the condenser at the top of the shell and comes into contact with the outside surfaces of the condenser tubes. The latent heat of the steam is transferred through the tube walls to the sea water that is

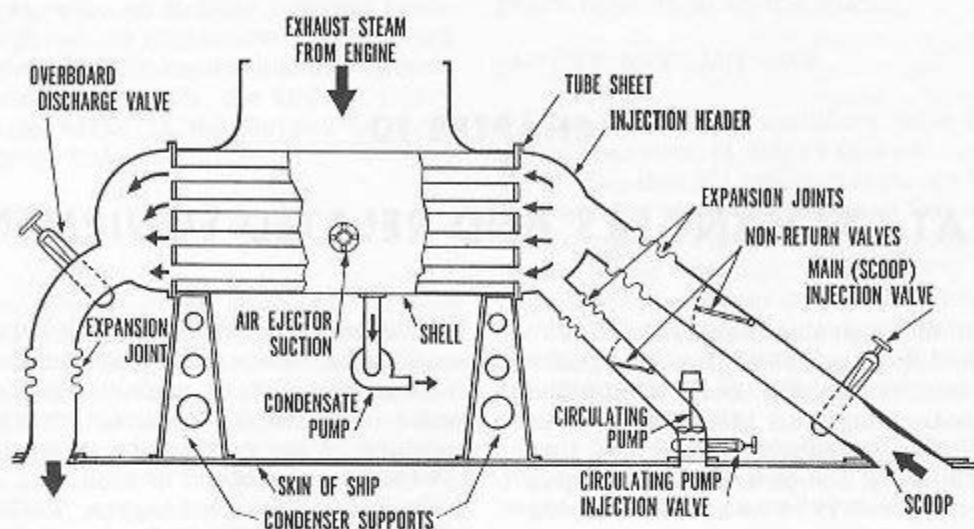


Figure 10-1.—Schematic arrangement of a main condensing system.

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flowing inside the tubes. As its latent heat of vaporization is removed, the steam condenses on the tube surfaces. The condensate then falls to the bottom of the condenser and drains into the hot well, from which it is removed by the condensate pump. Air and other noncondensable gases which enter with the exhaust steam are drawn off by the air ejector through an AIR EJECTOR SUCTION OPENING in the shell, above the condensate level. The second circuit in the condenser is the cooling water circuit. During normal ahead operation, sea water flow through the condenser is provided automatically by means of the INJECTION SCOOP. The scoop is located below the waterline, and the forward motion of the ship (5 knots or above) causes sea water to flow through the condenser. STRAINER BARS are installed in the sea chest to strain out debris which could foul the piping and the condenser tubes. The injection and overboard discharge lines are provided with expansion joints to prevent undue strains as a result of either change in temperature or working of the hull.

A main CIRCULATING PUMP provides a flow of water through the condenser at times when scoop injection is inadequate—as, for example, when a ship is stopped, backing down, or moving ahead at a very slow speed. A large SWING-CHECK VALVE OR NONRETURN VALVE, which prevents backflow of water, is

installed in the main injection line; another one is installed in the main circulating pump discharge line. When water is flowing into the condenser through the main injection line, the nonreturn valve in the main circulating pump discharge line prevents the backflow of water through the pump. When the circulating pump is in operation, the nonreturn valve in the main injection line prevents backflow of water through that line.

The main circulating pump, usually of the propeller type, must have a large capacity (as high as 30,000 gpm against a very low head). The main circulating pump is provided with a bilge suction line so that it can be used to pump water overboard in case of serious flooding of the engineroom.

Main condenser circulating pumps (provided with bilge suction connections) generally constitute the largest potential capacity available for pumping engineroom bilges; it is important that responsible personnel know how to make necessary connections to these suctions in an emergency. It is usually necessary only to turn the bilge suction line stop or stop-check valve one-fourth to one-third open, to obtain maximum bilge suction capacity.

To ensure proper maintenance of a condenser, there are certain installation and construction features which you should understand. Modern installation practice is to suspend the

condenser from the turbine rather than to have the condenser support the turbine. This allows for a greatly reduced weight, and makes it unnecessary to use an expansion joint between the turbine and the condenser.

All main condensers that have scoop injection are of the straight-tube, single-pass type; they are usually of the general construction shown in figure 10-2.

A main condenser may contain from 2,000 to 10,000 copper-nickel alloy tubes, usually of 5/8-inch diameter. The length of the tubes and the number of tubes depend upon the size of the condenser; the size depends upon the capacity requirements. The tube ends are usually expanded into the tube sheet at the inlet end and are flared after expansion. The outlet tube ends are either expanded or else packed or ferruled

into the tube sheet. Condensers having tubes ferruled into each tube sheet are found in some older ships.

The tube sheets serve as partitions between the salt water circuit and the vapor-condensate circuit. Access to the tube sheets is by way of manholes in each water chest. Zinc plates are attached to each manhole cover.

Various methods of construction are used to provide for relative expansion and contraction of the shell and tubes in main condensers. Packing the tubes at the outlet end is sometimes sufficient. Where the tubes are expanded into each tube sheet, the shell may have an expansion joint. In some condensers the tubes are arranged to bow upward about one-half inch at the middle; this provides for expansion and contraction and also makes it easier to drain the tubes. On some

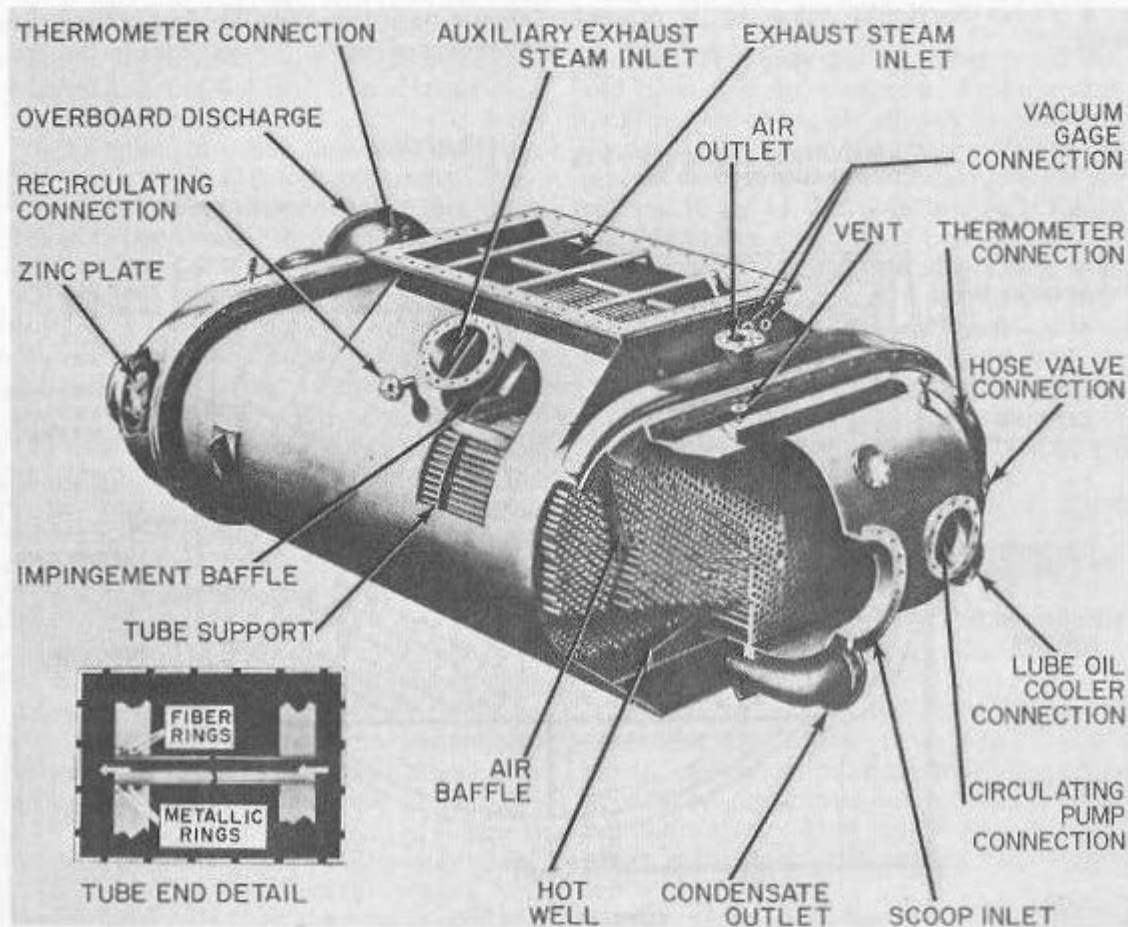


Figure 10-2.—Cutaway view of a main condenser.

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installations, a flexible support foot or lubricated sliding feet are provided to compensate for expansion and contraction differentials between the shell and the tubes.

As the steam is condensed on the tubes, the condensate drips down and collects on a receiving tray. Because of the arrangements made for steam flow in a main condenser, some steam flows down through the steam lane between the tube bundles and under the tube bundle where it reheats the condensate. From the receiving tray, the condensate drains to the hot well, where the condensate pump takes suction.

Main condensers have various internal baffle arrangements for the purpose of separating air and steam so that the air ejectors will not be overloaded by having to pump large quantities of steam with the air. One arrangement that provides separate air-cooling sections is shown in figure 10-2. The air baffles are extended up the side of the condenser shell. Figure 10-3 illustrates a cross-sectional view of a typical condenser.

Additional information on specific construction features of main condensers is available in the manufacturer's technical manual for the condenser concerned.

OPERATION

Under conditions of warming up, standing by, getting underway, cooling down, and securing the main engines, the condenser vacuum should be regulated in accordance with information given in chapter 9460 (46) of the Bureau of Ships Technical Manual, the manufacturer's technical manual, and any orders issued by the engineer officer.

Two basic rules that apply to the operation of single-pass main condensers should be kept in mind. The first is that the OVERBOARD TEMPERATURE should be about 10° higher than the INJECTION TEMPERATURE. The second rule is that the condensate discharge temperature, should be within a few degrees of the temperature corresponding to the vacuum in the condenser.

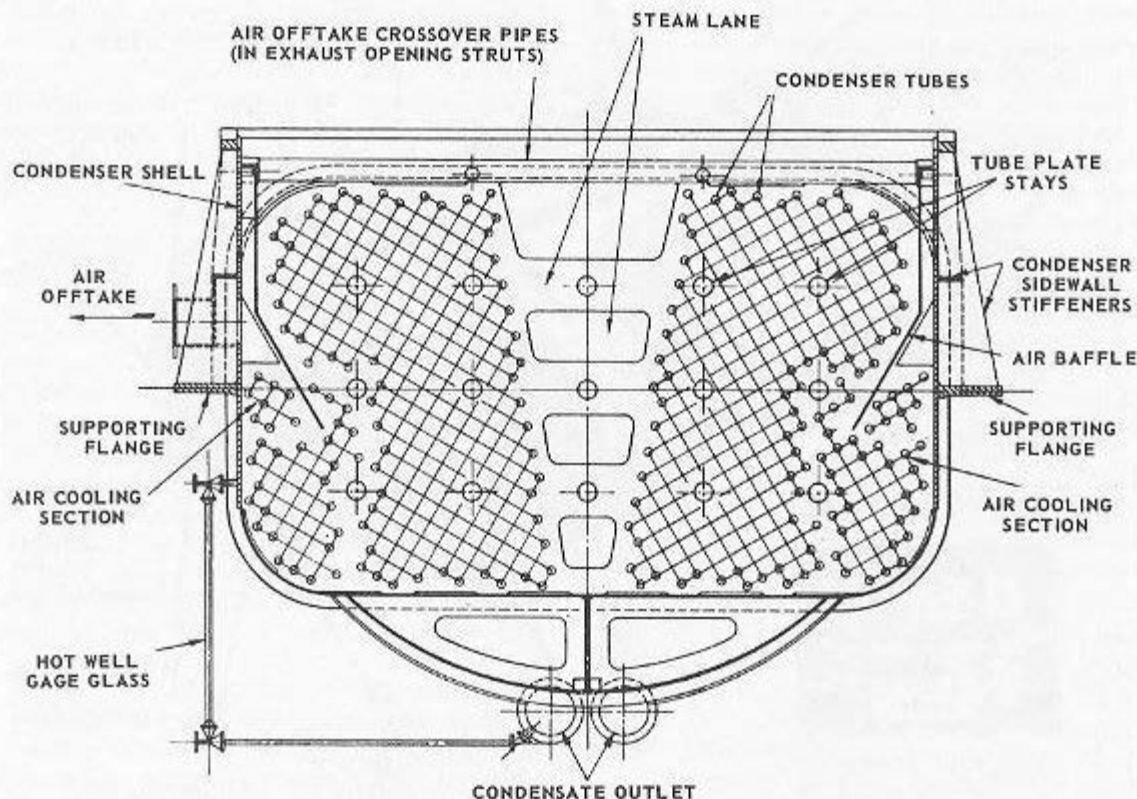


Figure 10-3.—Cross-sectional view of a typical condenser.

The accompanying chart lists vacuums (based on a 30.00-inch barometer) and corresponding temperatures.

Inches of Mercury	Corresponding Temperature (°F)
29.6	53
29.4	64
29.2	72
29.0	79
28.8	85
28.6	90
28.4	94
28.2	98
28.0	101
27.8	104
27.6	107

Scoop injection systems are designed to provide a sufficient amount of cooling water at speeds of 5 knots and above, with the injection and overboard valves wide open. Ordinarily it is not necessary to control the circulating water flow by throttling the valves. If throttling becomes necessary because the ship is in cold waters or because of other unusual operating conditions, the proper valve to use is the overboard valve; the valve should never be more than three-fourths closed. Using the inlet valve to throttle the flow of circulating water would cause turbulence and consequent erosion of the tubes.

If the condenser vacuum is not as high as it should be in relation to the condenser load and the cooling water overboard temperature, some part of the condensing system is not functioning properly. You may find, for example, that the air ejectors are not properly removing air from the condenser, that the condensate pump is not keeping the right condensate level, or that there is an air leak in the condenser or in some other part of the system under vacuum.

The condensate level should be kept as low as possible. It should not rise into the condenser shell. Allowing the level to rise slightly higher than the top of the hot well causes the condensate temperature to be lower than normal because the path for the flow of reheating steam is partially blocked by the condensate. (Reheating steam is the steam which enters the hot well by way of the central steam line. The central steam line extends completely through the tube bundle and provides for longitudinal distribution of steam from the exhaust inlet directly to the condenser

hot well.) If the condensate level is allowed to rise to the bottom row of tubes, the flow of reheating steam is further restricted, causing an even greater drop in condensate temperature. At this point, also, the high condensate level begins interfering with the flow of air toward the air removal areas, thus causing a gradual loss of vacuum. A rapid loss of vacuum, accompanied by a rapid increase in condenser shell temperature and exhaust trunk temperature, results if the condensate level rises to the lower end of the air baffles. This results not only because air removal ceases but also because a large part of the tube bundle is submerged and not available for cooling and condensing the incoming steam. If the condensate level rises and cannot be brought down to normal immediately by speeding up the condensate pump or by cutting in an additional pump, the speed of the main engine must be reduced to avoid serious damage to the engine and condenser.

An adequate flow of circulating water must be provided continuously to an operating condenser. This circulating water cools the steam and causes it to condense. Failure of the circulating water supply causes overheating of the condenser and loss of vacuum. Unless the situation is corrected immediately, steam pressure will build up to the point where it might cause the condenser shell to rupture.

Causes of insufficient circulating water are:

1. Condenser tubes clogged with foreign matter such as fish, seaweed, or mud.
2. Obstruction of injection or discharge sea chests, strainers, piping, or valves.
3. Injection or overboard valves not properly adjusted.
4. Inefficient or inoperative circulating pump.
5. Obstructed air vents (condenser vapor bound).
6. Faulty nonreturn valves in scoop injection lines or in main circulating pump discharge lines.

Steam or air connections are provided to clear foreign matter from sea chests. Sometimes, however, thick accumulations of marine growth on or around sea valve openings cannot be blown clear. When maximum pressure fails to clear a strainer, the obstruction must be removed by a diver.

Air vents must be kept open under all operating conditions where air is vented overboard through the hull or where the inlet water chest

is vented to the discharge water chest or piping, to minimize air erosion of the tubes and to avoid air-binding. Vents that are piped to the bilges should be kept slightly open at all times when the condenser is in use. As long as a trickle of water escapes, the unit will not become air bound and the circulating water flow will not be obstructed.

Auxiliary condensers (units into which turbo-generators exhaust) operate on the same principle as main condensers. In an auxiliary condenser, however, the cooling water is pumped through the condenser at all times instead of being scoop injected. Also, most auxiliary con-

densers are of two-pass rather than single-pass construction. Figure 10-4 shows a two-pass auxiliary condenser; the sea water chest is divided into an inlet chamber and a discharge chamber. In other construction features, including the metals used, auxiliary condensers are similar to main condensers.

Auxiliary exhaust steam, beyond that required for units such as the deaerating feed tank and the distilling plants, may be directed either to the auxiliary condenser or to the main condenser. In port, the auxiliary exhaust goes only to the auxiliary condenser. When getting underway, the

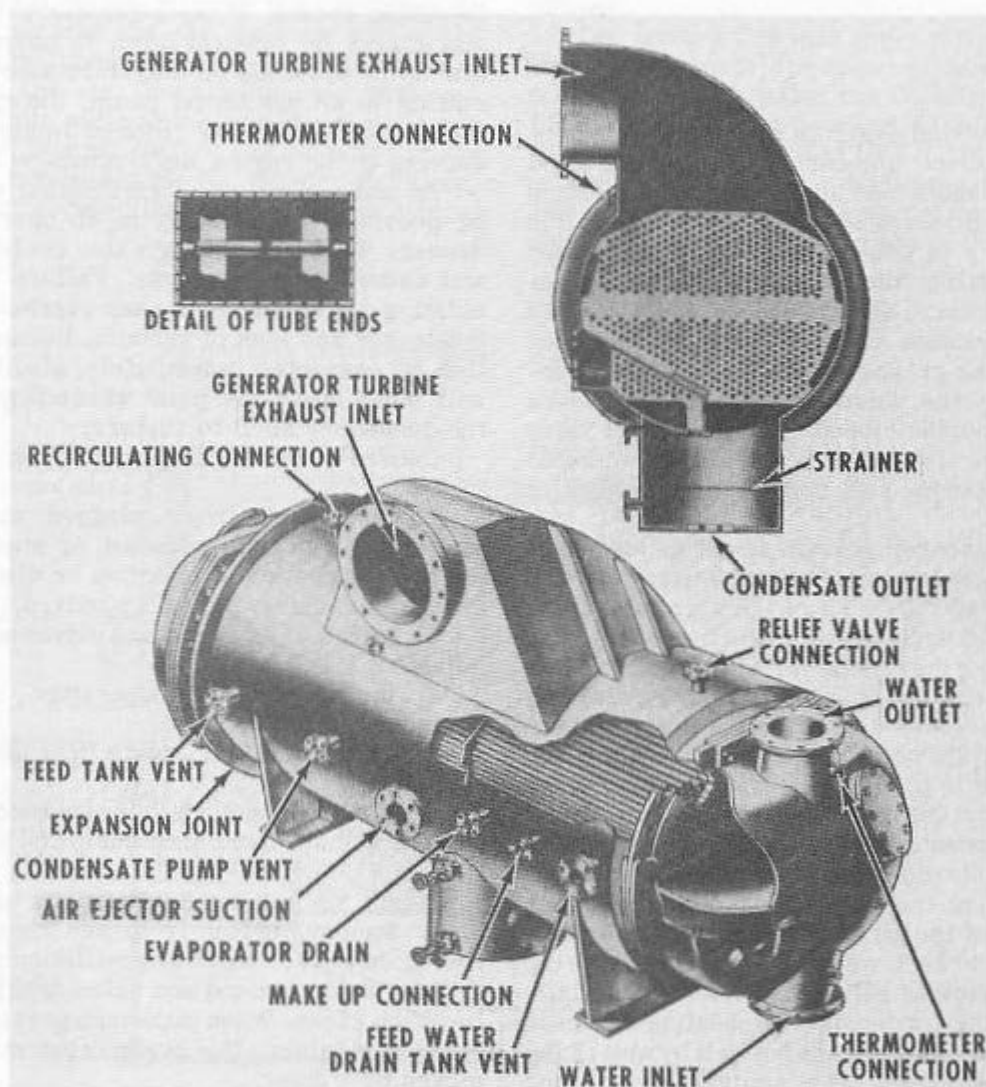


Figure 10-4.—Auxiliary condenser (turbogenerator).

exhaust goes to the auxiliary condenser until vacuum in the main condenser is sufficiently high.

Vacuum Regulation

Compared with the number of casualties that occur to some units of naval machinery, relatively few casualties occur to main condensers. The most frequent casualty to a main condenser is a reduction in vacuum. Inadequate vacuum or any other casualty to a main condenser will result in failure of the propulsion turbines to produce full power or in complete failure of the main engines. Condensers should be operated to obtain a vacuum in accordance with design requirements and to obtain maximum service life and reliability of the equipment.

Under normal operating conditions, condensers fitted with scoop injection should be operated to maintain the maximum vacuum obtainable and with the main injection and overboard valves wide open, except under the following conditions.

When making full power or speeds closely approaching full power, under cold injection conditions, the condenser will usually be capable of obtaining a higher vacuum than can be effectively used by the low pressure turbine. In the average installation, as the FULL POWER vacuum becomes higher than about one inch of mercury above the vacuum for which the low pressure turbine was designed, the extra steam that is required to heat the condensate will outweigh the added economy of turbine operation that is gained by the higher vacuum. The designed full power vacuum for any turbine installation may be obtained from the manufacturer's technical manual. Most turbines served by scoop injection condensers are designed for an exhaust vacuum of about 27 1/2 inches of mercury. If the injection temperature becomes low enough so that the full power vacuum tends to increase above 28 1/2 inches of mercury, the overall plant economy may be improved by using the overboard discharge valve to throttle the flow of circulating water to limit the vacuum to 28 1/2 inches of mercury.

When operating at cruising speeds, the turbines can generally make effective use of the maximum vacuum which the condensing plant is capable of maintaining. However, with cold injection at low power, the condenser becomes capable of producing a vacuum higher than that produced during normal operating conditions.

Under standby conditions when very little steam is being discharged to the condenser, most installations fitted with properly functioning air ejectors will produce a maximum vacuum of approximately 29 1/2 inches of mercury, with COLD injection temperature.

As the condenser vacuum approaches the maximum, when cruising at low or medium power, and with cold injection temperature, the air removal equipment tends to become unable to free the condenser of normal air leakage. The air collects in the condenser, and tends to insulate the tubes from the condensing steam and to settle in the hot well; and there is usually a noticeable increase in the condensate depression (difference between the temperature of the condensate discharge and the temperature corresponding to the vacuum maintained). To avoid the loss of economy and the absorption of air into the condensate under these conditions, it is good practice to throttle the flow of circulating water, as necessary to limit the vacuum to about 0.2 inch of mercury less than the maximum obtainable with full flow of circulating water, or as necessary to reduce the condensate depression to normal.

Under low power operations at medium injection temperature, if the condensate depression remains between 0 and 2°, it may be assumed that the air removal equipment is ridding the condenser of air, and therefore throttling the circulating water is unnecessary.

Circulating Water Control

When the overboard discharge (gate) valves in the circulating water piping are used to regulate the water flow through the condenser, these valves should be kept at least 1/4 open. If a gate valve used for throttling is closed more than 3/4, the gate is likely to pound against the seat rings and damage the valve so that it will not be watertight when closed. Some erosion of the valve gate and seating rings may take place if valves are continually used for throttling. Whenever a ship is drydocked, a careful inspection of injection and overboard valves should be made in order that the valves may be kept in good working condition and watertight.

If, while an overboard valve is throttled, a sudden increase in power is needed, a slight loss in vacuum will occur but the loss will not usually be serious and can be corrected by opening the overboard valve. In the event of an unexpected demand for full power astern, the overboard

valves should be opened wide as quickly as possible.

Loss of Vacuum

When a substantial or complete loss of vacuum occurs in a condenser, it means that the units of machinery exhausting into the condenser are out of commission. Maintaining proper vacuum is one of the more important duties of engineroom watchstanders. This chapter cannot cover all of the reasons for loss of vacuum; however, since air leakage into the vacuum system is the most common cause of vacuum loss, it is discussed in the paragraphs which follow:

Air leakage into a condenser decreases the vacuum obtainable and increases the condensate depression. If air leakage becomes excessive, the units of machinery exhausting into the condenser will have to be secured.

There are many ways in which air can leak into a system under vacuum. Every flange, gasket, connection, packing gland and valve bonnet that connects to the vacuum system can be a source of air leaking into the condenser. Air leaks can be very difficult to locate; they can be searched for in various ways. One method is by filling the condenser and the connected piping which is normally under vacuum, with fresh water—then using compressed air, to build up pressure of 5 to 10 psig in the turbine casing and checking the condenser and piping for water leaks. A water leak indicates an air leak.

Another method of locating an air leak is by making the candle flame test. With the system under vacuum, hold a lighted candle to all areas where leaks are suspected. If the candle flame is held close to a leak, the vacuum will draw the flame toward the leak.

A more reliable method of locating leaks is to apply soapsuds to areas where leaks are suspected. The soapsuds solution should be prepared so that it has the consistency of liquid hand soap and will work up lather on a brush. (NOTE: The system must be under pressure.) The lather should be applied all the way around the joints, then the joints should be carefully checked for bubbles; doubtful spots should be lathered a second time.

Another method of testing a vacuum system for leaks is by using the air test. If the test is to be conducted on a main condenser, the procedure is as follows:

Start a lube oil service pump; engage and start the turning gear. Cut in gland sealing steam

to the main turbines. Next, build up a pressure of 5 to 10 psig throughout the vacuum system. Listen carefully for air leaking out of the system. This method is more effective if all the vents and machinery in the engineroom, except the lube oil pump and turning gear, can be secured, since this method depends entirely on detecting the sound of air escaping.

When testing for air leaks, all places where it is possible for an air leak to exist must be investigated. Condensers have many fittings and joints which should be examined as far back in the lines as vacuum exists under any operating conditions.

Leaks at flanged joints and in porous castings can usually be stopped with an application of shellac when the condenser is under vacuum. If shellac is used, this should be considered a temporary repair—and permanent repairs should be made as soon as time and the ship's operation permit.

Main exhaust trunk flanges are generally fitted with a flange grooving system to provide for pressure pumping with a suitable sealing compound. If the shell relief valve (or its connection to the condenser shell) is suspected of leaking, it can, in most installations, be tested in place. Most shell relief valves are fitted with a small gage glass to permit introduction of water above the disk as a test for tightness.

MAINTENANCE

Heat exchangers and associated equipment should be periodically inspected to ensure that they are operating efficiently. Preventive maintenance is much more economical than corrective maintenance.

Inspecting and Cleaning Condensers

Under normal operating conditions, the salt water side of a main condenser should be inspected once each month or immediately after an extended cruise. The steam side of a main condenser should be inspected each quarter when the inspection covers are removed from the low pressure turbines.

Conditions may arise which will necessitate more frequent inspections of main condensers. The ship may operate in shallow water, or may operate in waters where there are large amounts of seaweed, schools of small fish, or large amounts of oil. When any of these conditions occur, the condenser should be opened for inspection and cleaning.

The sea water side of condensers must be carefully maintained to prevent failures due to deposits on tubes and also to prevent loss of heat transfer due to accumulations of these deposits. The sea water sides of condensers must be inspected and cleaned at the following times:

1. Once each month if permitted by ship's operations.
2. At any time the condenser is opened for inspection or the replacement of zincs.
3. During drydocking or at any other time the salt water side of the condenser is drained.
4. Before initial sea trials and before full power trials.
5. After an extended cruise.

Before opening the salt water side of a condenser, read and observe all precautions listed in this chapter and in chapter 9460 (46) of the Bureau of Ships Technical Manual.

Some of the more important condenser parts which require periodic inspection and cleaning are zincs, tubes, and steam sides.

ZINCS—If dissimilar metals immersed in an electrolyte (such as salt water) are connected, a simple galvanic cell is formed and an electric current flows from one metal to the other through the electrolyte. The metal from which the current is flowing to the electrolyte will tend to corrode rapidly, and the metal to which the current is flowing from the electrolyte will tend to be protected from galvanic corrosion. The direction in which the current will flow depends on the composition of the metals or the alloys exposed to the electrolyte.

Since condensers and other heat exchangers using salt water have all the requirements of a simple galvanic cell, electrolytic action will take place. This action cannot be stopped, but the metal parts of the condenser can be protected by using zincs. Because of its characteristics, zinc will cause the electric current to flow from the zinc plates to the metallic parts of the condenser. The effect of the electrolytic action will be to gradually destroy the zincs, but they can easily be replaced.

Zincs installed in the salt water side of condensers and other heat exchangers should be inspected and cleaned at least once a month. They should be renewed (replaced) when 50 percent destroyed.

A casual inspection of a badly scaled zinc, especially while it is still wet, may lead per-

sonnel to believe that zinc metal instead of scale is exposed. The zinc, even though it appears to be in good condition, should be tested with a chipping hammer to learn the true condition of the zinc metal. Whenever zincs are inspected or cleaned, the condition of the metallic contact between the zinc and its support should be checked. Figure 10-5 illustrates how a badly scaled zinc plate appears before and after the cleaning process.

WATERSIDE—Deposits which lodge within a condenser tube (sea water side) are likely to cause failure of the tube, unless promptly removed. Particles of mud, sand, or other foreign matter which lodge in the tube, cause corrosion pits to start under the particles. Once a pit is started, it will widen and deepen, even though the foreign matter is removed. Larger particles or such foreign matter as stones, shells, metal, and wood, will result in the formation of corrosion pits where the foreign matter touches the tube surface, and will cause an increase in velocity of the sea water (flowing past the obstruction) which

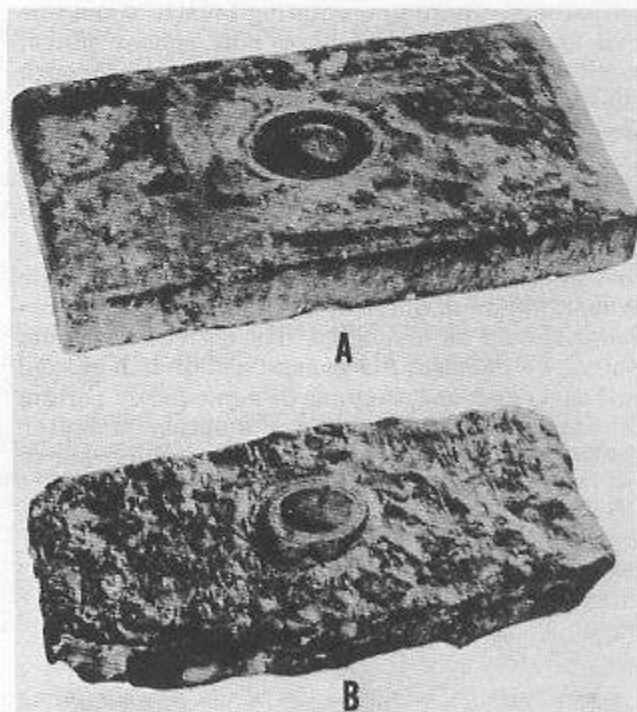


Figure 10-5.—Badly scored zinc plate.
A. Before being cleaned.
B. After being cleaned.

47.72

will result in breaking down the protective film on the tube.

The resistance of condenser tubes to corrosion depends on a thin, adherent, continuous film of corrosion products on the surface exposed to sea water; therefore, extreme care must be taken when cleaning the tubes not to use abrasive tools capable of marring or scratching the surface of the tube. Wire brushes or rubber plugs having metal parts should never be used inside condenser tubes. Any scratch or perforation of the corrosion-resisting film will form a pit which will widen and deepen and eventually result in tube failure (through corrosion pitting), in the same manner as occurs when foreign matter lodges on the tube surface. Any cleaning equipment must be carefully used to avoid damaging the protective film, which will cause tube failures.

For ordinary cleaning, an air lance should be pushed through each tube, the tube sheets should be washed clean, and all foreign matter should be removed from the water chests. In installations where there is severe fouling, a water lance should be pushed through each tube to remove foreign matter. In installations where there is extreme fouling, a rotating bristle should be run through each tube—or soft rubber plugs, available at shipyards, may be driven through the tubes by the use of air or water pressure—then this procedure should be followed by water lancing. Figure 10-6 illustrates types of rubber plugs used for cleaning condenser tubes.

STEAM SIDE—Whenever the manhole plates are removed from the low pressure turbine for inspection or maintenance, the steam side of the tubes should be inspected. The entire steam side should be checked for grease and dirt. If grease and dirt are found, they can be removed by boiling out the condenser, using a solution of boiler compound. Normally, condensers which serve

turbines should not require boiling out more frequently than once every 2 or 3 years. Instructions for the boiling out process may be found in chapter 9460 (46) of the Bureau of Ships Technical Manual.

Tube Leakage

Any tube leakage, however slight, will cause serious damage if neglected. The condensate system will become contaminated and this will result in serious damage to the boiler tubes. It is not unusual for a newly tubed condenser to develop leaks due to defective tubes or tube sheets, or to improper installation. However, if the defects are corrected, the condenser will give years of satisfactory service.

The most common cause of tube leakage is deterioration which starts at the sea water side of the tube and proceeds through the tubewall to the steam side. However, leakage may also be caused by deterioration starting at the fresh water side of the tube wall, by a defective joint between the tube and tube sheet, or by cracking of the tube wall or tube sheet.

IMPINGEMENT EROSION—Sea water flowing into the condenser tubes at high velocity tends to remove the thin protective film of corrosion products adhering to the tube walls. This protective film is replaced at the expense of further corrosion of the tube wall. As the protective film is continually removed and is replaced by corrosion products, the tube wall is gradually thinned and the joint between the tube and the tube sheet is weakened, so that a salt water leak ultimately occurs, through the failure of the tube joint or by perforation of the tube wall beyond the tube sheet. This type of attack is generally continued to the region of the tube at or near the inlet end and is known as impingement erosion, inlet end attack, or bubble attack. The occurrence and rapidity of the attack is influenced mainly by water velocity through the tubes. It is also influenced by the amount of air entrained with the circulating water, and by the design of water chests and injection piping.

Tube deterioration resulting from impingement erosion of the tube ends can be minimized by proper regulation of circulating water through condensers and by proper venting of water chests.

Figure 10-7 shows a tube which has been badly damaged at the inlet end by impingement erosion.



47.73

Figure 10-6.—Types of rubber plugs used for cleaning condenser tubes.

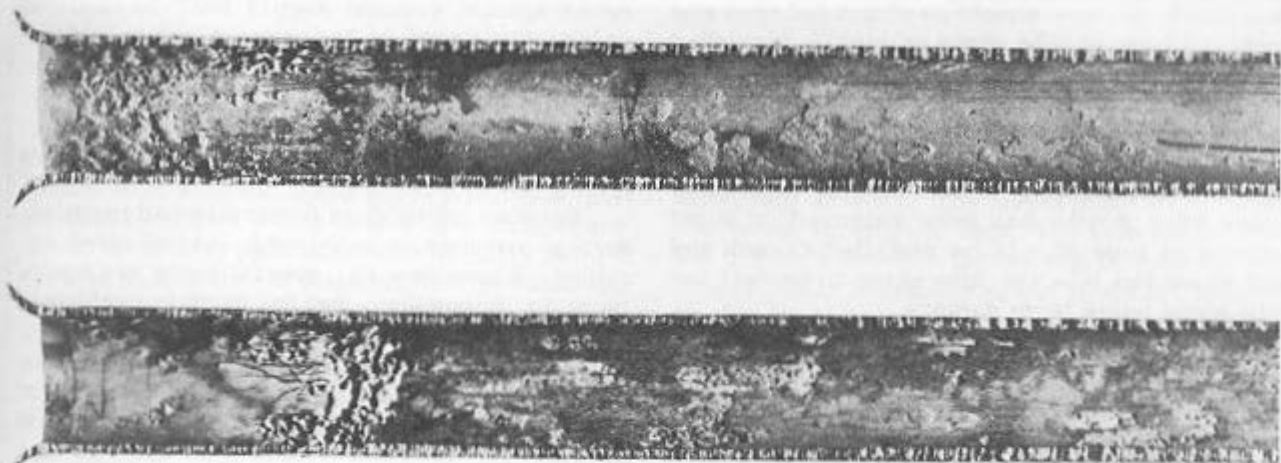


Figure 10-7.—Tube damaged by impingement erosion.

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If wet steam is permitted to impinge on condenser tubes at high velocity, the surface of the tubes will rapidly erode; and this erosion will eventually result in perforation of the tube wall and leakage of sea water into the condensate. Baffles or distribution pipes are installed within the condenser shell to prevent direct impingement of water and steam from the auxiliary exhaust line, the recirculating line, and the makeup feed line.

These baffles must be installed in such a way that they do not touch the tubes, since vibration will cause tube failure. If frequent tube leaks occur in the vicinity of a steam or water connection to the condenser shell, it is evidence that the baffling system is defective or that the plant is not being operated properly.

In order to prevent tube erosion from auxiliary exhaust lines, it is essential that the line be continuously and thoroughly drained. Before shifting the auxiliary exhaust to a condenser, all drain valves on the exhaust line should be opened and every precaution taken to ensure that the exhaust line is drained properly. If there is a pocket in the exhaust line which will allow condensate to collect, a drain should be installed to ensure complete drainage of the auxiliary exhaust line.

TESTING FOR LEAKS—Several methods for testing a condenser for tube leakage are described in chapter 9460 (46) of the Bureau of

Ships Technical Manual. The most common method is as follows:

1. Drain the salt water side of the main condenser and remove the manhole plates.
2. Ventilate the condenser.
3. Wash the waterbox, tube sheets, and tubes, and dry them by using compressed air.
4. Fill the steam side of the condenser with water of feed water quality, being careful not to flood the low pressure turbine.
5. Inspect the tube ends, since at this point a large leak may be detected.
6. If the detected leak is small, an air pressure of about 5 psig may be applied to the steam side of the condenser. (The test pressure must NEVER exceed 15 psig.)
7. Even if a leak is detected, continue the test. There may be more than one leak. **CAUTION:** Before starting any test procedures, review the "PRECAUTIONS TO BE OBSERVED WHEN TESTING OR CLEANING CONDENSERS" given in chapter 9460 (46) of the Bureau of Ships Technical Manual and those given later in this chapter.

Salt water leaks into the condensate system cannot always be detected by the use of salinity indicators (mentioned in chapter 11) alone. The first indication of a salt water leak may be a chloride buildup in the boiler or in the condenser hot well when there is no flow of condensate through the condenser.

PLUGGING TUBES.—Main condenser tubes that fail in service should be plugged at each end with the type of tube plugs originally furnished by the manufacturer of the condenser. The manufacturer's instructions should be followed in plugging condenser tubes. Plugs should be driven firmly into the tube ends by light hammer blows. If a metal plug is used to plug tube sheet holes after a tube has been removed, a short section of tube should be installed at each end and expanded into the tube sheet to protect the tube sheet holes from damage.

Tubes that leak at the tube joints but are otherwise in good condition should NOT be plugged. Such tubes should be rerolled or repacked rather than plugged.

When several tube leaks occur close together and in such a location that steam-side erosion may be suspected as the cause of trouble, steel rods should be inserted into the damaged tubes before ends are plugged. These rods will serve as a sort of baffle or shield to protect adjacent tubes from similar damage from erosion. The steel rods should be slightly smaller in diameter than the tubes. In order to minimize lengthwise working of the rods, that would tend to loosen the plugs, rods should be installed in the following way:

1. Cut each rod so that it is as long as it can be without interfering with the tube plugs.
2. Cut two or three grooves in each end of the rod. The grooves should start about 2 inches from the end, and should be spaced about 1 inch apart. They should be deep enough and wide enough to take a standard condenser tube fiber packing ring.
3. Cut a segment from one fiber packing ring for each groove in the rod. Cut the packing ring in such a way that when the ends are brought together the resulting ring will fill a groove in the steel rod and make a snug fit in the tube.
4. Insert the rods, together with the packing rings, in the tubes that are to be plugged. Center the rods properly; spray the packing with fresh water so that it will swell; and then plug the tube ends.

Main condenser tubes that have been plugged should be renewed at the first naval shipyard availability if the water chests are to be removed for other work. If more than 10 percent of the tubes are plugged, a retubing request should be submitted, via the type commander, to the Naval Ship Systems Command. Tubes that

have had steel rods inserted to protect other tubes against erosion should NOT be replaced unless the cause of the erosion has been found and corrected.

Retubing Condensers

Because of modern materials and manufacturing methods, condensers seldom need retubing. When they do, special tools and equipment are necessary, and the work is performed by tenders, repair ships, or a shipyard.

In general, specimen tubes should not be drawn from a condenser or heat exchanger, for examination purposes, except when removal is specifically directed by the Naval Ship Systems Command, or by a Board of Inspection and Survey. However, tubes MAY be drawn without authorization from the Naval Ship Systems Command, under the following conditions:

1. When frequent leaks have been caused by tube failures, specimen tubes should be drawn from widely separated parts of the unit in order to establish the general condition of the tubes.
2. When several tubes have failed in the vicinity of a steam or water inlet to the condenser shell, specimen tubes should be drawn unless the cause of the failure can be determined by visual inspection of the steam side of the unit.

Samples from the most badly deteriorated tubes should be carefully marked to show the top and the bottom of each sample, and the location from which the sample was drawn. The samples should be cut into lengths of about 12 inches, identified as to position along the length of the tube, split lengthwise, and opened to permit ready examination. These samples are then forwarded to the Naval Ship Systems Command, together with a complete report of the conditions found.

Retubing of auxiliary condensers and other small heat exchangers may be accomplished by forces afloat or by a shipyard without obtaining authorization from the Naval Ship Systems Command. Only the type commander need approve this type of retubing. Complete reports of such retubing must be forwarded to the Naval Ship Systems Command and are to include the same information that is required for requests for retubing main condensers.

Tube Replacement

When a main condenser is to be retubed, the most efficient way of removing the old tubes is to cut them inside the shell by use of a power-driven saw, or other suitable cutting tool and then drive the ends of the tubes out of the tube sheets with a drift. Figure 10-8 shows a drift suitable for tubes which have a 5/8-inch outside diameter and a wall thickness of 0.049 inch. If serious difficulty is encountered in removing expanded tubes, it may be necessary to ream the expanded ends so that only a thin shell remains at the outer surfaces of the tube.

If a reamer is used, it should be provided with a pilot which closely fits the inside bore of the tube, and extreme care must be taken to ensure that the reamer does not touch or mar the surfaces of the tube holes in the tube sheet. Figure 10-9 shows a reamer suitable for this type of work.

Regardless of the method used to remove the tubes, the tube holes in the tube sheets must not be damaged in any way.

Before installing replacement tubes, a very careful examination of the interior parts of the condenser shell must be conducted. If there is any reason to believe that the joints between the tube sheet and the condenser shell are not in perfect condition, the tube sheets should be removed, the flanges trued, and new gaskets installed. Joints between the stay-rods and the tube sheets should be remade and the stay-rods repacked. Should any defects be found after the new tubes are installed, it may be necessary to

cut out the newly installed tubes to correct the defect(s).

Only copper-nickel tubes conforming to the Naval Ship Systems Command specifications are to be used in condensers that are salt-water cooled. These tubes are furnished in stock lengths and must be cut to proper length by the installing activity. The usual practice is to cut the tubes in lengths about 1/8 inch longer than the distance between the outside faces of the tube sheets. After installation, the tubes are finished to the exact length, by using an air-driven end mill or surface grinder.

EXPANDING TUBES.—Nearly all condensers installed aboard naval ships have the inlet tube ends expanded in the tube sheet, forming a metal-to-metal joint. In many installations, the outlet tube ends are also expanded. If the condenser tubes are expanded at both ends, it is common practice to provide one or more grooves, or serrations, in the tube holes in order to increase the holding power of the expanded tube joint. Such grooves should be thoroughly cleaned out and any burrs removed prior to the installation of new tubes.

Tube expanders used in retubing condensers and other heat exchangers must meet Navy specifications. No type of tube expander should be used by forces afloat or shipyards, except the expanders furnished to the ship by the manufacturer and approved by the Naval Ship Systems Command. The tube expander rolls should be tapered to correspond with the taper of the expander mandrel to ensure parallel expansion of the tube walls. The inner ends of the rolls should

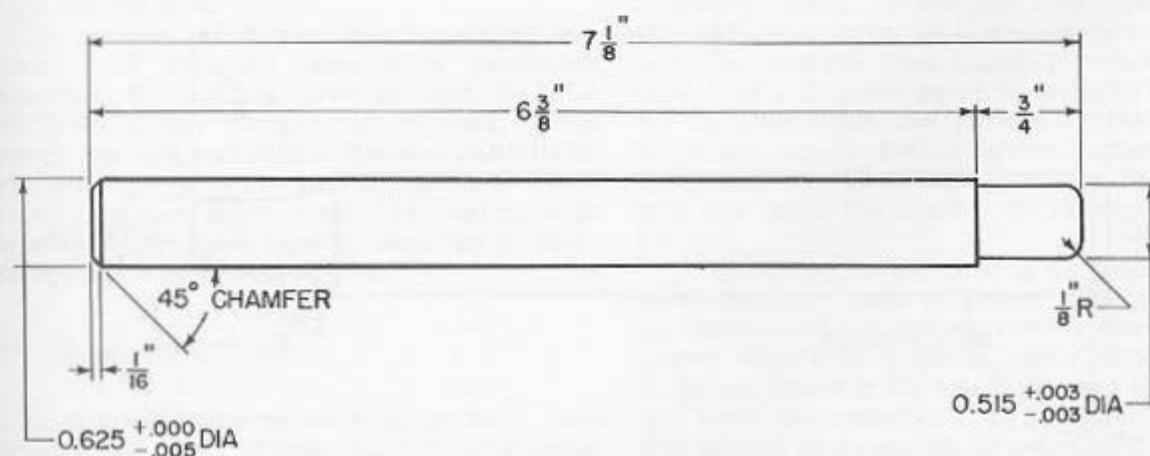
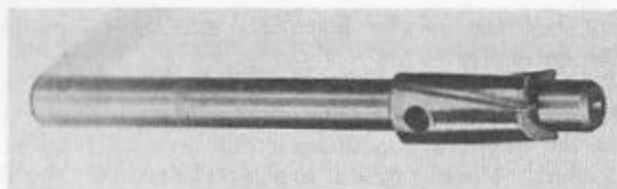


Figure 10-8.—Drift for driving tube ends from tube sheets.



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Figure 10-9.—Reamer for removing expanded tube ends.

be suitably rounded off to form a torpedo-shaped end in order to prevent ridging and cutting of the tubes at the inner end of the expanded joint. In order for a tube expander to be properly set for a given job, it is generally necessary that the overall length of the rolls be not less than $3/16$ inch greater, and not more than $5/8$ inch greater than the thickness of the tube sheet into which the tube is expanded. The expander should be adjusted so that the expanded portion of the tube does not extend completely through the cylindrical portion of the tube sheet hole; about 1.8 inch of the tube at the inner end of the tube hole is left unexpanded. If the tubes are expanded completely through the tube sheet, the part of the expanded joint which extends into the condenser and beyond the support of the tube hole, will bulge and the subsequent removal of tubes will be extremely difficult.

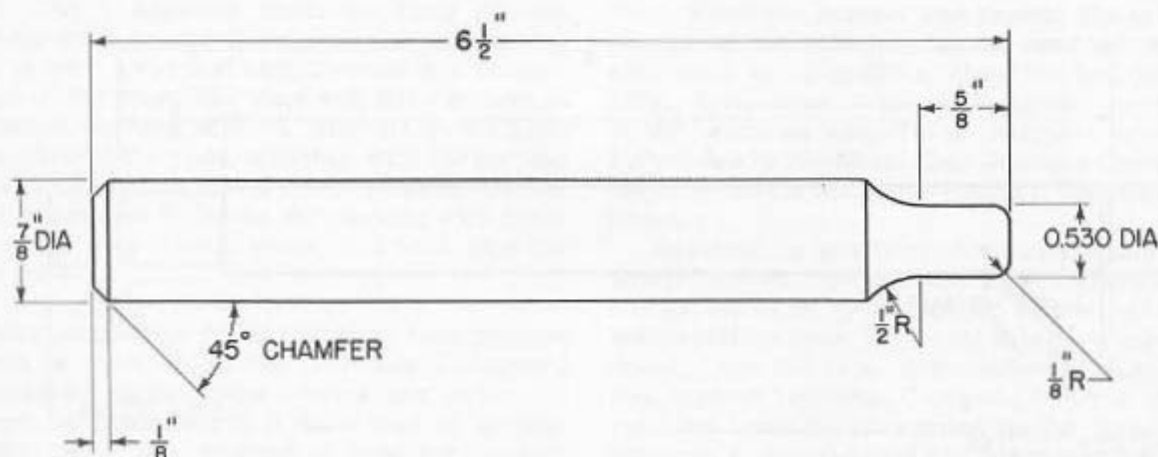
After the tubes are expanded, the inlet ends of the tubes should be belled or flared to an outside diameter of not more than $3/4$ inch for $5/8$ -inch OD (outside diameter) tubes, and not more than $7/8$ inch for $3/4$ -inch OD tubes.

Flaring tools must not be driven into the tube end so hard that the wall of the tube is appreciably thinned or cut. Figure 10-10 shows a flaring tool that is suitable for $5/8$ -inch OD tubes which have a wall thickness of 0.049 inch. It is good practice to mill or grind the projecting flared ends of the newly installed tubes flush with the tube sheet surface in order to provide a smooth entrance for the circulating water flowing into the inlet ends of the tubes. It is not necessary to flare the outlet ends of the tubes; the tube outlet ends may be allowed to project $1/16$ inch from the face of the tube sheet surface.

PACKING TUBES.—Flexible metallic packing, in accordance with Navy specifications, should be used to pack the outlet ends of packed condenser tubes. The inlet ends of the tubes should be expanded into the tube sheets before the outlet ends are packed. The old packing must be completely removed and the threads and serrations of the glands thoroughly cleaned of all foreign matter.

When stuffing box glands are $3/4$ inch deep, the proper packing consists of two fiber rings and two metallic rings. To facilitate the installation of packing, a loading pin (fig. 10-11) should be inserted into the outlet ends of the tubes.

After the loading pin is inserted, a fiber packing ring is placed on the pin and driven to the bottom of the stuffing box. Next, a metallic packing ring is placed on the loading pin and calked into the packing box with three or four light hammer blows, to cause the metal to flow into the threads of the gland. Then these operations are repeated, another fiber ring and



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Figure 10-10.—Tool for flaring main condenser tubes.

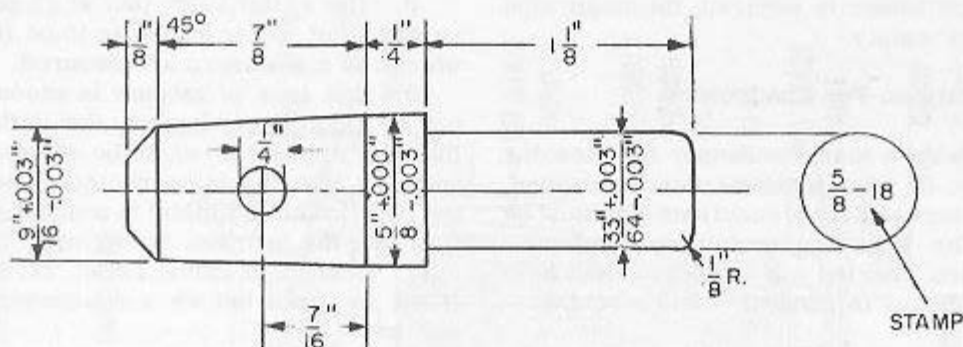


Figure 10-11.—Loading pin for packing main condenser tubes.

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another metallic ring are inserted in the same manner; each ring is calked in place separately. If the depth of the stuffing box is greater than $3/4$ inch, an additional metallic ring should be installed and calked into place in order to completely fill the stuffing box with packing.

If the stuffing box is $5/8$ inch deep instead of $3/4$ inch deep, only three rings of packing can be used; one metallic ring is calked in place, followed by a fiber ring and a second metallic ring. The outlet ends of packed condenser tubes are never flared, expanded, or belled.

When a condenser is retubed, the tubes should be tested for leaks. The test is made by filling the shell with warm water. (Warm water must be used to avoid condensate forming on tubes and tube sheets and giving a false indication of leaking.) If any leaky tubes are found, they can be recalked with light hammer blows applied to the calking tool.

The amount of force used in striking the calking tool with the hammer is extremely important. If too little force is used, the joint will leak. If too much force is used, it will "neck" the tube end so that the tube end will be held too tightly in the packing gland to allow proper movement during normal expansion. When the necked tube does move through the packing, leakage at the joint will result.

Care of Idle Condensers

Most condensers on naval ships have condenser tubes either at both ends, or expanded at the inlet end and packed at the outlet end. These units should normally be drained and kept empty

when secured. However, if the condenser is to be used within a few days, it may be completely filled with water (which should be circulated daily) unless the ship is lying in highly polluted water. When in polluted water, the condenser should be drained and thoroughly washed out whenever it is secured.

Whenever the sea water side of a condenser is drained, special care should be taken to ensure that the tubes do not have water anywhere along their lengths. Tubes frequently become sagged and water trapped in these pockets at one or more points along the tube length, if allowed to remain in a drained condenser, will gradually evaporate. The impurities left behind (after the water has evaporated) will corrode the tubes at these points, and in time will result in tube failure. This action is particularly acute when condensers are drained of highly polluted water. The best method of avoiding this type of tube deterioration, when an ample supply of fresh water is available from a pier, is to water-lance each tube with fresh water in order to wash out the polluted water and remove foreign matter from the tubes. Following the water-lancing operation, the tubes should be air-lanced and left dry until the condenser is again put in service.

If sufficient fresh water is not available for water-lancing, each condenser tube should be air-lanced and left completely dry; then the condenser should be inspected daily. If any water tends to collect in the tubes, through condensation from the atmosphere, the air-lancing operation should be repeated, as necessary, to avoid the formation of water pockets at low points along the tubes.

When a condenser is secured, the steam side should be kept empty.

Safety Precautions For Condensers

When opening a main condenser for cleaning or inspection, or when testing a main condenser, there are several safety precautions that must be observed. The following procedures and precautions, when carried out properly, will help prevent casualties to personnel and machinery:

1. Before the salt water side of a condenser is opened, all sea connections, including the main injection valve, circulating pump suction valve, and main overboard valve, are to be closed tightly and secured against accidental opening with wire, and tagged, DO NOT OPEN, and signed by the person tagging the valve. This is necessary to avoid the possibility of flooding an engine room. Safety gates, where provided, are to be installed.

2. On condensers having electrically operated injection and overboard valves, the electrical circuits serving these motors are to be opened and tagged to prevent accidentally energizing these circuits.

3. Before a manhole or handhole plate is removed, drain the salt water side of the condenser by using the drain valve provided in the inlet water box. This is done to make sure that all sea connections are tightly closed.

4. If practicable, inspection plates are to be replaced and secured before work is discontinued each day.

5. Never subject condensers to a test pressure in excess of 15 psig.

6. When testing for leaks, do not stop because one leak is found. The entire surface of both tube sheets must be checked, as other leaks may exist. Determine whether each leak is in the tube joint or in the tube wall, so that the proper repairs can be made.

7. There is always a possibility that hydrogen or other gases may be present in the steam or the salt water side of a condenser. No open flame or tool which might cause a spark should be brought close to a newly opened condenser. Personnel are not to be permitted to enter a newly opened condenser until it has been thoroughly blown out with steam or air.

8. The salt water side of a condenser must be drained before flooding of the steam side and must be kept drained until the steam side is emptied.

9. The relief valve (set at 15 psig) mounted on the inlet water chest is to be lifted by hand whenever condensers are secured.

10. If a loss of vacuum is accompanied by a hot or flooded condenser, the units exhausting into the condenser must be slowed or stopped until the casualty is corrected. Condensate must not be allowed to collect in condensers and overflow into the turbines or engines.

11. Condenser shell relief valves are to be lifted by hand before a condenser is put into service.

12. No permanent connection which could subject the salt water side to a pressure in excess of 15 psig, is to be retained between any condenser and a water system.

13. No permanent connection which could allow salt water to enter the steam side of the condenser, is to be retained.

14. Test the main circulating pump bilge suction, when so directed by the engineer officer. To conduct this test, it is generally necessary only to start the main circulating pump, open the bilge suction line stop or check valve, and then close down on the sea suction line valve to about 3/4 closed, or until the maximum bilge suction capacity is obtained.

AIR EJECTORS

In most ships, the first and second stages of the air ejectors and their condensers have been combined into one complete assembly, such as is shown in figure 10-12. In many ships, the gland exhaust condenser has been incorporated within the shell of the after condenser. The shell is rectangular, and is divided by a longitudinal plate into the inter-condenser and the after condenser sections. A baffle at the gland vapor inlet deflects the air and vapor downward over the lower bank of tubes in the after condenser section.

In order to provide for continuous operation, two sets of nozzles and diffusers are furnished for each stage of the air ejectors. Only one set is necessary for operation of the plant; the other set is maintained ready for use in case of damage or unsatisfactory operation of the set in use. The two sets can be used simultaneously when excessive air leakage into the condenser necessitates additional pumping capacity.

An inter stage valve is provided between the discharge of each first-stage ejector and the inter condenser so that the pressure built up by

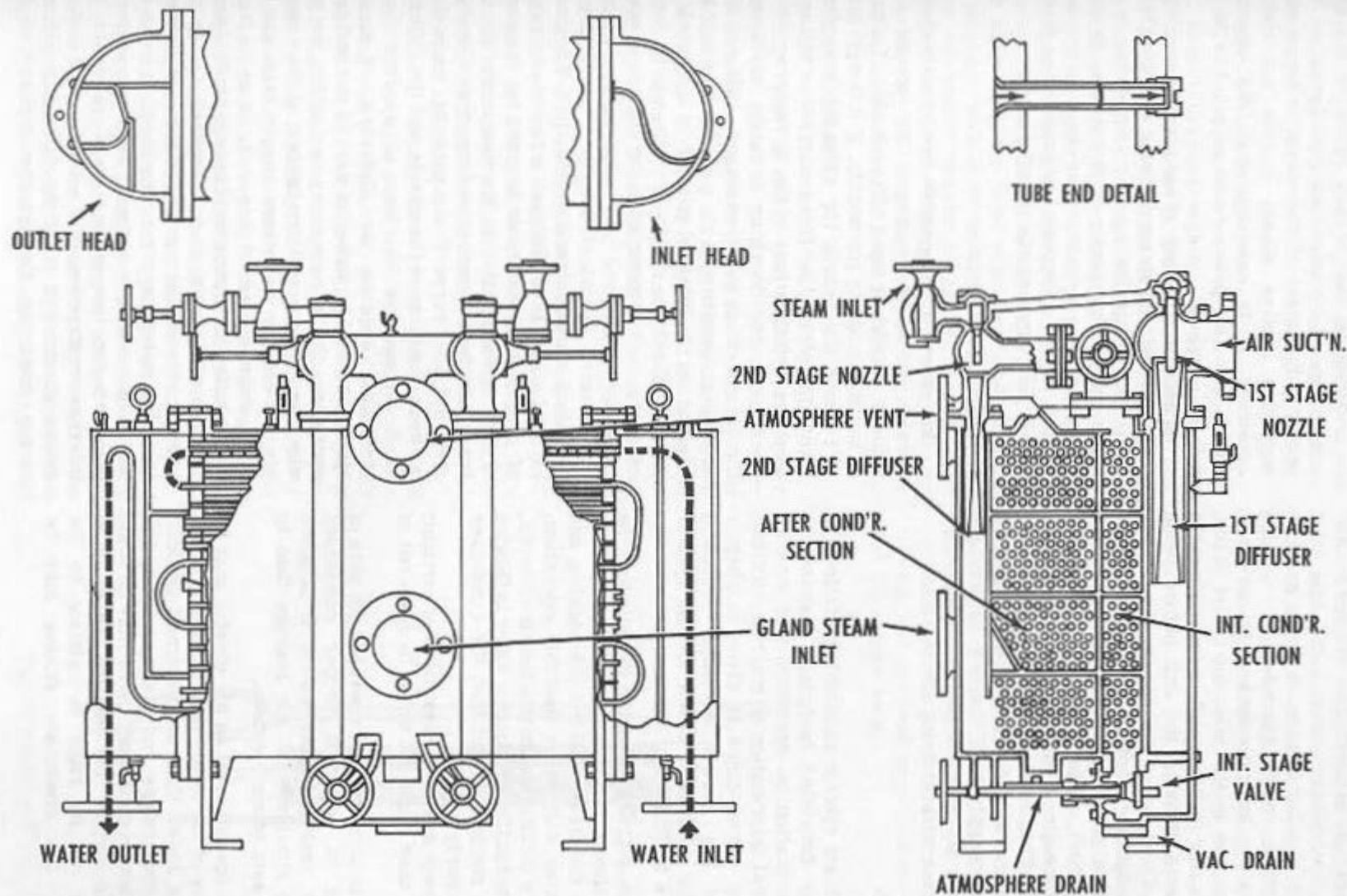


Figure 10-12.—A main air ejector and condenser assembly.

the first-stage jet, in operation, will not be lost back to the condenser through the idle first stage. For a similar reason, a cutout valve is located between each second-stage suction chamber and the inter condenser. By means of diaphragm plates in the inlet and outlet heads, the cooling water (condensate) is forced to make several passes through the unit before being discharged.

The atmospheric vent is usually connected to the suction of a small motor-driven fan (gland exhauster), which provides a positive discharge through piping to the atmosphere above decks. This is necessary to avoid filling the engineroom with steam should the air ejector cooling water supply fail, thereby allowing the steam to pass through the inter condenser and after condenser without being condensed.

OPERATION

With each air ejector assembly installed, the manufacturer furnishes technical manuals to provide information on operation and maintenance. General information on starting, shifting, and securing air ejectors is given in chapter 9460 (46) of the Bureau of Ships Technical Manual. Some additional items for air ejector operation are as follows:

1. Before starting a steam air ejector, the steam line should be drained of all moisture; moisture in the steam will cut the nozzles, and slugs of water will cause unstable operation.
2. Before cutting steam into the air ejectors, make sure that sufficient cooling water is flowing through the condenser and that the condenser has been properly vented.
3. The loop seal line must be kept airtight; an air leak may cause all water to drain out of the seal.
4. If it is necessary to operate both sets of air ejectors to maintain proper condenser vacuum, air leakage is indicated. It is more desirable to eliminate the air leakage than to operate two sets of air ejectors.

Unstable operation of an air ejector may be caused by any of the following: the steam pressure may be lower than the designed amount, the steam temperature and quality may be different than design condition, there may be scale on the nozzle surface, the position of the steam nozzle may not be right in relation to the diffuser, or the condenser drains may be stopped up.

Difficulties due to low pressure are generally caused by improper functioning or improper adjustment of the steam reducing valve supplying motive steam to the air ejector assembly. It is essential that DRY steam at FULL operating pressure be supplied to the air ejector nozzles.

Erosion or fouling of air ejector nozzles is evidence that wet steam is being admitted to the unit. Faulty nozzles make it impossible to operate the ejector under high vacuum. In some instances, the nozzles may be clogged with grease, boiler compound, or some other deposit which will decrease the jet efficiency.

MAINTENANCE

In general, it is possible to clean air ejector nozzles by using reamers. The proper size reamer should be used for each size of nozzle, to avoid damage to the nozzle. If it is necessary to remove the nozzle for cleaning or replacement, the internal surfaces must not be damaged. Dents or deformations of the downstream end of the nozzle, and rough or scratchy surfaces in the throat or diffuser passages, will result in improper operation of the unit. Foreign deposits present on the internal surface of the nozzle or diffuser should be removed by the use of nozzle reamers, soft copper wire, or a piece of wood.

Before disassembly or reassembly of nozzles or diffusers is undertaken, the manufacturer's technical manual should be consulted. If replacement of a nozzle or diffuser is required, gaskets of proper thickness must be used for reassembly. It is essential that the nozzle and the diffuser tube be concentric and in proper alignment and that the correct distance be maintained between the ends of the nozzle and the diffuser.

It is possible to clean or replace steam strainers, nozzles, or diffusers, of an air ejector assembly while the rest of the unit is in operation. It is necessary to isolate the unit which is to be opened from the rest of the assembly, by closing the steam supply valve and the inter stage valves of this unit, to avoid burns being suffered by personnel engaged in this work.

In installations where separate inter and after condensers are provided for each element, isolating valves are not required. In some installations where a common after condenser is provided for two second-stage elements, the internal construction of the unit is such that the steam discharged from the operating element cannot back up through the diffuser of the

second-stage element, and isolating valves are omitted from the second-stage diffuser discharge.

Division Plate Leakage

Should internal leakage occur across the division plate between the inter condenser and the after condenser, the second-stage element becomes overloaded since the air-steam mixture discharged by the second-stage element leaks back to the inter condenser instead of being discharged to the atmosphere. A leak of this type rarely happens in modern air ejectors, but if it is suspected, the inter condenser and the after condenser should be hydrostatically tested and the condenser drains should be inspected to determine whether leakage is indicated. Repairs involve removal of tubes, disassembly of the unit, and replacement of internal gaskets.

Flooded Condenser

Improper drainage or leaking condenser tubes will cause flooding of the inter and after condensers, which will result in a loss of vacuum. If flooding should occur, the effective condensing surface is decreased, and a loss of vacuum occurs. Flooding may also cause condensate to be drawn into the second-stage element, which will result in erratic operation of the unit.

If flooding is suspected, drain lines should be cleared out and a hydrostatic test should be performed on the unit to check for leaks at tube joints and tube walls. Tubes rarely need replacing as most installations use condensate as a cooling medium.

If tube leakage does occur, the packed ends can be repacked by use of copper-asbestos packing rings supplied by the manufacturer. The removal of old packing rings and installation of new ones can be accomplished in the same manner as for packing of main condenser tubes except that copper-asbestos rings should be set up with several very light hammer blows on the calking tool. Copper does not flow into the threads of the packing box as readily as does the lead packing used in main condensers.

Emergency repair of a tube is accomplished by plugging both ends. Should retubing or other major repairs be necessary, all parts of the assembly should be hydrostatically tested to the test pressure specified by the manufacturer. It should be determined that all internal parts of

the assembly are in proper working order before the new tubes are installed. A positive test should be made to establish the tightness of the gaskets between the inter and after condensers both before and after installing new tubes.

Maintaining the Loop Seal

Should an air leak be present in the U-shaped loop seal line (fig. 10-13) provided for draining the inter condenser, it will become impossible to maintain a seal between the inter condenser and the main condenser. Water from the inter condenser passes down through the small 1-inch pipe then through the short loop, and up through the internal pipe. The larger pipe surrounding the internal pipe is 3 inches in diameter and is connected to the main condenser. Water overflowing the internal pipe fills the external pipe and the larger loop.

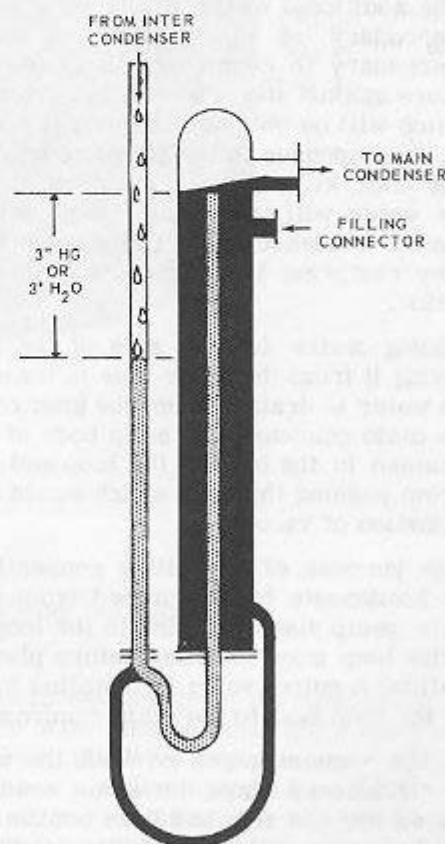


Figure 10-13.—Loop seal.

If no vacuum existed in either condenser, and water from the inter condenser entered the internal pipe, it would maintain the same height in each leg.

When a vacuum is formed in both condensers, the difference between the vacuum maintained in the main condenser and that maintained in the inter condenser will be about 3 inches. The vacuum in the main condenser will be about 29 inches, that in the inter condenser about 26 inches. Expressing vacuum in terms of absolute pressure, a pressure of 1/2 psi will be acting down on the internal and external pipes, and a pressure of 2 psi will work down against the water level in the primary 1-inch pipe. This means that the pressure of 2 psi from the primary pipe will push water through the pipe and cause it to overflow from the external pipe into the main condenser.

When the water level in the primary leg is approximately 3 feet below that of the secondary leg, the additional weight of the water present in the secondary leg will provide the extra 1 1/2 psi necessary to counteract the 2 psi absolute pressure against the primary leg. Thus, a static condition will be obtained. If water is added from the inter condenser to the primary leg, the level on that side will rise, and the additional weight of the water will cause water to be pushed into the main condenser, from the secondary leg, thereby restoring the loop to its original static condition.

Adding water to one side of the loop and removing it from the other side is the means by which water is drained from the inter condenser to the main condenser. A solid body of water is maintained in the base of the loop and prevents air from passing through, which would cause an equalization of vacuum.

The purpose of the filling connection is to allow condensate to be pumped from the condensate pump discharge line to the loop seal so that the loop may be filled before placing it in operation. A cutout valve is installed in the line from the loop seal to the main condenser.

If the vacuum gages on both the main and inter condensers show the same reading, this indicates that the seal has been broken. Opening the filling valve will correct this condition, if it is due to a sudden surge in vacuum, or a violent roll of the ship. If the condition is the result of an air leak, the leak will have to be corrected before the loop will remain properly sealed.

DEAERATING FEED TANKS

Deaerating feed tanks serve three purposes: (1) to free the condensate of oxygen and other noncondensable gases, (2) to heat the feed water, and (3) to act as a reservoir in which to store water to take care of rapid fluctuations in feed water demand or condensate supply. Deaerating feed tanks "scrub" the feed water free of air by use of spray nozzles. The feed water is heated by direct contact with auxiliary exhaust steam. Deaerating feed tanks generally operate at 13 psi and at approximately 246°F with 15 psig auxiliary exhaust steam. The water is kept just under its boiling point at the operating pressure so that it will not flash into steam.

A deaerating feed tank is shown in figure 10-14. Condensate enters the tank through the tubes of the vent condenser and then flows to the spray head. It is forced out through multiple spring-loaded spray nozzles in the spray head. The nozzles are designed to open at a very low pressure and to maintain good atomization even at very low loads. The water leaves the spray nozzles in a very fine spray and is discharged throughout the steam-filled upper section of the tank. The water is heated and scrubbed by the steam and releases some oxygen. The water, partially heated and deaerated, then falls into a cone-shaped baffle which conducts it to a central port. Here the steam coming into the deaerating unit picks up the water and throws it radially outward and upward against the lower side of the conical baffle. In this process, the water and steam are so thoroughly mixed that the water is heated to practically the same temperature as the steam, and the dissolved gases in the water are removed. The deaerated water then falls into the storage space at the bottom of the tank, where it remains under a blanket of air-free steam until it is needed for the boilers.

Steam sweeps the air from the deaerating feed tank. The mixture of steam and air travels across the vent condenser tubes, where most of the steam is condensed into water which drops back into the deaerating tank. The air, together with any remaining steam is vented to the gland exhaust condenser.

The steam control valve remains wide open during normal operation and the flow of steam into the tank is controlled by the rate of condensation. Normally the pressure drop between the auxiliary exhaust line and the deaerating feed tank will be 1/2 psig or less. At low loads, the

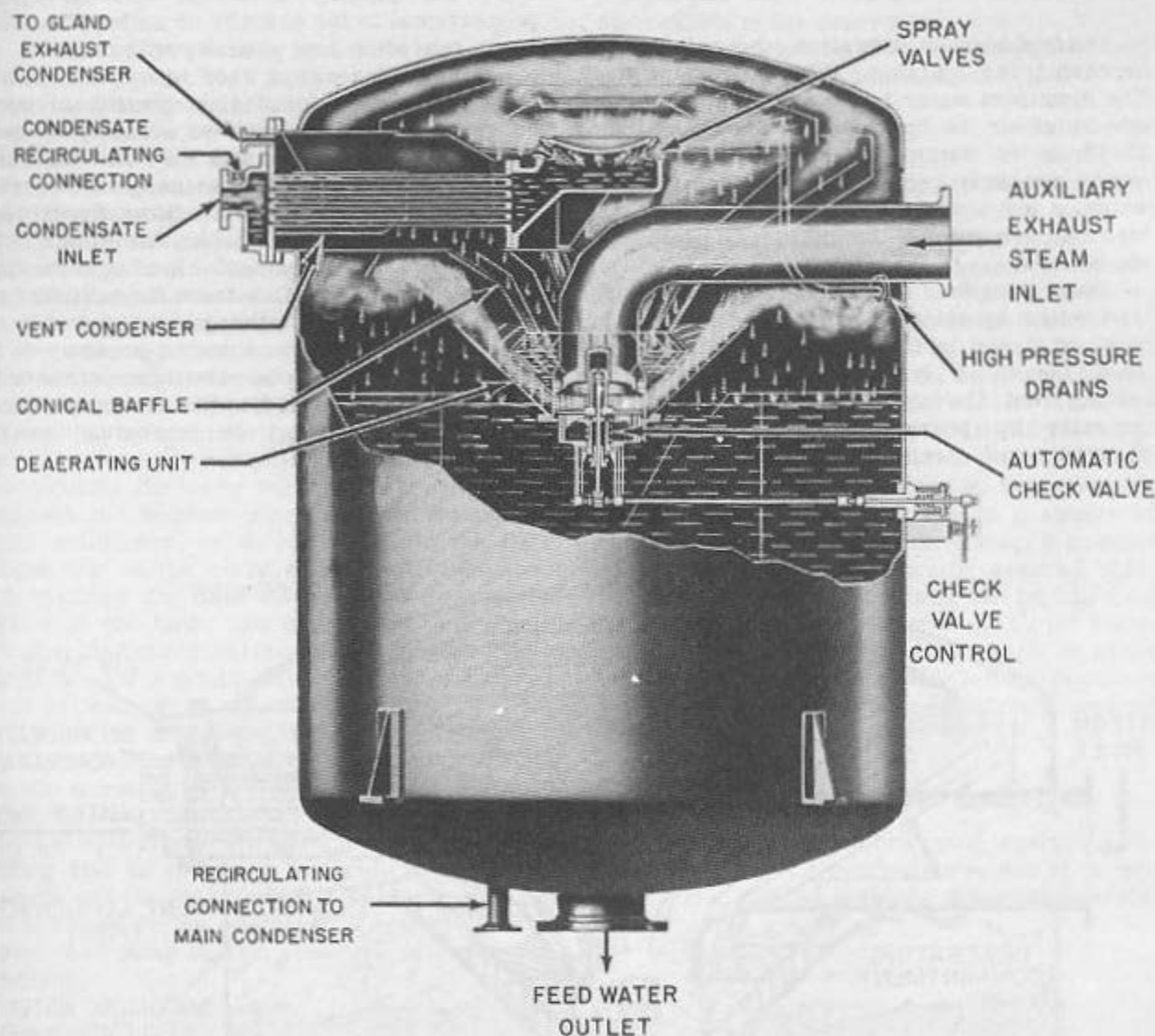


Figure 10-14.—Elliot type deaerating feed tank.

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water overflowing the cup-shaped recess fills the space within the conical baffles. This causes a cessation of steam flow until the tank pressure had decreased, because of condensation, to a point where the pressure drop is great enough to allow steam to blast through the water in the helical baffles. At high loads, the rate of steam flow is great enough to prevent accumulation of water in the baffles; the steam drives the water out as it overflows the cup-shaped recess.

A shaft extends from the steam valve through the side of the tank; the shaft has a lever attached to it. When the lever is thrown in one direction, it presses a collar against the check valve and forces it to the fully closed position. When the lever is thrown in the opposite direction, another collar forces the check valve to the wide open position. When the lever is in the center position, the check valve is free to operate automatically.

OPERATION

During normal operation, the only control necessary is maintaining the proper water level. The maximum water level, beyond which the unit should never be operated, is shown in figure 10-15. If the water level is too high, the tank cannot properly remove the air from the feed water. A low water level may endanger the main feed booster pumps, the main feed pumps, and the boilers.

Deaerating feed tanks remove gases from the feed water by using the principle that the solubility of gases in feed water approaches zero when the water temperature approaches the boiling point. During operation, steam and water are mixed by spraying the water so that it comes in contact with steam from the auxiliary exhaust

line. The quantity of steam must always be proportional to the quantity of water, otherwise, faulty operation or a casualty will result.

In most deaerating feed tanks, the manhole provides access for the inspection of spray nozzles; other tanks are so designed that the spray nozzle chamber and the vent condenser must be removed in order to inspect the nozzles.

Auxiliary exhaust steam flows directly into the deaerating unit. A check valve either in the deaerating tank, or in the line leading to the tank, allows the steam to flow from the auxiliary exhaust line whenever the pressure inside the deaerating tank is less than the pressure in the exhaust line. The check valve also prevents the return flow of water into the auxiliary exhaust line, in the event that the deaerating tank becomes flooded.

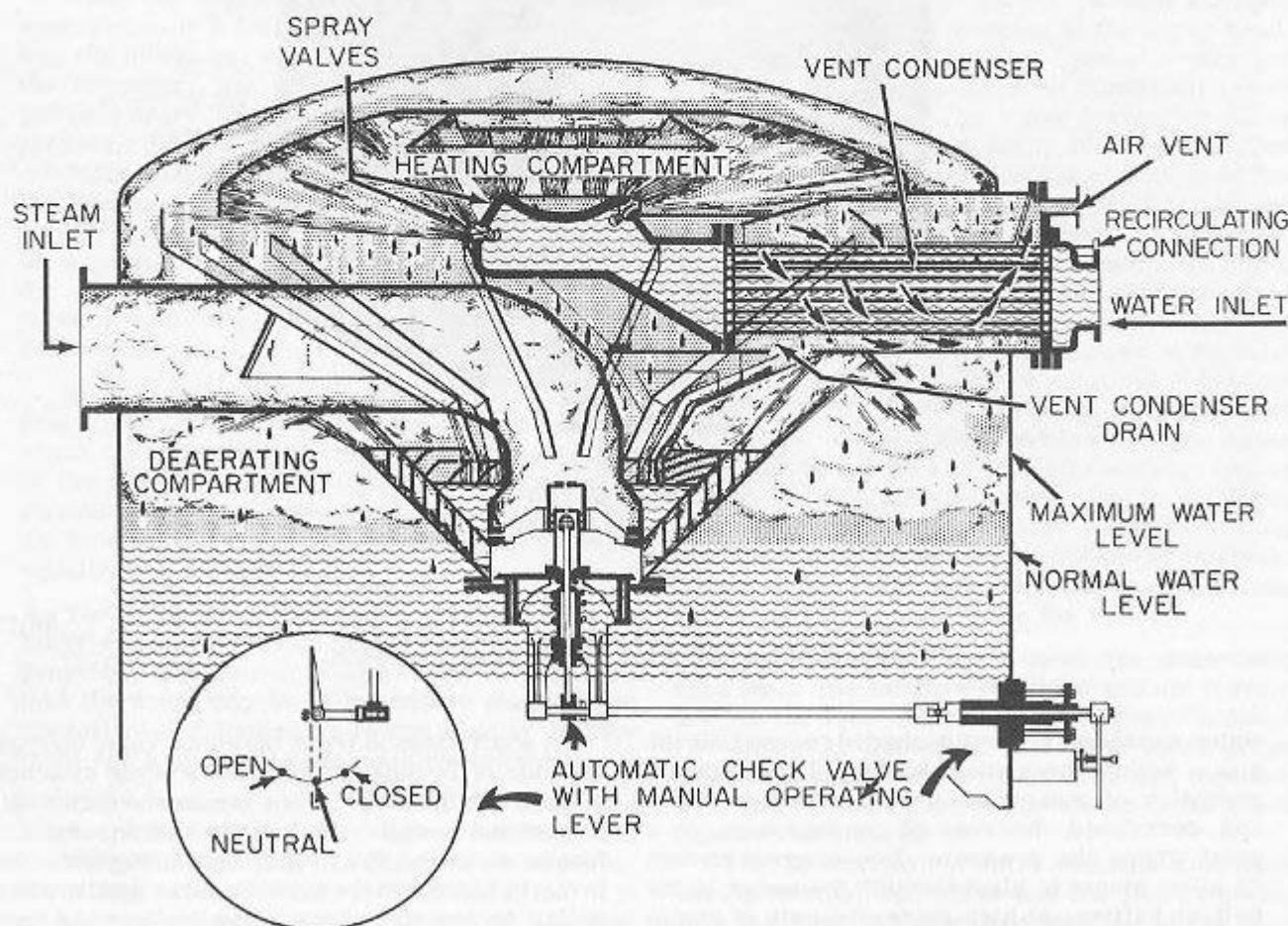


Figure 10-15.—Deaerating feed tank (diagrammatic arrangement).

Start-Up

A secured deaerating tank must be kept isolated from the feed water system and its contained water must be deaerated before the tank is put into service. If the tank is empty, it may be filled by means of the emergency feed pump, taking suction from a reserve feed tank and discharging to the condensate line, or in some installations, discharging directly to the deaerating tank. During this operation, the auxiliary exhaust must be cut in to the deaerating tank to heat and deaerate the feed water.

In warming up a deaerating tank, the steam and water supply valves should be opened slowly to avoid sudden temperature changes in the tank. When the tank is filled to the normal operating level, a feed booster pump should be started to recirculate the water from the deaerating tank, through the booster pump and then through the vent condenser, or directly back to the DFT, depending on the class ship. It will take about 10 minutes for this recirculation to heat the water in the tank. The deaerating tank should be operated at normal operating temperature and pressure for a minimum of 10 minutes before it will be ready to be put into service.

When the deaerating tank is fully warmed up, and before it is cut into the feed system, the valve in the warming up line should be closed slowly. The starting line should be closed during all normal operating. The main feed pump recirculating line is relied on to protect the booster pumps and the feed pumps. If the starting up line is left open during operation, it could reduce the main feed pump suction pressure below that required.

Underway

In order to have effective deaeration, it is necessary to vent sufficient steam from the deaerating feed tank to sweep out all air which has been separated from the feed water. This separated air is continuously concentrated in the uncondensed portion of the steam, as the steam passes through the deaerating unit, preheater, and vent condenser. If all the steam were condensed in the vent condenser, the separated air would again mix with the condensate.

The amount of vented steam is controlled by an orifice installed in the vent line of the vent condenser. The vent line orifice must be large enough so that the minimum quantity of steam-air mixture necessary for proper deaeration is

discharged when the minimum operating pressure exists in the deaerating tank.

A vent condenser, showing the path of gases into the unit, is shown in figure 10-16.

Shutdown

In securing the deaerating tank, the vent valve should be opened before the water supply is secured. When securing the water, the pressure in the tank should not be allowed to build up. Should the tank pressure rise too high for normal operation, due to some external means (high pressure drains), a recirculating connection, leading from the base of the tank into the main condenser, provides increased circulation through the tank. This recirculating connection enables the water to be discharged back into the tank, after it has been cooled by the condenser, thereby causing a reduction in pressure and temperature within the tank. Except in an emergency, the steam must not be secured before securing the water, the tank will be filled with cold water that is not deaerated. Under normal securing conditions, the vent should be shifted from the gland seal condenser to the atmosphere; if this is not done, the gland seal condenser will overheat.

MAINTENANCE

Deaerating feed tanks must operate effectively to provide a continuous supply of oxygen-free water for the boilers. Effective operation

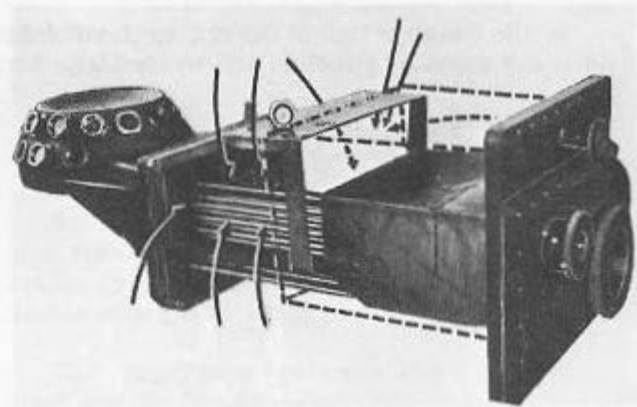


Figure 10-16.—Vent condenser, showing path of gases.

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depends primarily on the operation of the spray valves. The spray valves should be tested at least once each 6 months.

Complete information on constructing and using a test rig for spray valves can be found in chapter 9560 (56) of the Bureau of Ships Technical Manual. This rig is available at all repair activities ashore and afloat. When testing spray valves with this rig, the following items should be carefully checked:

1. The spray valve must be fully open or completely shut. Any leakage indicates faulty operation which will seriously affect deaeration. If leakage does exist, the valve should be examined for scored or damaged seats or improper spring tension.

2. When the valve opens, the spray should be a complete cone. Any other form of discharge is a positive indication of faulty operation. An incomplete cone indicates cocking of the disk which may be caused by a defective spring.

3. All valves should open at the same pressure to avoid leaving gaps in the spray area. The valves and seats should be free of deposits and should operate freely in any position.

4. When test procedures described in the Bureau of Ships Technical Manual are used, the results will not be definitive, however, they will indicate MAJOR malfunctioning of the unit. All naval shipyards have the equipment and personnel to perform proper tests for more positive results. For any test results to be of value, all testing should be accomplished with samples taken from an operating deaerating feed tank feeding a steaming boiler.

In the construction of deaerating feed tanks, as many parts as possible are welded together,

but some bolts and nuts are used. When parts are disassembled, all nuts should be secured with split pins. Split pins must be of a corrosion-resistant metal such as Monel or stainless steel. Ordinary steel will corrode too rapidly to give satisfactory service.

A screen is installed in the bottom of the deaerating feed tank (booster pump suction) so that if an internal part of the tank should come loose, or if metal from the condensate or steam system should enter the tank, the screen will prevent the part from entering the booster pump suction.

A MANHOLE in the shell provides access to the interior of the tank. All removable parts of the tank section are small enough to be taken out through this manhole.

The vent condenser can be removed as a unit by breaking the flanges on the condensate inlet, the vent line, and the recirculating line, then removing the vent condenser flange bolts and pulling the vent condenser out. The spray chamber and spray nozzles are attached to the vent condenser and are removed as a unit.

For safety purposes, all deaerating feed tanks are equipped with two spring-loaded relief valves. One is to prevent a high pressure from accidentally building up inside the tank, and the other, called a vacuum breaker, is to prevent a high vacuum from developing inside the tank. The vacuum breaker allows atmospheric air to enter the tank whenever the vacuum exceeds a predetermined amount.

The steam control valve automatically controls the amount of steam admitted to the deaerating tank. There are many different arrangements of these valves; this publication does not contain information on the repair procedures for each type. For complete information on each type of steam control valve, refer to the manufacturer's technical manual.

CHAPTER 11

DISTILLING PLANTS

This chapter deals with the general description, operation, and maintenance of steam operated and vapor compression distilling plants. Evaporation followed by condensation is the means used to produce distilled water from salt water or river water. This distilled water is sufficiently free of impurities that it can be and is used for boiler feed water. Boiler feed water must be of high purity to maintain high heat transfer and prevent excessive scaling and corrosion. Distilled water is also used aboard ship for drinking, cooking, and washing.

Basically all distilling plants operate on the same principle, although designs differ. Each plant has a heating section to produce evaporation, a condenser to condense the vapors from the evaporators, a preheater to preheat the evaporator feed water, and a cooler to cool the distillate.

Steam operated distilling plants are classified as coil, submerged tube, vertical basket, and flash types. (NOTE: In accordance with military specification MIL-D-18641 (Ships), steam operated distilling plants are classified as types and classes.) For additional information on vapor compression units, reference should be made to MIL-D-16196. Reference may also be made to other specifications and manuals for specific plant plants. Formerly marine distilling units were constructed for use of high pressure steam, typically 15 psig. High boiling temperatures and consequent rapid scaling characteristics of such designs have made them obsolete for marine use. In the submerged tube type, sea water surrounds the evaporator tubes into which low pressure (less than atmospheric) steam flows; the steam gives up heat to boil the sea water, and then is condensed.

In the vertical basket type, low pressure steam flows into a corrugated basket surrounded by sea water, gives up its heat to boil the sea water and is condensed. The fresh water vapor

from the boiling sea water is condensed and is removed as distillate.

In the flash type, preheated feed water is discharged into a vacuum chamber where a portion of the water vaporizes (flashes) because the pressure in the chamber is lower than the saturation pressure corresponding to the temperature of the heated feed water. The remaining water passes into a second flash chamber where a lower pressure (higher vacuum) is maintained which causes further vaporization of the water.

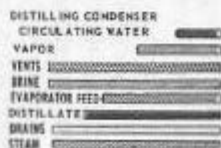
Any number of vaporization stages can be used. Each stage has a condenser in which the fresh water vapor is condensed. The condensed vapor is removed as distillate.

The vapor compression type distilling unit was first developed for submarine service, where the absence of a steam supply necessitated some other source of heat for the evaporating process. These units require electrical energy for their operation. They are also used on small diesel-driven surface craft, and on ships with daily requirements which do not exceed 4,000 gallons.

SUBMERGED TUBE DISTILLING PLANTS

Submerged tube distilling plants are divided into three types: Soloshell double effect (fig. 11-1), triple effect, (fig. 11-2) and two-shell double effect (fig. 11-3).

The difference between the triple-effect plant and the double-effect plant is in the number of stages of evaporation. In the double-effect plant, evaporation takes place in two stages, while in the triple-effect plant evaporation takes place in three stages.



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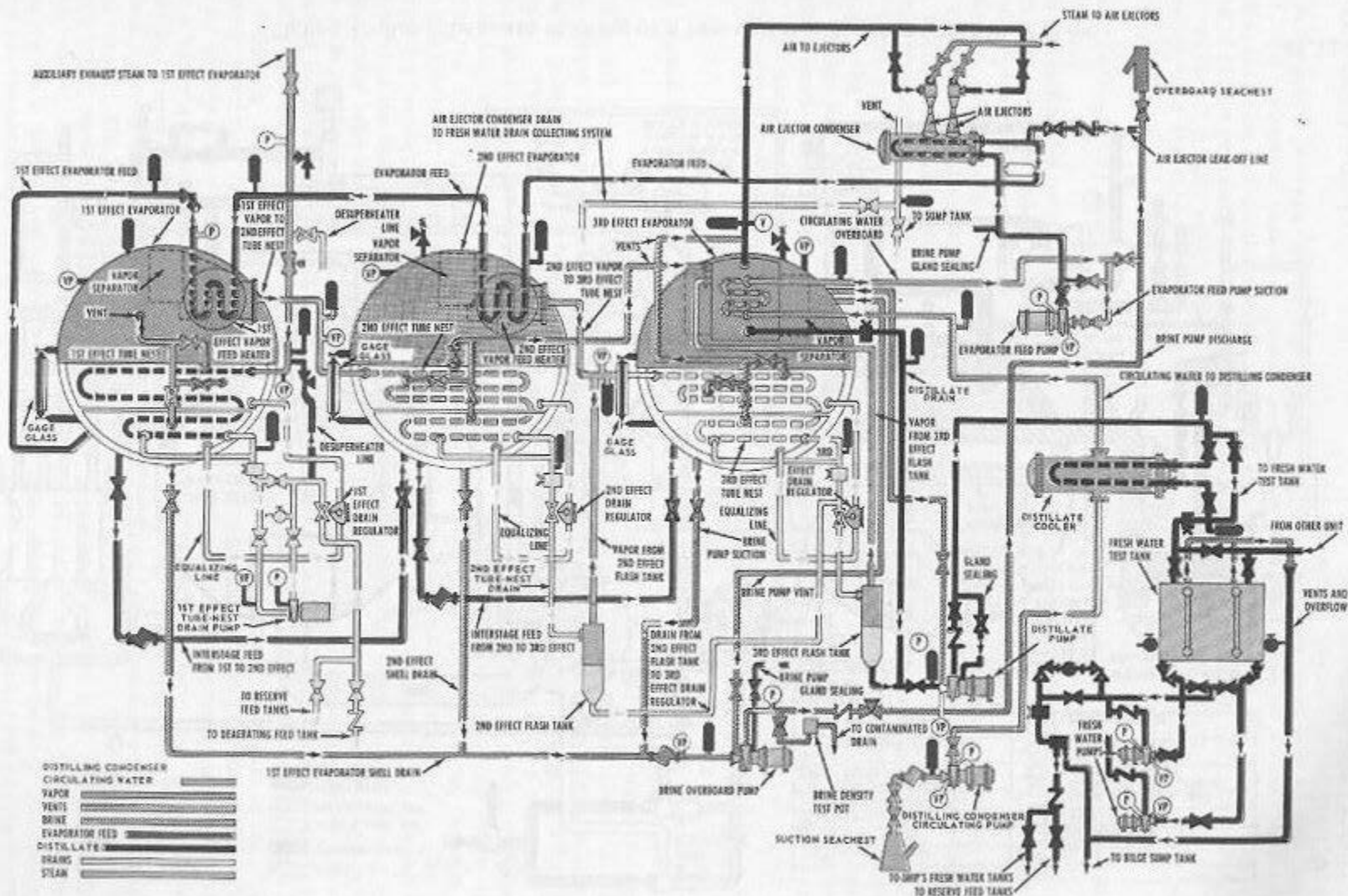


Figure 11-2.—Schematic drawing of a triple-effect distilling plant.

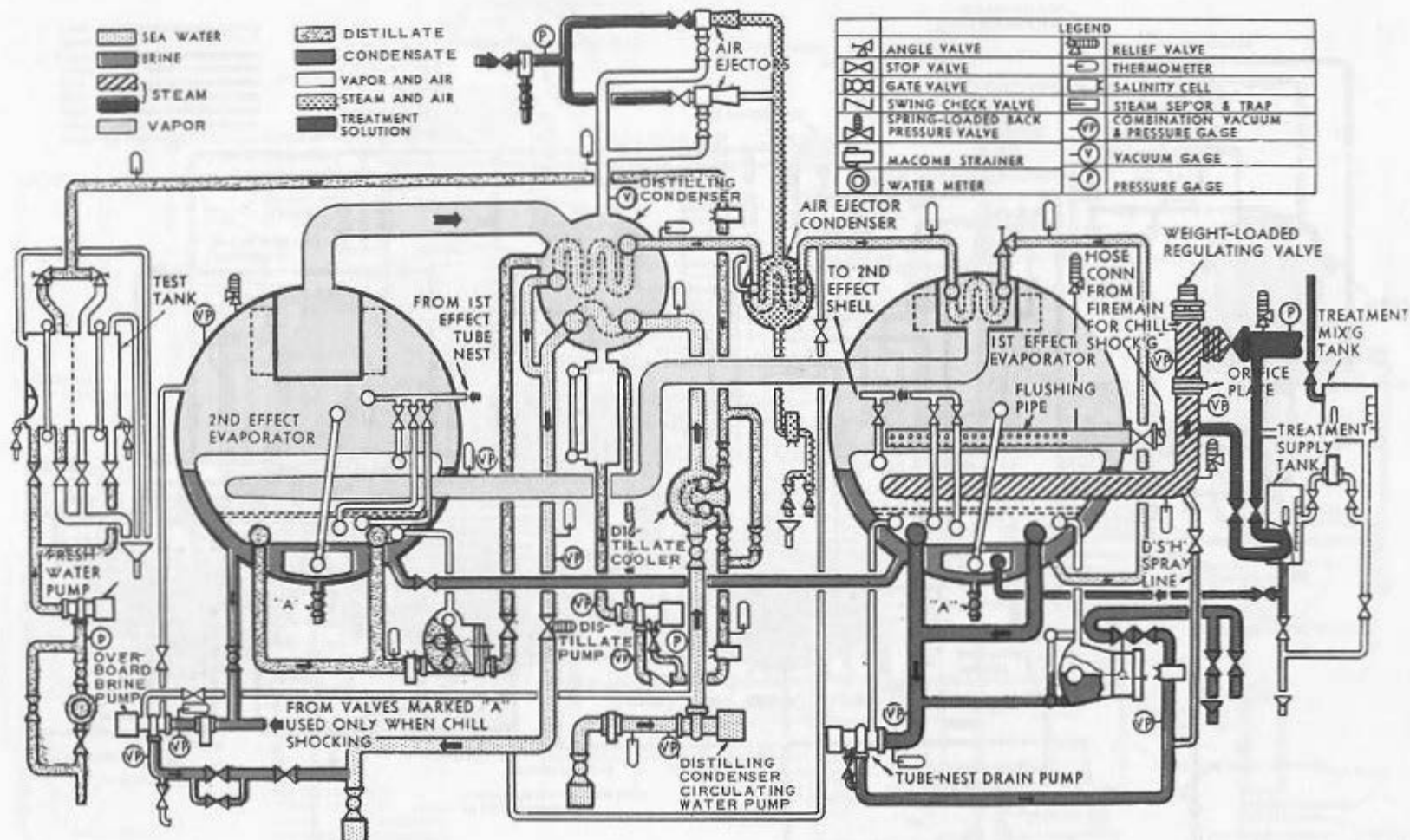


Figure 11-3.—Schematic drawing of a two-unit double-effect distilling plant.

TYPES AND COMPONENTS

The differences between the three principal types of low pressure distilling plants are briefly discussed in the sections which follow. The types of plants generally found aboard ships are the two-shell double effect, the Soloshell double-effect, and the three shell triple-effect plants.

Two-Shell Double-Effect Plants

The most commonly used 20,000 gallons per day (gpd) double-effect plant is built with two horizontal, cylindrical evaporator shells (fig. 11-3), one for each effect, and usually mounted with the axes of the shells parallel. Tube nests for both shells may be removed from the front head. The first-effect vapor feed heater is built into the upper part of the first-effect shell. In this design, the distilling condenser and the distillate cooler are built into separate shells, and usually mounted between the two evaporator shells. The air ejector condenser, also an independent unit, is mounted on one of the two shells.

Soloshell Double-Effect Plants

Virtually all low pressure submerged tube distilling plants up to and including the 12,000 gpd capacity plant are of the Soloshell double-effect type. This type consists of a single cylindrical shell mounted with the axis horizontal. A vertical partition plate (fig. 11-4), parallel to the axis, divides the shell into two evaporator chambers. Each of these chambers has a separate removable tube bundle bolted to the front head of the shell (the first- and second-effect evaporator tube bundles in fig. 11-4). The first effect vapor feed heater is built into the upper part of the first-effect shell, and also has a removable tube bundle bolted to the front head.

The distilling condenser (condensing and feed-heating sections) is built into the upper part of the second-effect shell. This unit does not have a removable tube bundle but the tube sheets project beyond the front and rear heads of the shell, providing access for cleaning or replacing tubes. The air ejector condenser is a separate unit, mounted on brackets on the evaporator shell. The distillate cooler is also in a separate shell and may be located wherever convenient for the necessary piping connections.

One type of 20,000 gpd capacity Soloshell double-effect plant was typically installed on light and heavy cruisers. Two such plants are installed when it is necessary to furnish an overall capacity of 40,000 gpd. In such plants, the vertical partition separating the first and second effects is at right angles to the axis of the cylinder. The first-effect vapor feed heater is in the upper part of the first-effect shell; the distilling condenser is in the upper part of the second-effect shell, and the air ejector condenser is mounted on the main evaporator shell. The distillate cooler is mounted similarly to that in the smaller Soloshell plants.

The steam is obtained from the auxiliary exhaust line through a weight loaded or an air controlled regulating valve. This valve is set to maintain a constant steam pressure of 1 to 5 psi to the tube nest of the first-effect evaporator. A pressure gage is installed ahead of the regulating valve. A relief valve, a thermometer, and a compound gage are installed on the steamhead of the evaporator tube nest in order to keep a check on the steam supply.

In passing through the regulating valve, the auxiliary exhaust steam is reduced to a pressure of 5 psi. The steam then passes through an orifice plate in the steam line between the regulating valve and the inlet to the first-effect tube nest. This orifice plate is designed to control the amount of steam, by weight, entering the plant to an amount required for the plant's designed output of distilled water. A change in the size of the orifice alters the plant output.

Because of the throttling effect in passing through the reducing valve, the low pressure steam becomes superheated. The auxiliary exhaust steam is therefore passed through a desuperheating area in the steam line. Desuperheating is accomplished by a spray of hot water, at saturation temperature, piped from the first-effect tube nest drain pump. This water is sprayed into the steam supply line in sufficient quantity to reduce the steam temperature to that corresponding to the pressure existing in the tube nest so that the incoming steam will commence to give up its latent heat of condensation immediately on entering the tube nest.

After being desuperheated, the steam passes into the first-effect tube nest. Here the steam gives up its latent heat of condensation to the feed water surrounding the first-effect tubes. The resulting condensate (condensed steam) from the first-effect tube nest is discharged by

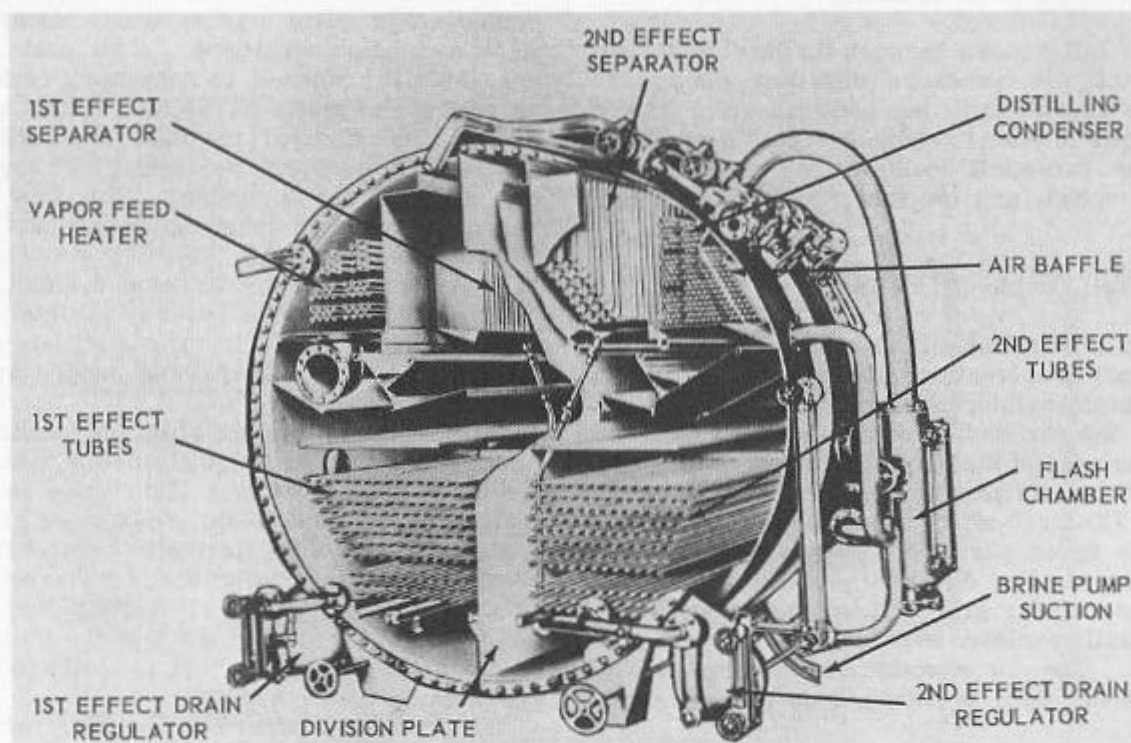


Figure 11-4.—Internal construction of a Soloshell distilling plant.

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pump to the deaerating feed tank. In an emergency, the condensate may be discharged to the main condensers, the auxiliary turbo-generator condensers, or the fresh water drain collecting system. This condensate is returned to the boiler feed system to help maintain the heat and water content of that system constant.

Steam generated in the evaporator shells by the evaporation of the feed water is referred to as VAPOR, to prevent confusing it with the steam which is introduced into the first-effect evaporator tubes and is the outside source of heat for the plant. The vapor is separated from the feed water at the water surface and, although the vapor itself is pure, small particles of raw, unevaporated feed water are mixed with it. The particles of feed water are removed from the vapor by a series of baffles above the surface of the water in the evaporator shell, and by additional baffles or vanes in the first-effect vapor separator.

The vapor changes its direction of motion several times in passing around the hooked edges of the baffles and vanes. The hooked

edges trap particles of feed water and drain them into pipe lines. These pipe lines discharge the separated moisture as far away as possible from the vapor separator in the evaporator shell.

After passing through the vapor separator on its way to the second-effect tube nest, the vapor passes through a vapor feed heater. Part of the vapor is condensed as it gives up its latent heat to the feed water passing through the tubes of the heater. The remaining vapor and distillate pass together into the tube nest of the second-effect evaporator. Here the first-effect vapor gives up its latent heat in generating vapor from the feed water in the second-effect evaporator shell. This exchange of heat condenses the remaining first-effect vapor.

In the second-effect shell, the pressure surrounding the sea water is considerably less than in the first-effect shell. This makes it possible to use the vapor formed in the first-effect shell to boil and vaporize the sea water in the second-effect shell.

The vapor generated in the second-effect shell passes through a vapor separator and into a distilling condenser. The condensing tubes nearest the incoming vapor are utilized as a feed heating section where the vapor is partially condensed, thereby heating the feed water circulating through the condenser tubes. The remainder of the vapor is condensed in the condensing section and is discharged to the test tanks as fresh water.

The first-effect distillate in the second-effect tubes is discharged through the second-effect tube-nest drain regulator and led to the distilling condenser through the flash chamber.

The distilling condenser circulating water pump takes suction from the sea and discharges the water through the distillate cooler and the distilling condenser. A strainer is installed in the pump suction piping. The cooling water passes through the shell of the distillate cooler and then through the tubes of the distilling condenser. The cooling water is then discharged overboard through a spring-loaded back-pressure valve set to maintain a back pressure of about 5 psig.

A portion of the sea water discharged from the cooling water circuit is used as feed to the first-effect evaporator. A 5 psi back pressure provides sufficient head to force water through the feed heater to the first-effect shell. The evaporator feed water is discharged into the second-effect vapor feed heater which is located near the distilling condenser section of the shell. After passing through the second-effect vapor feed heater tubes, the feed water travels through the tubes of the air ejector condenser. From there, the feed water is led into the first-effect vapor feed heater tubes. After passing through the first-effect vapor feed heater, the feed water enters the first-effect shell through perforated internal feed distributing pipes located well below the working water level in the shell.

A portion of the feed water is evaporated after entering the first-effect shell. This increases the density, or salinity, of the remaining portion. This denser or saltier water, commonly referred to as BRINE to distinguish it from sea water, is led into the second-effect shell.

The brine is transferred to the second-effect shell through a pipeline having a manually controlled feed regulating valve installed in it. The higher pressure in the first-effect shell is utilized to force the brine into the second effect, where it is distributed by means of perforated internal feed pipes. (In a triple-effect plant,

the brine then passes to the third-effect shell through a pipeline and is distributed in a manner similar to that in the second-effect shell of a double-effect plant.)

A brine overboard pump takes suction from the second-effect shell through a Macomb-type strainer, and discharges the brine overboard. To permit rapid draining of the first- and second-effect shells, as when chill shocking, they have suction connections leading directly to the brine overboard pump. Since these connections are not used in normal operations, they are provided with valves that can be locked closed to prevent accidental opening, which would upset proper operations of the plant.

Triple-Effect Plants

The triple-effect distilling plant is similar to the double-effect plant except the triple effect has an intermediate evaporating stage. A standard 20,000 gpd triple-effect plant consists of three horizontal, cylindrical shells (fig. 11-5) set side by side with their axes parallel. The tube bundles can be withdrawn from the front cover of each shell. The first- and second-effect vapor feed heaters are built into the front end of the second- and third-effect evaporator shells. The distilling condenser is contained within the third-effect shell. The air ejector condenser and the distillate cooler are in separate shells and are mounted on the third-effect shell. Figure 11-5 illustrates the internal arrangement of a first-effect evaporator shell of a triple effect plant.

Another 20,000 gpd triple-effect design consists essentially of three horizontal shells bolted together end to end, with vertical partition plates between each section (shell) to form the three effects. The tube bundles can be withdrawn horizontally through one side of the cylinder. Vapor separators in independent shells are installed in the vapor piping between effects and between the third effect and the distilling condenser. The first- and second-effect vapor feed heaters are in separate shells and are mounted in the piping at the inlet to the second- and third-effect tube bundles, respectively. The two sections of the distilling condenser and the distillate cooler are built into a single shell and independently mounted as space and piping arrangements may permit. The air injector condenser is also a separately mounted unit.

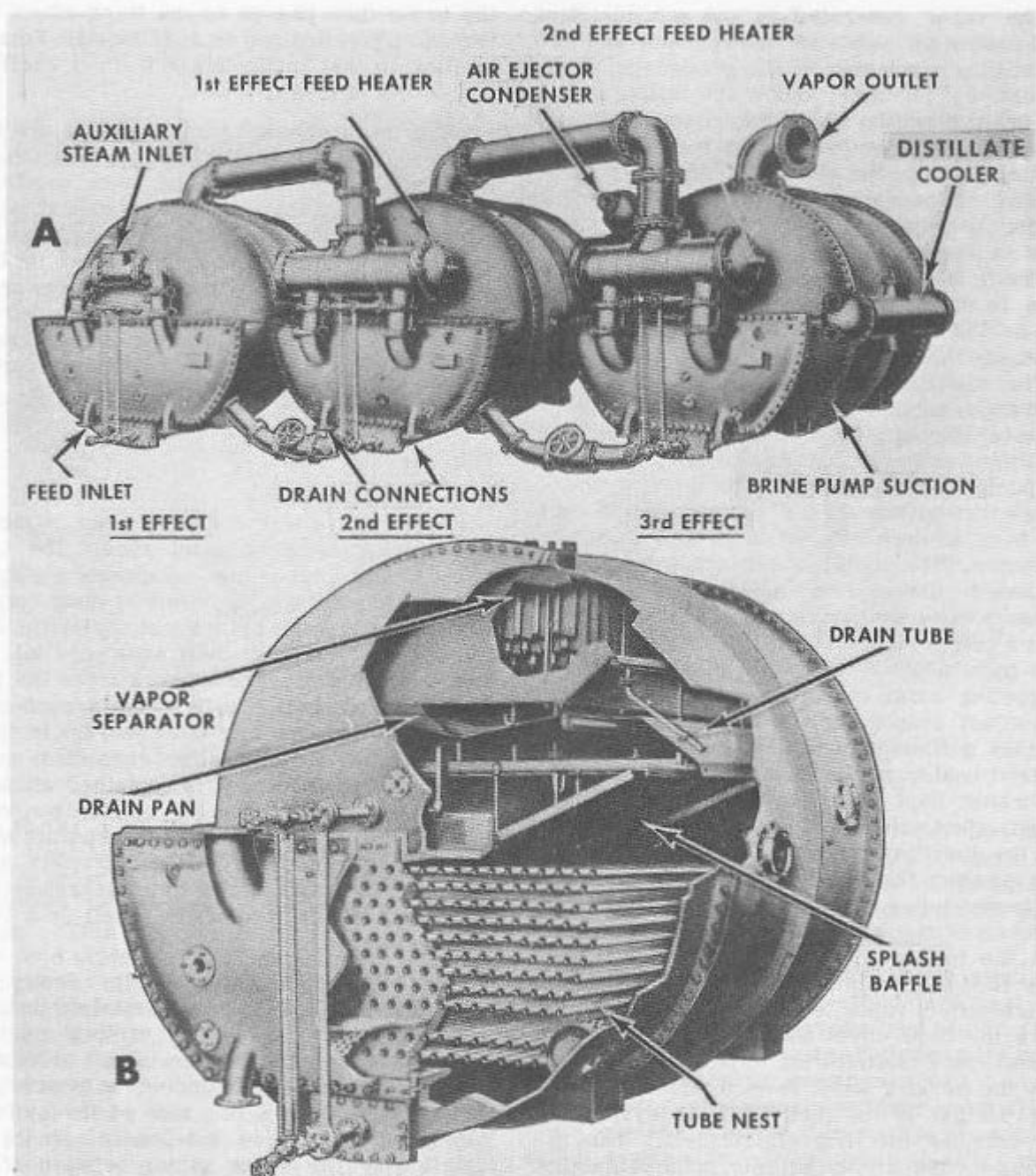


Figure 11-5.—Triple-effect distilling plant: (a) outside arrangement, (b) internal arrangement of the first-effect shell.

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The 30,000 gpd triple-effect plant is similar to the 20,000 gpd plant, except for the increased size of the units.

There are two types of 40,000 gpd triple-effect plants which are widely used in naval ships. The first type uses exactly the same arrangement as

the 20,000 gpd triple-effect plant, with the size of the units and parts increased as necessary for the greater capacity. The second type consists of three horizontal shells, usually mounted side by side with axes parallel. The tube bundles can be withdrawn through the front end of the shells as in the 20,000 gpd two-shell double-effect plant. In this design, both vapor feed heaters and distilling condenser are built as three independent units, each mounted separately outside the evaporator shells. The air ejector condenser and the distillate cooler, also in independent shells, are separately mounted outside the evaporator shells.

When comparing a low pressure triple-effect distilling plant with a low pressure double-effect plant, it will be noticed that:

1. **UNITS ADDED** to the triple-effect plant include one evaporator shell, one vapor separator, one feed water heater, one feed pump, and several salinity cells. The evaporator feed pump takes suction from the distilling condenser cooling water circuit at a point between the outlet of the condensing section of the distilling condenser and the spring-loaded back-pressure valve.

2. The **SALT WATER FEED** is piped successively from the first-effect shell to the second- and third-effect shells. The water decreases in heat and increases in density as it progresses from the first to the third effects.

3. The **BRINE DISCHARGE** is made from the third-effect shell instead of from the second-effect shell.

4. The **GENERATOR HEAT** in the tube nests of the second- and third-effect shells is derived from the vapor created in the preceding shell.

5. The **VACUUM** is increasingly higher in each successive evaporator shell and in the plant as a whole, as the distance from the air ejector and the distilling condenser is decreased. This higher vacuum, lowering the boiling point, makes it possible to generate vapor with the lower overall temperatures of the sea water or brine and the vapor filled tubes.

The principal parts of a low pressure distilling plant include the tube nests, distilling condenser, vapor feed heaters, level controllers, air ejector, flash chamber, air ejector condenser, distillate cooler, and tube-nest drain regulator.

EVAPORATOR TUBE NEST.—The evaporator tubes are made of copper-nickel alloy. The tube bundle (fig. 11-4) consists of two sets

of tubes—an upper set of either eight or nine rows of horizontal tubing, and a lower set of two or three rows of similar tubing. Tube ends are inserted into and expanded to fit tightly in holes in the front and rear tube sheets (fig. 11-5). Both front and rear tube sheets are provided with flanged heads or cover plates. The internal areas of the tubes and heads thus form the evaporator heating section (tube bundle). The front head and tube sheet are flanged to the front head of the shell cylinder.

The rear tube sheet and head, and an intermediate tube supporting plate are supported inside the shell cylinder by rollers which are mounted on rails. This "floating head" design permits unrestricted expansion and contraction of the tube bundles. In addition, this type of construction permits removal of the tube bundles for cleaning.

DISTILLING CONDENSER.—This condenser consists mainly of a bank of tubes through which the cooling sea water flows, a baffle plate which deflects the water vapor away from the air pre-cooling section, a section of tubes known as the inner heating section, and an outside shell.

On the feed inlet end of the condenser there is a zinc pencil, and at the outlet end a zinc plate is installed. In standard designs, the condensing unit is generally built into the third-effect shell. The distilling condenser of the Soloshell double-effect plant is built into the uppermost part of the second-effect shell (fig. 11-1). However, in some distilling plants the condenser is a separate unit, such as that illustrated in figure 11-6.

VAPOR FEED HEATERS.—The number of vapor feed heaters in a distilling plant varies, depending upon the number of effects and the design of the plant. The feed water passes through the tubes in these heaters on its way to the first-effect shell. Vapor from one of the evaporator shells passes into each heater and flows around the heater tubes, thus heating the feed water. A typical vapor feed heater is shown in figure 11-7.

LEVEL CONTROLLERS.—In practically all of the distilling plants built prior to 1950, the water level in the shell of each effect is controlled by manually regulating the individual feed inlet valves. Many of the plants built since that date, however, are provided with automatic feed-level control devices. These adjustable

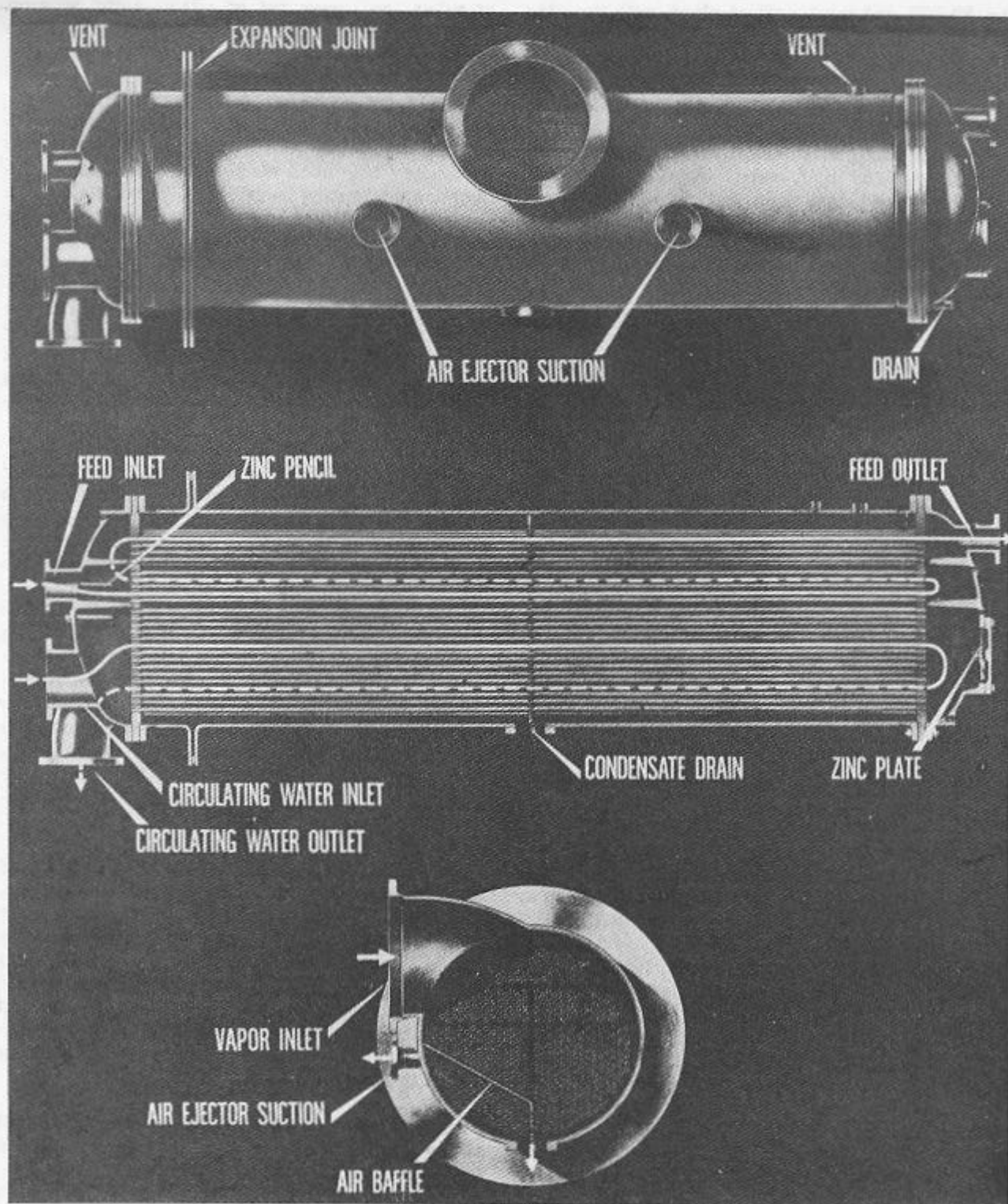


Figure 11-6.—Distilling condenser.

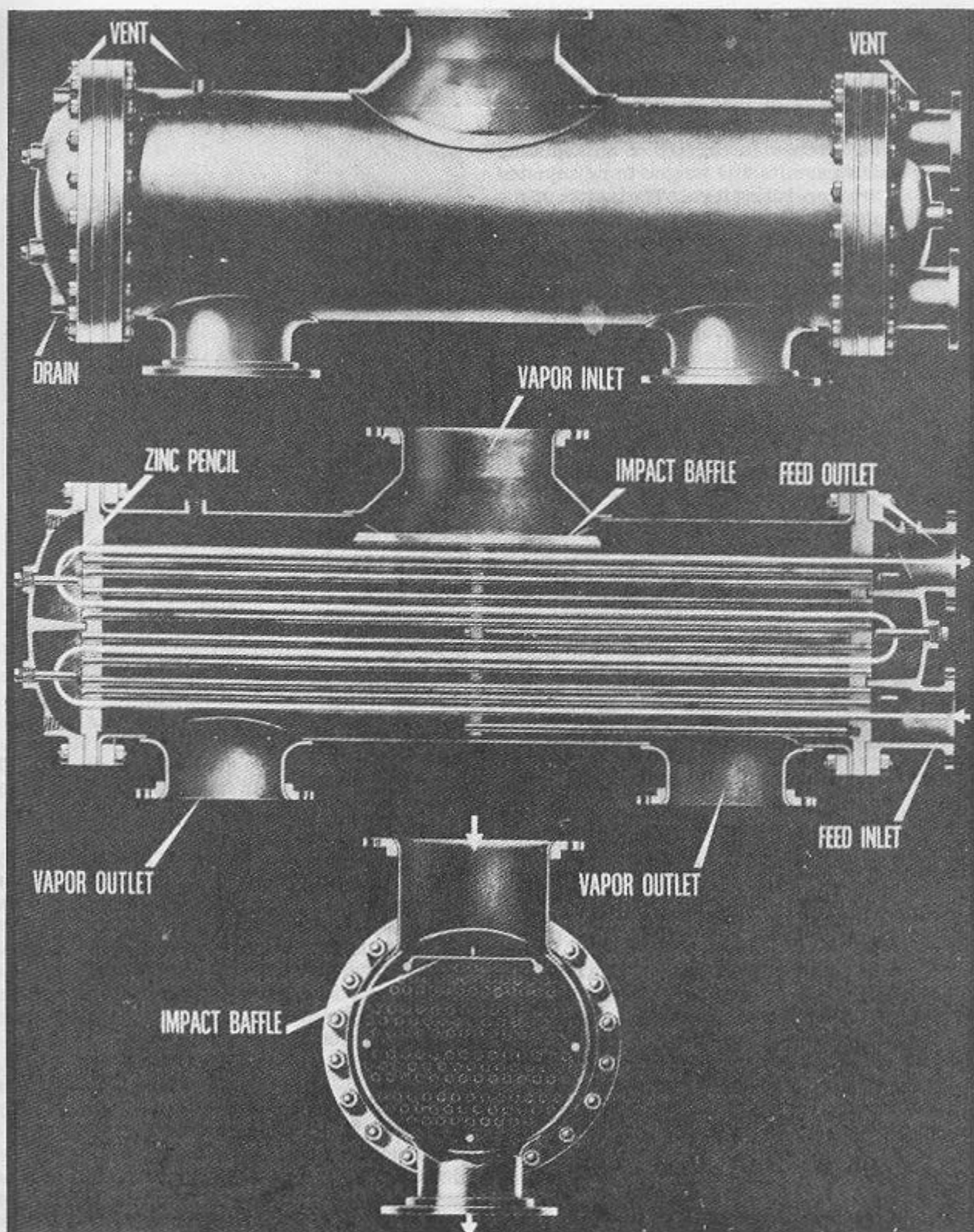


Figure 11-7.—Vapor feed heater.

weir type level controllers (fig. 11-8) are located in the brine discharge from each effect. The feed from each effect to the next is only the amount of brine that spills over the weir and is the excess of feed over evaporation in that effect.

The weir proper is carried on an adjusting screw which permits the height to be adjusted to any desired operating level. The bottom of the weir chamber is water-sealed to prevent equalizing shell pressures.

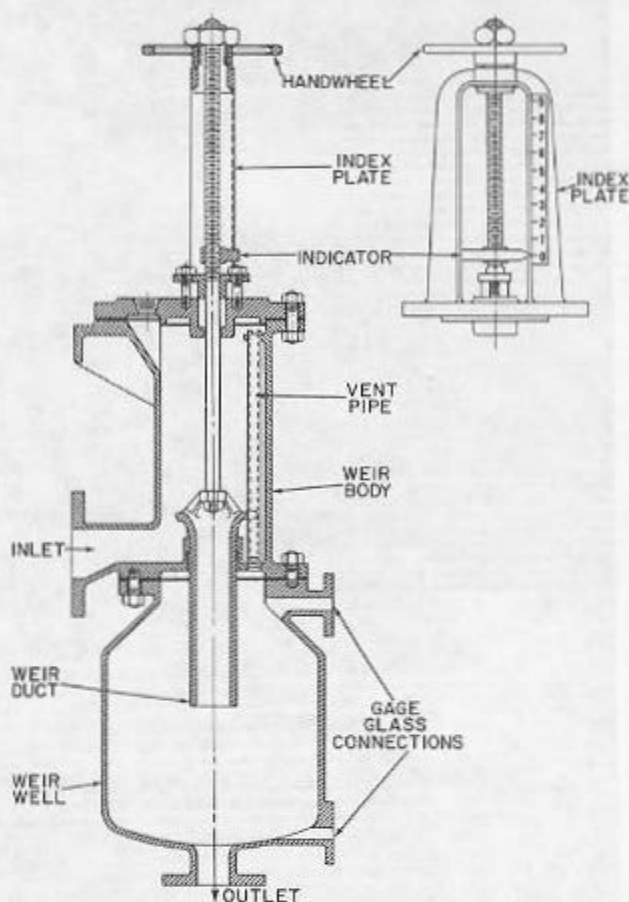
The level controllers consist of a chamber in parallel with the evaporator shell. A weir pipe within each evaporator shell discharges into a weir well. Feed water in excess of that which is evaporated spills over the weir pipe and into the weir well.

The internal weir pipe may be raised or lowered by the external handwheel. The weir well vents into the weir chamber by a pipe which also serves as a guide for the weir pipe. A gage glass is installed on the weir well.

FLOWRATOR.—Some distilling plants may be equipped with a flowrator or rotameter or some other visual flow indicator in the evaporator feed line. Flowrators are calibrated in gallons per minute (gpm) and it is possible to set the rate-of-feed by adjusting a hand valve in the feed line. In order to maintain the proper brine density of 1.5 pounds of dissolved salt to 32 gallons of sea water (1.5/32) in the last-effect shell, three gallons of sea water must be fed into the distilling plant for each gallon of distilled water produced. The remaining two gallons of concentrated sea water (brine) are pumped overboard. The flowrator compares the amount of incoming feed against the amount of brine leaving the last effect, thus making it simple to keep the feed rate adjusted correctly.

SOLENOID-OPERATED DISTILLATE BY-PASS VALVE.—In later installations, a three-way solenoid trip valve is usually provided to divert the output to the bilge whenever the purity is unsatisfactory. The solenoid valve is tripped automatically whenever the salt content at the distillate cooler outlet exceeds 0.25 grains per gallon (gpg) or 0.065 equivalents per million (epm). When this occurs, the distillate continues to flow to the bilge and an alarm is sounded on the salinity indicator.

The solenoid valve is so wired that flow can be directed to the ship's tanks only when the



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Figure 11-8.—Weir type level controller.

solenoid is energized. An increase in salinity to more than 0.25 gpg (0.065 epm) deenergizes the solenoid and trips the valve to the bilge. This arrangement makes it impossible to reset the valve to discharge to the ship's tanks until the salinity is below 0.25 gpg (0.065 epm) and the solenoid is again energized. In the event of a power failure at the panel, the solenoid valve will trip and discharge to the bilge.

AIR EJECTOR.—The function of air ejectors is to remove the noncondensable gases, mainly air, which may leak or be discharged into condensers operating under a vacuum. The air ejector (fig. 11-9) is a comparatively simple mechanism consisting of a steam inlet and nozzle, an inlet for the saturated air from the condenser, and a diffuser tube.

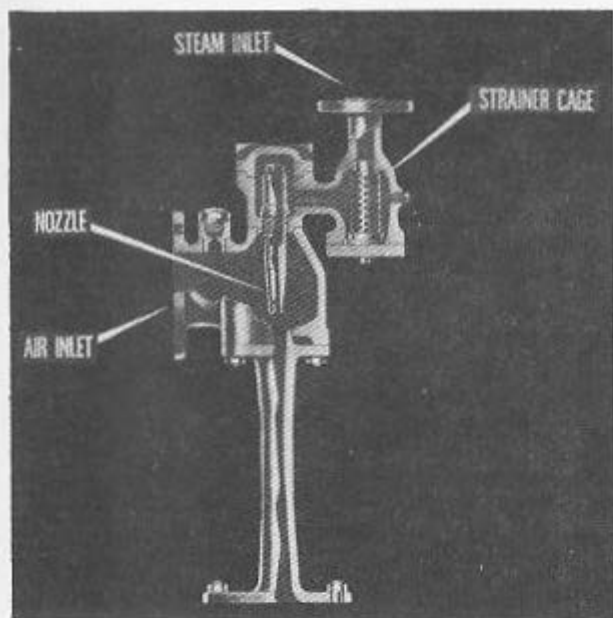


Figure 11-9.—Air ejector.

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Steam (125 to 150 pounds) is led to the air ejector and passes through the nozzle. The steam attains a high velocity as it passes from the nozzle. The high-velocity steam jet issuing from the nozzle creates a suction and draws in the saturated air from the distilling condenser. Two air ejectors are usually provided for each distilling plant; however, one unit is sufficient to operate the plant.

AIR EJECTOR CONDENSER.—The steam-air mixture discharged from the air ejector is normally condensed in a shell and tube type air ejector condenser (fig. 11-10). This is nothing more than a bank of tubes divided by a series of baffles and enclosed in a shell. The baffles ensure that the steam-air mixture passes over the entire cooling surface of the tubes before reaching the air vent. The steam is condensed and the resulting condensate is led into the low pressure drain system.

DISTILLATE COOLER.—The distillate cooler (fig. 11-11) is a tubular surface multipass heat exchanger. The fresh water (distillate) from the distilling condenser is drawn out by the distillate pump and discharged through the tubes of the distillate cooler. (Later units cir-

culate the sea water through the tubes and the distillate around the tubes.) From here the distillate is further drawn out by the fresh water pump. (Later units omit the fresh water pump.)

FLASH CHAMBER.—The flash chamber is essentially a receptacle within which the second-effect drains are reduced to a pressure and temperature corresponding to the distilling condenser vacuum. The flash chamber is attached or located on the third-effect side of the evaporator shell.

TUBE-NEST DRAIN REGULATOR.—A tube-nest drain regulator (fig. 11-12) is installed in the drain line from each evaporator tube nest. The drain regulator consists of a body and cover enclosing a balanced cage or rotary valve operated by a ball float. The drain regulator prevents the generator steam from blowing through the tube bundle in the first and second effects, and thus forces it to give up its latent heat of condensation in the tube nest.

PUMPS.—Distilling plant pumps are the constant speed, centrifugal, motor-driven type. No details on operation, construction, or maintenance are given here; information on centrifugal pumps may be found in chapter 9 of this training course and in BuShips Technical Manual, chapter 9470 (47). Distilling plant pumps should always be installed with a submergence equal to that specified on the nameplate or given by the manufacturer. The pump's speed and direction of rotation should be checked frequently and rechecked after any work is done on the pump or motor. For detailed information on any given unit, consult the manufacturer's technical manual.

OPERATION

This section deals with the operation of low pressure submerged tube plants. The large quantities of pure fresh water required aboard ship make it impossible to store sufficient water for more than a few days' supply. With proper operation and maintenance, submerged tube distilling plants can make adequate fresh water to supply the needs of the ship.

Careful starting, operating, and securing of distilling plants will, to a great extent, ensure trouble-free operation. Operating procedures and important maintenance factors are discussed in the sections which follow.

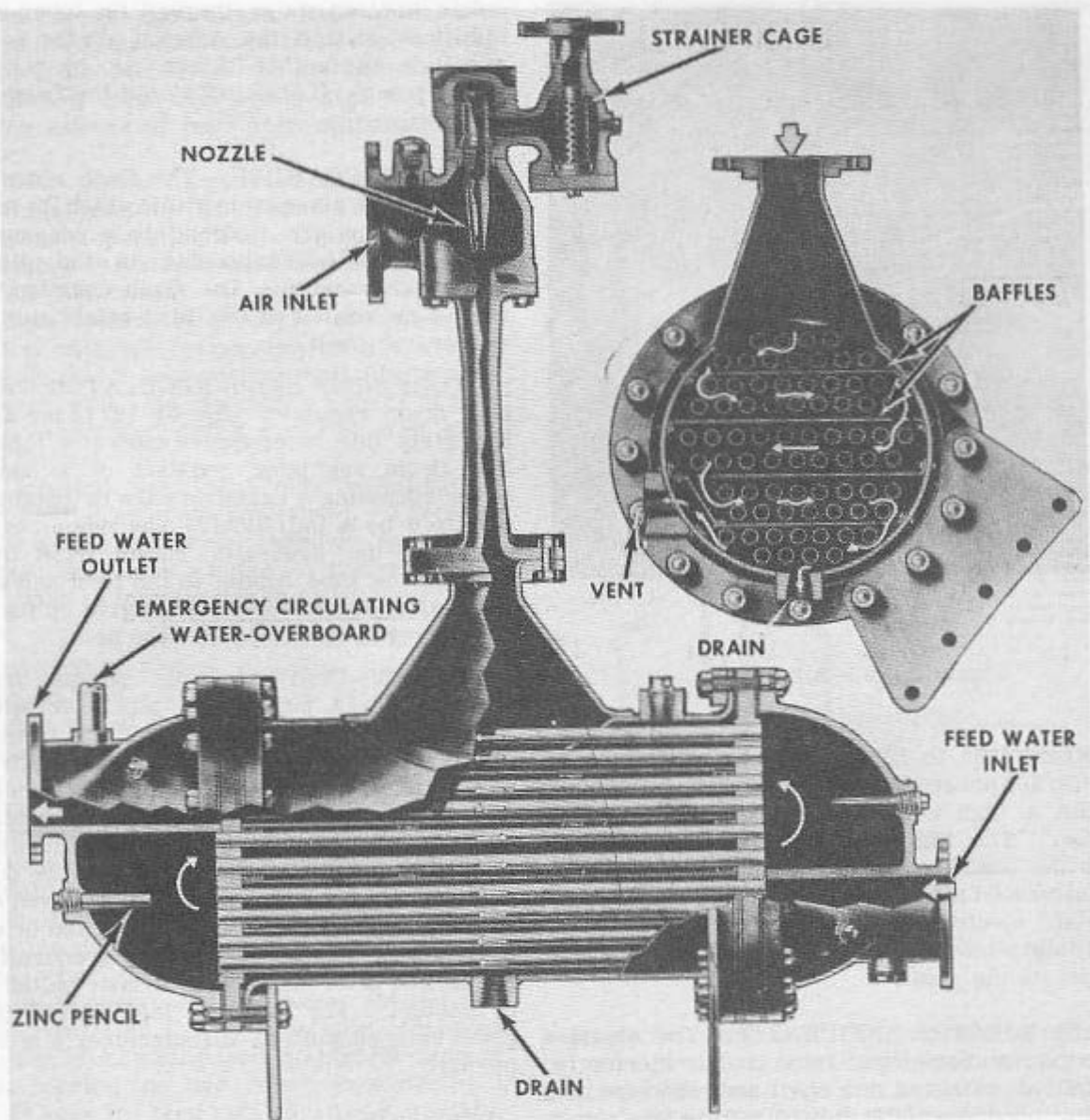


Figure 11-10.—Air ejector condenser.

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Starting a Manually Controlled Plant

To start a low pressure submerged tube distilling plant, when the evaporators are empty and all pumps are secured, the following procedure should be used:

1. Open all valves and air vents in the circulating water circuit from the sea suction to the overboard discharge, and start the circulating pump.

2. Adjust the spring-loaded back-pressure valve in the circulating water overboard line to maintain a pressure of 5 psig on the feed pump suction.

3. Open all valves in the evaporator feed system and the brine overboard line, except the brine pump discharge valve and the air ejector condenser emergency circulating water overboard valve.

4. Start the evaporator feed pump.

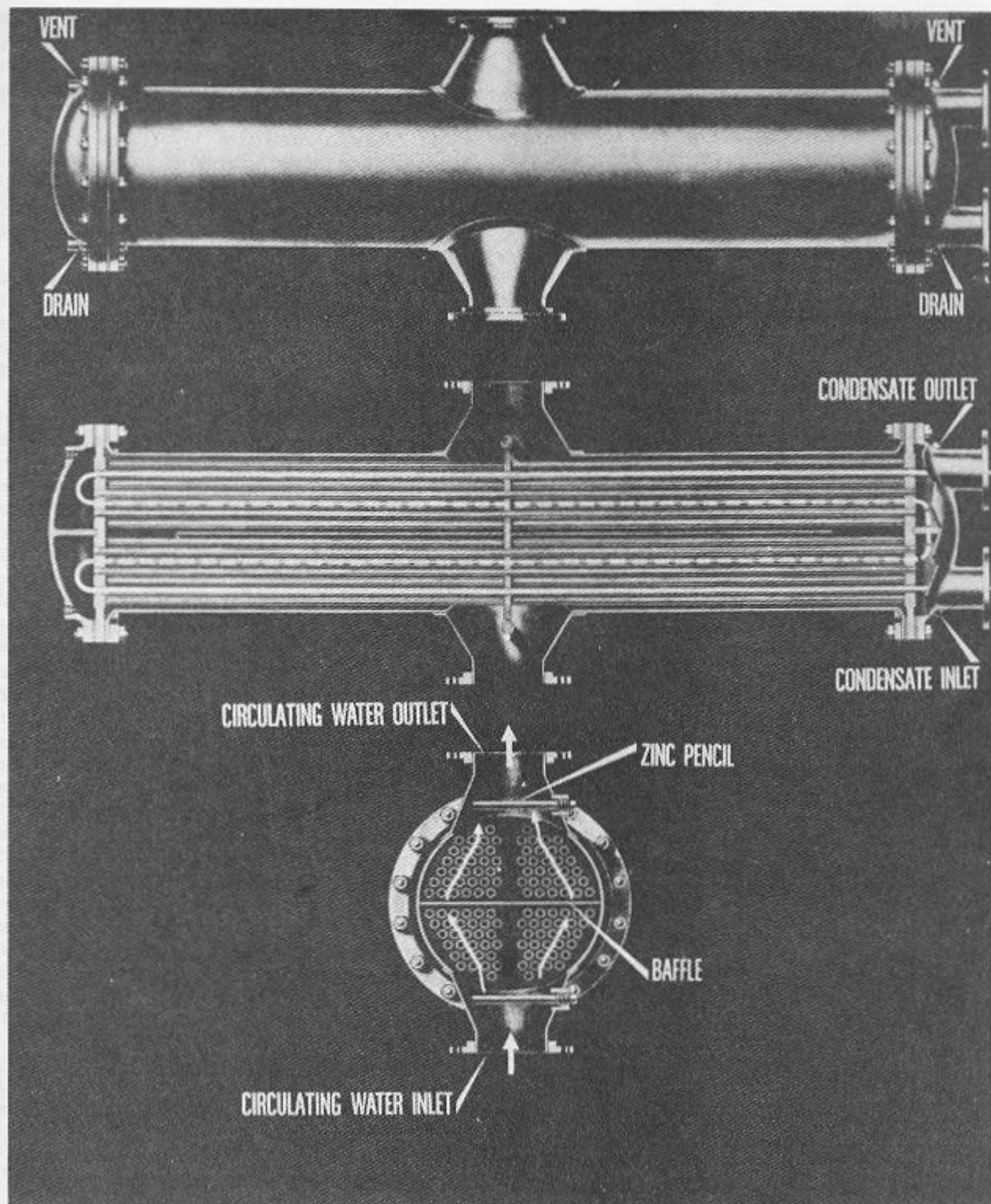
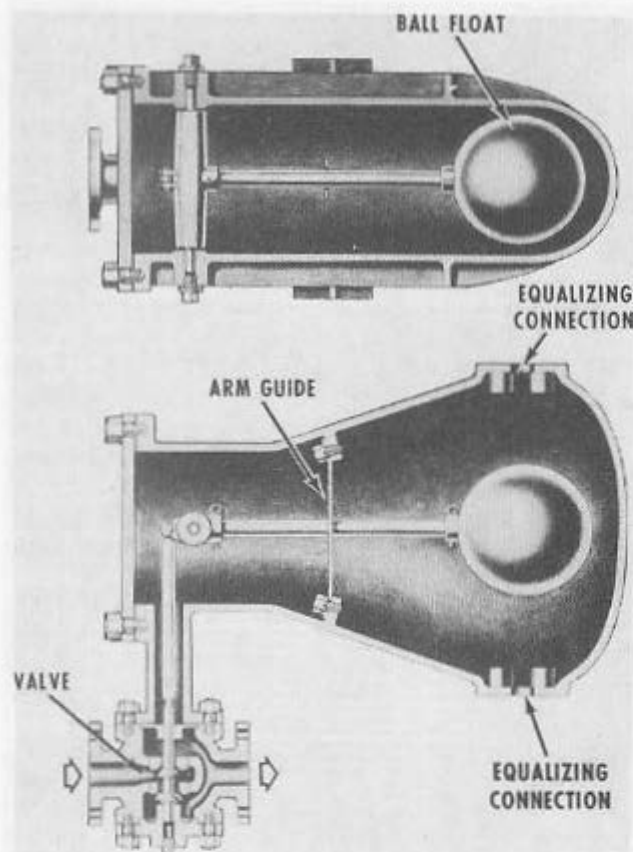


Figure 11-11.—Distillate cooler.

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Figure 11-12.—Tube-nest drain regulator.

5. When a water level of 10 to 13 inches appears in the second-effect shell, start the brine overboard pump, and crack open the discharge valve on this pump. The brine overboard valve at the ship's side and the valve in the suction to this pump should always be wide open during operation.

6. Open the valve in the emergency circulating water line from the air ejector condenser. Open the second-effect tube-nest vent valve wide; the first-effect tube-nest vent valve remains closed. Open the air ejector suction valve, then open the steam supply to the air ejector; be sure that the full pressure required is available at the nozzle and that the steam supply line is drained.

7. When the second-effect evaporator shell indicates about 16 inches of vacuum, partially open the first-effect steam valve. When condensate appears in the first-effect drain regulator, drain off some of the condensate and test it chemically. If the condensate is salty, discharge

it to the bilge until the salinity drops to 0.25 grains per gallon (gpg). If the condensate is acceptable, start the first-effect tube-nest drain pump and discharge to the deaerating feed tank.

8. When a distillate level appears in the second-effect drain regulator gage glass, open the discharge valve at the drain regulator and when distillate appears in the flash chamber gage glass, open the valve at the distillate pump suction.

9. Start the condensate pump and open all valves in the discharge line from this pump to the test tank. When water appears in the gage glass of the test tank, draw off some of the distillate and test it. If the distillate is not of sufficient purity, discharge to the bilges.

10. Open all the required valves in the fresh water system, except the fresh water pump discharge. Start the fresh water pump and regulate the discharge valve to maintain a desired level in the test tank. Open the water meter cutout valves and close the bypass valves around the water meter so production can be recorded.

11. As the output of the plant is gradually increased, the feed valves should be adjusted to the desired position. When sufficient feed water is flowing through the air ejector condenser, close off the emergency circulating water valve. The valves in all vent lines should be adjusted to their normal operating position. When the first-effect steam pressure and the second-effect vacuum both have attained their desired values, check the density of the brine pump discharge. Carefully manipulate the brine overboard control valve until the brine density reaches a value of 1.5 thirty-seconds.

12. If the flow of evaporator feed through the air ejector condenser is stopped temporarily, such as when correcting high feed level in the first-effect evaporator shell, vapor may discharge into the evaporator room through the air ejector condenser vent pipe. This condition may be remedied by slightly opening the valve in the overboard line from the feed outlet of the condenser to permit the circulation of water through the after condenser and overboard. This valve should not be opened more than is required in order to prevent an excessive amount of heated feed water being discharged overboard. When, for any reason, the salinity indicator indicates higher than 0.25 gpg (.065 epm), immediately shift the distillate to the bilges.

Securing a Manually Controlled Plant

The correct procedure for securing a manually controlled low pressure distilling plant begins by notifying the engineer officer of the watch that the evaporator plant is ready to be secured. When permission to secure has been received, the following procedure should be used:

1. Secure exhaust steam to the first-effect tube nest and the discharge from the first-effect tube-nest drain pump to the ship's condensate system. Open drain to the bilges.

2. Secure the tube-nest drain pump.

3. Secure the distillate pump.

4. Secure the fresh water pump.

5. Secure the inlet and discharge valves to the fresh water meter.

6. Secure the steam to the air ejector.

7. Close the first-effect tube-nest vent valve.

8. Allow the circulating pump, evaporator feed pump, and brine overboard pump to continue operating for a few minutes to cool the distilling plant.

9. Secure the brine overboard pump.

10. Secure all pumps, suction and discharge, making sure that evaporator tube bundles are fully covered with water.

11. Close the sea injection valve and the brine overboard valve at the ship's side.

12. Secure the inlet and outlet valves of the second-effect tube-nest drain regulator.

13. Secure the feed valves for each evaporator.

Starting an Automatically Controlled Plant

To start an automatically controlled low pressure distilling plant when the evaporators are empty and all pumps have been secured, the following procedures should be used:

1. Open wide all valves in the circulating water circuit from the sea suction to the overboard discharge.

2. Start the circulating pump. Pumps must not be run dry. Before starting any pump, see that the suction, vent, and gland seal valves (where provided) are open, and that the pump casing is full of water. On centrifugal pumps, it is preferable to leave the discharge valve closed until after the pump has been started.

3. Check to see that the spring-loaded back-pressure valve is properly adjusted to maintain 5 psi in the discharge line from the distilling condenser.

4. Open all air vent cocks on the distilling condenser, vapor feed heater, and air ejector condenser heads until the air is expelled, then close the vent cocks.

5. If evaporator bundles are submerged, see that the first-effect feed valve is closed and that the overflow weir pipes are set at their highest position. If the bundles are not submerged, see that the weirs are at their highest position, open the feed valves until the tube nests are fully covered, and then close the feed valves.

6. Open the valve in the emergency circulating water line from the air ejector condenser.

7. Open wide the second-effect evaporator tube-nest vent valve. The first-effect tube-nest vent valve should remain closed.

8. See that the first-effect tube nest and the air ejector condenser drains are directed only to the bilge, and not to the ship's tanks.

9. Open the air suction to the ejector. Open the steam supply to the ejector, making sure that the full pressure required (stamped on the nameplate) is available at the nozzle, and that the steam supply is properly drained.

10. Test the salinity of the air ejector condenser drain. When less than 0.25 gpg (0.065 epm), close the bilge drain and open the drain to the tank.

11. When the second-effect shell vacuum is about 16 inches, gradually open wide the first-effect tube-nest steam supply valve. Adjust the regulating valve to maintain a steady pressure of 5 psig. The last-effect shell vacuum should continue to increase to 26 inches or more.

12. When the distillate discharges from the first-effect drain line to the bilge, test for salinity. When satisfactory, close the bilge drain valve, set the drain valves to discharge the distillate to the return system, and open the first-effect tube-nest vent valve one full turn.

13. When distillate appears in the second-effect drainer, see that the drainer discharge valve is open, and then adjust the second-effect tube-nest vent valve to operating position (approximately one turn open).

14. When distillate appears in the flash chamber, be sure the distillate cooler discharge is directed to the bilge by manually tripping the solenoid-actuated valve. Then start the distillate pump. (The same point applies here as was given in 2, with reference to starting a pump.)

15. The following steps should now be performed in fairly rapid sequence:

- (a) Lower the overflow weir pipes to their operating positions.
- (b) Start the brine pump and open all valves in its discharge line.
- (c) If a loop seal of at least 8 feet has been provided in the feed line between effects, open wide the second-effect feed valve. Otherwise open it partially.
- (d) Close the emergency circulating water overboard line from the air ejector condenser and open the first-effect feed valve.

16. When the salinity of the distillate leaving the distillate cooler is less than 0.25 gpg (0.065 epm), set the solenoid valve to discharge to the ship's tanks.

17. Open and adjust the feed-treatment injection valve or pump, if feed treatment is to be done.

18. After the plant has been in operation about half an hour, check the density of the brine. If the density is more than 1.5 thirty-seconds, open wider the first-effect feed valves; if less than 1.5 thirty-seconds, close down on the valve. Repeat every half hour until two successive readings of 1.5 thirty-seconds are obtained. Then test at hourly intervals.

Securing an Automatically Controlled Plant

The correct procedure for securing an automatically controlled low pressure distilling plant begins by notifying the engineer officer of the watch that the evaporator plant is ready to be secured. When permission to secure has been received, the following procedure should be used:

1. Shut off the steam supply to the first-effect tube nest.
2. Close the first-effect tube-nest drain line to the return system, and open the drains to the bilge.
3. Close the first-effect tube-nest vent valve.
4. Close the air suction and steam supply valves to the air ejector.
5. Open wide the second-effect tube-nest vent valve.
6. Secure the distillate pump.
7. Raise the weir pipes, on both effects, to their highest positions and continue operation

of the circulating water pump and brine overboard pump for 10 minutes or longer to cool off the distilling plants.

8. Secure the brine overboard pump.

9. When both tube nests are fully covered with water, secure the circulating pump.

10. Secure the suction and overboard sea chests.

11. Secure the feed valve to the first effect.

12. Close the air ejector and condenser drain lines to the return system and open the drains to the bilge.

13. Trip the solenoid valve in the distillate lines to discharge to the bilge.

MAINTENANCE

The full output of a distilling plant can be maintained for relatively long periods without interruption only if every part of the plant is kept in proper operating condition. This can be accomplished by periodic tests, inspections, cleaning, and maintenance. No strict schedule can be set up but experience with a particular installation may indicate the frequency of testing, inspecting, cleaning, and maintenance required for the unit. The following are some of these maintenance procedures and the approximate frequency required.

Plant Output

Failure to obtain full rated capacity is one of the most frequent troubles encountered during operation of a distilling plant. The trouble may be very difficult to remedy since it may result from a combination of things. The various factors which promote full output of the distilling plant are as follows:

1. Proper steam pressure above the orifice.
2. Highest possible vacuum in the first-effect tube nest.
 - a. No air leaks.
 - b. Proper water levels in the evaporator shells.
 - c. Evaporator tube nests continuously vented.
 - d. Evaporator tube nests reasonably clean.
 - (1) Continuous feed treatment and periodic chill-shocking.
 - (2) Tubes mechanically cleaned when necessary.
 - e. Density of brine overboard not over 1.5/32.

- (1) Overboard piping reasonably clean.
- (2) Proper valve settings.
- (3) Proper operation of brine pump (clean piping and strainers, proper speed and direction of rotation, pump properly vented, gland properly packed and sealed, no air leaks in piping).
- f. Tube nests properly drained.
 - (1) Proper operation of all drain regulators.
 - (2) Proper operation of the tube nest drain pump.
- 3. Highest possible vacuum in the last-effect shell.
 - a. No air leaks.
 - b. Proper air ejector operation.
 - (1) Clean nozzle and strainer.
 - (2) Steam at the required quality and quantity.
 - c. Ample flow of circulating water.
 - (1) Clean strainer, pipeline, and tubes.
 - (2) Proper valve settings.
 - (3) Proper operation of the circulating pump.
 - d. Effective surface in the distilling condenser.
 - (1) No undue deposits inside the tubes.
 - (2) Proper venting of the condenser tubes.
 - (3) Proper operation of the condensate pump.

The preceding outline indicates the manner in which the listed factors affect not only another but also the overall performance and the output of the plant. The location of the factors in the outline does not necessarily indicate their relative importance. For example, improper operation of the condensate pump may affect the output directly (in addition to affecting the condenser vacuum), since undrained distillate will decrease the condensing surface in the distilling condenser, thus affecting the vacuum; or, in some plants, it may spill back into the last effect and be re-evaporated. Other factors which may affect the overall performance and the output of a submerged tube distilling plant are considered in the following paragraphs.

Evaporator Steam Supply

A distilling plant cannot maintain its full output unless it is supplied with dry steam at the designed pressure. The orifices supplied

are designed to pass the proper amount of steam to ensure designed plant output with a pressure of about 5 psig above the orifice. The orifice should be inspected annually. At this time the orifice should be measured and the reading compared with the figure stamped on the plate. If necessary, the orifice should be renewed.

If the steam pressure above the orifice varies, the source of trouble should be located and corrected. First the weight-loaded regulating valve should be checked, and then the pressure reducing valve (if installed), to determine whether or not the valve is operating properly. If they are functioning properly and the pressure cannot be maintained above the orifice, an insufficient amount of steam is being supplied to the plant.

The auxiliary exhaust steam supply for the distilling plants, after passing through the regulating valve, is usually slightly superheated, due to the pressure drop through the reducing valve and orifice plate. A small amount of superheat has little or no effect on operation or scale formation; however, if it is necessary to use live steam, the installed desuperheater spray connection should be used to control the superheat. The water for desuperheating must be taken from the boiler feed system, preferably from the first-effect tube nest drain pump, since this source provides water at the saturation temperature associated with the first effect pressure. Water for desuperheating must never be taken directly from the fresh water distilled by the distilling plant.

Fluctuations in the first effect generating steam pressure and temperature cause fluctuations of pressure and temperature throughout the entire plant. The fluctuations may cause priming, with increased salinity of the distillate, as well as erratic water levels in the shells. Proper operation of automatic pressure regulators in the steam supply line will eliminate fluctuation of the pressure in the first-effect heat exchanger.

First-Effect Tube Nest Vacuum

The pressure maintained in the first-effect tube nest must be within the range of from 16 inches of mercury, with clean tubes, to 1 to 2 inches of mercury. The output of a submerged tube distilling plant is not greatly reduced until the deposits on the tubes have caused the vacuum to drop to about atmospheric pressure. When the first-effect tube nest vacuum is lost entirely,

the reduction in output becomes very great. Assuming the reduction in vacuum is due to scale and not to improper operating conditions, the tubes must be cleaned.

Keeping the vacuum in the first-effect tube nest as high as possible helps keep scale formation to a minimum, enabling the plant to operate at full capacity.

A vacuum reduction resulting from any factor other than deposits on tube surfaces should be corrected. This will reduce deposits and greatly prolong the interval of time between cleanings. The primary factors affecting the first-effect tube nest vacuum are: air leakage, low water level in the evaporator shells, improper venting of the evaporator shells, scale or other deposits on the tubes, and improper draining of the evaporator tube nests.

Loss of vacuum resulting from deposits on evaporator tubes should be gradual. Under normal conditions, there will be no large change of vacuum for any one day's operation. A sudden drop in vacuum can be traced to causes other than scale deposits.

AIR LEAKAGE.—The generating steam circuit operates under vacuum and is subject to air leaks. Leaks from the steam side of the first-effect tube nest to the first-effect shell space will cause losses of capacity and economy. Air leaks from the atmosphere into the generating steam line (downstream from the orifice plate), the first-effect tube nest front header, and the first-effect tube nest drain piping will cause a loss of vacuum and capacity. Air leaks in this part of the distilling plant may be less noticeable than air or water leaks elsewhere because the effect on the plant is similar to the scaling of the tube surfaces.

The importance of eliminating air leaks cannot be overemphasized. Many distilling plant troubles are direct results of air leaks. Extreme care must be taken in making up joints and in keeping them tight. Joints should be periodically tested under pressure and, when necessary, shellacked.

There are several methods by which tests can be made for air leaks in the tube nests, heat exchangers, shells, and the piping systems of the distilling plant. When the plant is in operation, a candle flame or a soapsuds test can be used to test all joints and parts under vacuum. With the plant secured, air pressure tests can be used on the various component parts of the distilling plant. The manufacturer's technical

manual describes how the various parts of the plant can be isolated and placed under air pressure.

Air leakage may also be detected by hydrostatically testing the various parts of the plant. When performing air tests or hydrostatic tests, precautions should be taken not to exceed the maximum limit of the test pressures specified by the manufacturer.

WATER LEVELS IN EVAPORATOR SHELLS.—A reduced first-effect tube nest vacuum can result from too low a water level in any evaporator shell. On older plants, the water levels are controlled by manually regulating the feed valves. On newer ships, the water levels are automatically controlled by weir type feed regulators. Inability to feed the first effect is usually due to scale deposits in the sea-water sides of the air ejector condenser and the vapor feed heater, or to obstructions in the feed line. Inability to feed second or third effects is due to air leakage or heavy scale deposits in the feed lines between the effects. It is important that the gage glass and the gage glass fittings be kept free of scale or false water level indications will result. Air leaks around the gage glass will also result in false level indications in the gage glass.

Once the distilling plant is in operation, the feeding must be maintained at a steady rate. Sudden rising of the water levels or too high a water level will cause carry over of small particles of brine with the vapor (priming). The level of water in the shell must be carried at the highest level that can be held and still prevent the carrying over of salt water particles with the fresh water vapor or scale will form rapidly on exposed tube surfaces.

The pressure differential between the first and second effects permits the second-effect feed to be discharged into the second-effect shell. A partial or total loss of pressure differential indicates that air leaks have occurred between the first and second-effect shells in the two-effect distilling plants. Large air leaks between the first and second effects can be readily detected because the vacuum gage for the first effect will read approximately the same as the vacuum gage for the second effect. Large air leaks of this type will disrupt the operation of the plant and must be located and repaired before the plant will operate properly.

IMPROPER VENTING OF EVAPORATOR TUBE NESTS.—Improper venting of the evaporator tube nests causes either an accumulation of air in the tubes, with a loss of capacity, or an excessive loss of tube nest steam to the distilling condenser, with loss of economy. Troubles of this type usually result from improper operation rather than from material failures.

SCALE DEPOSITS ON EVAPORATOR TUBES.—When the first-effect tube-nest vacuum decreases, the evaporator output also decreases. Assuming the reduction in vacuum is due to scale, and is not the result of improper operating conditions, the evaporator tubes **MUST** be cleaned when the tube-nest vacuum approaches zero. To maintain adequate output the tubes **SHOULD** be cleaned when the first-effect tube-nest vacuum falls below 3 inches of mercury.

Salt water flows inside the distilling condenser tubes, air ejector condenser, and vapor feed heaters. Under some operating conditions, scale deposits may accumulate inside these tubes, particularly in the air ejector condenser and the first-effect feed heater. Every 6 months, or whenever the plant is secured for descaling evaporator tubes, the inside surfaces of these heat exchanger tubes should be inspected and cleaned if necessary. Neglect can lead to thick scale deposits which will be difficult to remove.

Scale Prevention.—Very little hard scale should form in a distilling plant using sea water for feed if: feed water distribution is proper, steam pressure above the orifice is not more than 5 psig, a high vacuum is maintained, and the density of the brine overboard is not over 1.5 thirty-seconds.

During normal operating conditions, scale deposits will form at a certain rate on the distilling plant evaporator tubes. The rate of scaling depends upon the concentration of suspended matter and carbonates present in the sea or fresh water used to feed the distilling plant. However, the important point to remember is that excessive scaling of the evaporator tubes can be caused by improper operation of the distilling plant.

The scale deposits increase as the density of the brine in the last-effect shell increases. The brine concentration is dependent mainly upon the quantity of brine pumped overboard and upon the amount of fresh water produced. If the brine concentration is too high, there will be an increase in the rate of scaling of

the evaporator tubes, and the quality of the distillate may be impaired.

To retard the formation of scale on evaporator tubes and to minimize priming, solutions are continuously injected into the evaporators.

A chemical compound known as HAGEVAP replaces cornstarch and boiler compound for the treatment of evaporator feed water and has been accepted as the Navy **STANDARD FEED TREATMENT COMPOUND**. Hagevap has proved to be superior because of its ability to prevent the formation of scale. The use of Hagevap increases the production of distilled water by decreasing the amount of time that plants must be shut down for cold shocking and scale removal.

Hagevap is composed of polyphosphates, lignins, and antifoam agents. The polyphosphates combine with the scale-forming particles in sea water, while the lignins keep the resulting solids dispersed and suspended. The antifoaming agents prevent foaming and help prevent scale.

Proportioning pump and tank assemblies, available from the ships parts supply segment of the naval supply system, consist of a 30-gallon mixing tank having a capacity of 24 gallons from top to bottom of the gage glass and a simplex or duplex proportioning pump having a maximum capacity of 2.5 gallons per hour per pump. Some assemblies may differ in the capacity of tank and/or pump. Installation instructions in the form of **SHIPALTS** have been issued for all classes of ships having low pressure submerged tube or vertical basket type distilling plants installed.

The required amount of Hagevap should be dissolved, by stirring, in a bucket of warm water at a temperature not to exceed 100°F. This concentrated solution is dumped into the 30-gallon mixing tank, enough cold water is added to dilute the solution to a total of 24 gallons, then the mixture should be stirred thoroughly to ensure a uniform solution. This mixing and dilution can be carried out while the pump continues to deliver Hagevap to the operating evaporator.

The simplex pump consists of one pump and one motor. The duplex pump consists of two pumps, driven by one motor, served by the same mixing tank. Duplex pumps may serve two distilling plants **ONLY** when the two plants have the same design distillate capacity and when these two distilling plants are located in the same compartment. In all other cases simplex pumps must be installed.

With either the simplex or duplex pump, the length of the stroke determines the pump capacity. The stroke is adjusted but is never set at less than 20 percent, as accuracy of the injection rate and lubrication of the pump plunger will be affected. If possible, the pump stroke (or strokes on a duplex pump) should be set to empty the mixing tank, from the top to the bottom of the gage glass, in exactly 24 hours. If this rate of injection should require a pump stroke of less than 20 percent, then the stroke should be set to empty the tank in less than 24 hours, preferably in 12 or 8 hours to enable easy establishment of a routine for refilling. However, if the time is 12 hours the solution will contain only half the amount of Hagevap required for a 24-hour period, and the tank must be filled twice a day. If the period of time for emptying the mixing tank is 8 hours, the solution will contain only 1/3 the required daily amount, and the tank must be filled three times each day.

If the pump stroke must be changed, the setting can be made from the indicator scale mounted on the crank arm, and verified by checking the amount of time required to empty the mixing tank. The indicator scale is calibrated from 0 to 10. If the pump has a maximum capacity of 7 gph, setting the indicator pointer on 5 will result in a delivery of 3 1/2 gph. To change the stroke, stop the pump and loosen the crankpin locknut. Watch the pointer on the indicator scale and turn the adjusting screw the required amount. Tighten the crankpin locknut and restart the pump. Check the time required to empty the tank and reset the pump stroke if necessary.

A vacuum drag injection line, used when the proportioner pump fails, runs from the mixing tank to a point downstream (vacuum side) of the feed control valve. A needle valve is installed in the line to allow the operator to make relatively fine adjustments in the amount of solution allowed to follow into the evaporator.

For submerged tube and basket type distilling plants, Hagevap should be injected into the evaporator feed system at a rate not to exceed 1 pound per 10,000 gallons per day distilling plant output. This rate of injection is required during the entire time the plant is in operation. A 4000-gpd plant requires 4/10 of a pound for a 24-hour period. Two 12,000-gpd plants require the same quantity as a 24,000-gpd plant, or 2.4 pounds per day.

The injection rate of 1 pound per 10,000 gallons per day is a maximum figure; the most effective figure will probably be closer to 3/4 pound. The best figure can be arrived at by reducing the amount of Hagevap for each batch. Each mixture should be tried for a week and if no scale is found on the evaporator tubes the amount of Hagevap can be reduced further. If scale forms during this trial, it will gradually crack off when the proper injection rate is established. The brine overboard density should always remain at 1.5 thirty-seconds as the density will influence the effectiveness of the Hagevap.

For flash type distilling plants, Hagevap feed treatment is not necessary for scale prevention in two-stage units; for units with more than two stages, however, this treatment has proven beneficial. In a 50,000-gpd flash type distilling plant, 6.0 pounds of Hagevap should be injected per 24-hour period.

The effectiveness of the Hagevap treatment can be checked by observing the shell steam temperature in the evaporator feed water heater. Changes in the shell temperature, with the same feed water flow, indicate changes in the resistance in the heat path between the steam and the feed water. Increases in the shell temperature indicate a buildup of either scale or Hagevap sludge; inspection will determine which.

At least weekly and more often if necessary, the solution left in the bottom of the mixing tank should be drained to the bilges and the tank flushed out with fresh water. Particularly in warm climates, the Hagevap solution will be affected by bacteria action forming a sludge or jellylike substance. This formation is harmless, insofar as the evaporator distillate is concerned, but it will affect the scale control performance of Hagevap treatment.

Scale Removal.—As previously stated in this chapter, the evaporator tubes of a submerged tube type unit MUST be cleaned when the first-effect tube-nest vacuum approaches zero. The vertical basket type unit should be cleaned when it becomes necessary to use a steam pressure of 4 psig, or more, in the first-effect steam chest, to produce rated capacity. The flash type unit will require cleaning when it becomes necessary to use a steam pressure of 4 psig in the evaporator feed water heater. Assuming these reductions in capacity are due to scale and not the results of improper operation, an approved cleaning method should be used to remove the scale. Some of the approved scale removal

methods are discussed in the paragraphs which follow. (NOTE: Chemical cleaning is the first choice; however, cold shocking will have to be used when facilities are not available for chemical cleaning.)

The first-effect tube nest, in which the temperature of the tube nest is near that of the steam supply, tends to scale up more quickly than other parts of the plant. To combat this scale, some method of CHILL SHOCKING (COLD SHOCKING) the tubes is generally provided. This is done by draining the brine from all shells, then reflooding them by means of a hose line connected to a flushing pipe or flooding connection on the shell. This reflooding chills the tube-nest bundles. Steam is then quickly admitted into the tubes, causing differential expansion and contraction to take place, which breaks the scale loose from the tubes.

If a feed treatment is not used, the distilling plant should be chill shocked daily. If the Navy standard feed treatment is used, chill shocking will not be required.

Chill shocking on a submerged tube type evaporator is performed as follows:

1. Secure the steam supply to the first-effect tube nest, the tube-nest drain pump and its discharge valve, the distillate pump, and the fresh water pump.

2. Open the emergency circulating water overboard valve at the outlet from the air ejector condenser and secure the first-effect feed valve.

3. Open wide all interstage feed valves. In plants which have shell drain or pump-out lines connected to the brine pump suction, unlock and open wide the valves in these lines.

4. Pump out the brine from all evaporator shells.

5. Connect a hose line to the flushing pipe or flooding connection.

6. Open the hose (water supply) valve to spray or flood the evaporator shells until the tubes in all evaporator shells are fully submerged.

7. Secure the hose valve and again pump out all evaporator shells.

8. Flood all shells again until the tubes in all shells are submerged. This second flooding is to lower the tube bundle temperature as much as possible. When the tubes are fully submerged, secure the hose valve and open quickly the steam supply valve to the first-effect tube nest. The flow of steam will be

restricted somewhat by the orifice, if installed, and should be increased by loading the weight-loaded regulating valve to produce not more than 10 psig pressure above the orifice. After the plant has warmed up, the pressure should be cut back to normal.

9. Start the pumps and regulate the water levels as necessary to put the plant in steady operation.

10. If the plant is one of the earlier installations which have chill shocking and spraying water supply from the fire and flushing main, disconnect the hose line from the flooding or flushing connection to protect the evaporator shells from possible excessive pressure. Such installations should be changed to utilize the distilling condenser circulating water pump discharge at the earliest opportunity.

After chill shocking, and about once a week, remove the handhole plates on the bottom of the evaporator shells and rake out the scale which has flaked off the tubes.

The capacity of a distilling plant is not appreciably reduced by scale deposits on the EVAPORATOR TUBES until the deposits have caused the first-effect vacuum to be reduced to 1 or 2 inches of mercury. When scale deposits cause the vacuum to approach zero, the tubes MUST be cleaned to keep the plant operating at its maximum efficiency. When the plant is properly operated and the feed water is treated, the interval between cleanings should be about 6 months. The evaporator tube nest must be withdrawn from the shell for the cleaning. Lifting gear suitable to the type of installation is usually provided to facilitate removing the tube nest.

Some submerged tube type evaporators or distilling plants are provided with an overhead trolley from which the tube nest may be suspended for cleaning. Another type is provided with tracks and roller brackets which bolt to the front head of the tube nest. Chain falls can be used to handle the tube nest in small installations.

When the tube nest is withdrawn beyond the support plate, the tube-nest stop should be bolted in place to prevent accidental dropping of the rear head. The tubes are cleaned with a light scaling tool operated by a light air hammer. It should be held against the tube with moderate pressure, and moved over the entire length of the tube. Every tube in the nest must be cleaned, as missing one will impair the output of the plant and also make cleaning more difficult in the future.

A torch should never be used for descaling a tube nest made up of straight tubes. The expansion and contraction caused by the heat may cause the tubes to loosen at their joints.

After cleaning the tubes, a hydrostatic test of 50 psi should be applied to the bundle before replacing it within the shell.

When the evaporator tubes are pulled for cleaning, the DISTILLING CONDENSER, AIR EJECTOR CONDENSER, and the VAPOR FEED HEATERS should be inspected and cleaned, if necessary. The distilling condenser on Soloshell plants must be removed for inspection and cleaning. On other types of plants the distilling condenser can be inspected and cleaned by removing the heads at both ends. The air ejector condensers on all plants can be cleaned by removing both heads. The vapor feed heater tubes on practically all designs must be removed for cleaning.

The cleaning of these tube nests is accomplished by means of an extended shank drill, driven by a reversible motor at 250 or 300 rpm, or by standard tube-cleaning equipment adapted for use with 5/8-inch outside diameter condenser tubes.

CHEMICAL CLEANING has proven to be faster, more economical, more effective, and less detrimental to evaporator parts than mechanical cleaning. In chemical cleaning, a heated, diluted acid solution is circulated through the salt water circuits of the system. The two acids most commonly used are hydrochloric and sulfamic. In using these acids which may be harmful to personnel, OBSERVE THE SAFETY PRECAUTIONS AND FOLLOW THE PROCEDURES LISTED in chapter 9580 (58) of BuShips Technical Manual.

Hydrochloric acid comes in liquid form and presents hazards in handling and storing. The use of hydrochloric acid is authorized ONLY when properly supervised by qualified naval shipyard personnel, never by ship's force alone.

Sulfamic acid comes in powdered form and is safe for storage aboard ship, when stored in the original containers. The use of sulfamic acid is authorized under the supervision of qualified tender or naval shipyard personnel. At the discretion of type commanders, individual ships may be authorized to carry sulfamic acid, and cleaning may be performed by qualified personnel in the ship's crew. Cleaning can be accomplished by passing 50-gallons slugs of solution through the feed and brine systems.

This should be done while the plant is in operation. A solution containing 50 gallons of sea or fresh water and 50 pounds of sulfamic acid powder can be injected into the distilling plant in two ways; by taking feed pump suction through a hose-valve assembly directly from a container of acid solution, or by using the plant vacuum to draw in the solution. Regardless of the method of injection used, the solution should be injected as rapidly as possible. The distilling plant should remain in operation so the solution will be heated as it passes through. The plant may be unbalanced by interruptions in flow but will settle down quickly when the feed water flow is again constant.

Careless handling of the acid solution can result in injury to personnel and equipment. The chemicals are harmful to the eyes and skin. If possible the chemicals should be handled by mechanical means rather than manually; protective clothing should be worn at all times during cleaning operations.

Chapter 9580 (58) of BuShips Technical Manual has a complete list of safety precautions and procedures which must be carefully followed when chemically cleaning distilling plant tubes.

Last-Effect Shell Vacuum

Most manufacturers' technical manuals indicate that a vacuum of approximately 26 inches of mercury should be obtained in the last-effect shell when the temperature of the sea water is 85° F, and that the vacuum should be higher when the sea water is colder. Failure to obtain a vacuum of 26 inches of mercury, or more, can generally be traced to one of the following factors: air leaks, improper operation of air ejectors, insufficient flow of sea water, and ineffective use of heat transfer surface in the distilling condenser (improper drainage).

PROPER OPERATION OF AIR EJECTORS.—In operation, air ejectors require little attention. However, the following points should be noted.

1. The steam pressure at the nozzle inlet must not be less than that for which the ejector is designed (and which is stamped on the nameplate). There may be a substantial pressure drop in the steam line, and it may be necessary to carry a higher pressure on the gage. Pressures at the air ejector nozzle may be 10 to 15 psig higher than the minimum specified by the manufacturer.

2. The primary causes of air ejector trouble are low steam pressure, wet steam, an obstructed nozzle, or a clogged steam strainer. Such trouble is indicated by failure to obtain or to maintain the required vacuum. If the trouble is due to low steam pressure or to wet steam, it will be necessary to increase the steam pressure or to provide suitable drainage, either by installing a trap or by manual means. If the nozzle or steam strainer is clogged, it must be removed and cleaned. Most plates are provided with two sets of air ejectors; this permits the use of the plant on one unit while the second is available for cleaning or repair. However, some of the latest plants have only one set of air ejectors.

When it becomes necessary to clean air ejector nozzles, they can be cleaned with the special nozzle reamers furnished each ship for this purpose. Sharp-edged tools should never be used for cleaning nozzles. The nozzle surfaces will be damaged and the efficiency of the air ejectors will be impaired.

A procedure for testing air ejectors can be found in the manufacturer's technical manual. In general, the same maintenance procedures should be followed for distilling plant air ejectors as for air ejectors for main condensers.

The air ejector strainer is usually an integral part of the air ejector inlet. It should be inspected regularly and cleaned when necessary. When a new plant is first put into operation, the strainer may require cleaning every day or even more frequently, but once the lines have been thoroughly cleaned, monthly inspections should be adequate. Failure to keep the strainer clean will cause a reduced or fluctuating vacuum. In the event a strainer or a nozzle becomes damaged, it should always be replaced with a new one.

INSUFFICIENT CIRCULATING WATER.—An insufficient flow of circulating water is indicated if the temperature of the water rises more than 20° F in passing through the condensing section of the distilling condenser. The last-effect shell pressure is directly dependent upon the distilling condenser vacuum. The vacuum is dependent upon the temperature and quantity of the circulating water, and the proper operation of the air ejectors. Too low an overboard discharge temperature of the distilling condenser circulating water is accompanied by efficiency losses in the

distilling plant. The overboard discharge temperature should be kept as high as possible, without exceeding the desired 20° F temperature rise through the distilling condenser. In addition, limiting the quantity of circulating water tends to prolong the service life of the tubes and tube sheets. When troubles occur which do not result from improper operating procedures, an inspection should be made of the condenser circulating water system to determine the cause of faulty operation.

Routine preventive maintenance procedures should be carried out to ensure that the circulating water pump is maintained in good material condition. The maintenance and repair procedures for this pump are similar to those for the other pumps of the plant.

Routine procedures should be carried out to ensure the proper setting and maintenance of the back-pressure regulating valve. If this valve is not functioning properly, the valve should be disassembled, the valve parts replaced, and repairs to the valve made (as found necessary), before its faulty operation interferes with the operation of the distilling plant.

To ensure that the condenser circulating water system is clean and free from scale and foreign matter, the piping should be inspected at regular intervals. The operators of the distilling plant should periodically inspect and clean the strainers to prevent accumulations of foreign matter from interfering with the proper operation of the plant.

IMPROPER DRAINAGE.—Failure of the distilling plant to produce designed output when the pressure above the orifice is 5 psig and the first-effect tube nest vacuum is several inches of mercury always indicates improper drainage of the distilling condenser or of one of the evaporator tube nests subsequent to the first effect. Complete flooding of the flash chamber gage glass is also a positive indication of improper draining of the condenser, but the fact that the level appears to be in the gage glass or below, is not necessarily an indication of improper drainage because air leaks at the gage glass fittings may indicate a false liquid level.

A temperature difference of more than 5° F to 10° F between the last-effect shell temperature and the temperature of the distillate at the distillate cooler inlet is another indication of improper drainage; however, the fact that the temperature difference is within the proper

range does not necessarily indicate proper drainage.

Scale deposits are unlikely to form in the distilling condenser tubes if the plant is properly operated and a full flow of circulating water is maintained. However, if scale deposits do occur, the tubes must be cleaned.

Venting of the vapor side of the distilling condenser is continuously accomplished by the air ejector. Venting of the salt water side of this and other units of the distilling plant need not be continuous. While starting the plant and once every watch thereafter, the vents on all salt water heads should be opened until all air is expelled and a solid stream of water appears, then the vents should be closed.

Testing for Salt Water Leaks

If a leak is detected in a heat exchanger, the defective tube(s) should be located by means of an air test or a hydrostatic test, in accordance with the recommended procedure in the manufacturer's instructions. Blueprints should also be used to study the construction details of the individual heat exchanger.

As soon as a leaky tube has been located, it should be plugged at both ends. Special composition plugs, which are provided in the allowance of repair parts, should be used.

Since plugging the tubes reduces the amount of heating surface, the heat exchanger will fail to give satisfactory performance after a number of tubes have been plugged. It will then become necessary to retube the heat exchanger. Under normal conditions, this work should be accomplished by a naval shipyard or tender. However, repair parts and a number of special tools are included in the Ship's Allowance List, so that emergency repairs can be made to the heat exchangers and to other parts of the distilling plant.

To find which of the tubes within a REMOVABLE TUBE BUNDLE is leaking, it is necessary to test the individual bundles hydrostatically. If the leak is in a removable bundle (vapor feed heaters when within an evaporator shell, evaporator tube nests, distilling condensers on Soloshell end-pull plants), the bundle must be withdrawn and a hydrostatic test at full pressure (50 psi) must be applied on the tube side.

If a leak occurs in a NONREMOVABLE TUBE BUNDLE (distillate coolers, air ejector condenser, external vapor feed heaters), the tube

nest covers must be removed, and the full test pressure (50 psi) applied on the shell side of the unit.

If a nonremovable distillate condenser bundle is within an evaporator shell, the tube nest covers must be removed and a full test pressure of 30 psi should be applied to the evaporator shell.

If the distilling condenser is fitted with a diaphragm-tube (Goubert) expansion joint, a test ring will be required to replace the tube nest cover for testing.

Constant Brine Density

The concentration of brine in the evaporators, to a certain extent, has a direct bearing on the quality of the distillate, and since varying quantities of brine discharged overboard may affect the operating conditions, the quantity of brine discharged and the brine density must be kept as constant as possible.

If the brine concentration is too low, there will be a loss in capacity and economy. If the brine concentration is too high, there will be an increase in the rate of scaling of the evaporator heating surfaces, and the quality of the distillate will be impaired.

The brine density (which should never exceed 1.5/32) is dependent mainly on the quantity of brine pumped overboard and the amount of fresh water being produced. The density must be checked frequently during each watch (usually at intervals of 1 hour) and adjusted to the required density. On older distilling plants the brine density is adjusted by means of a hand-controlled valve located in the discharge line of the brine overboard pump. In plants equipped with weir control valves and in basket type plants, the brine density is controlled by adjusting the first-effect feed valve. Increasing the rate of feed decreases the brine density, and decreasing the rate of feed increases the brine density.

Frequent changes of brine density have a tendency to disrupt steady performance of the plant, therefore, only very small changes should be made. The proper setting for a specific plant should be maintained in accordance with manufacturer's instructions.

Use of the Salinometer

The salinometer is an instrument (on the principle of a float) for measuring the degree of salinity or the concentration of the brine (pounds of dissolved salts to 32 gallons of sea water). It is a hollow, metal vessel weighted at

the bottom, and having a projecting stem which is graduated in four scales to read the salinity for various temperatures of the brine. The graduations are marked in thirty-seconds, as shown in figure 11-13. When the salinity of a sample of brine is to be measured, the temperature of the sample should be brought to a temperature corresponding to that of one of the scales on the instrument in order that an accurate reading may be obtained. The accuracy of the salinometer should be checked occasionally by placing it in distilled water; if it is accurate, it should sink to the zero mark on the scale corresponding to the temperature of the water.

A pot is provided for holding the sample of brine. The pot must be amply deep so that there is no danger of breaking the bottom of the salinometer when it is placed in the pot. To use the salinometer proceed as follows:

1. Draw off a sample of brine, from the test cocks on the discharge side of the brine pump, then insert the thermometer into the sample.

2. Allow the sample to cool to the temperature of one of the scale temperatures.

3. Put the salinometer in the pot and read the degree of salinity.

4. Remove the salinometer and wipe off all moisture since accumulations of salt or dirt will result in false readings.

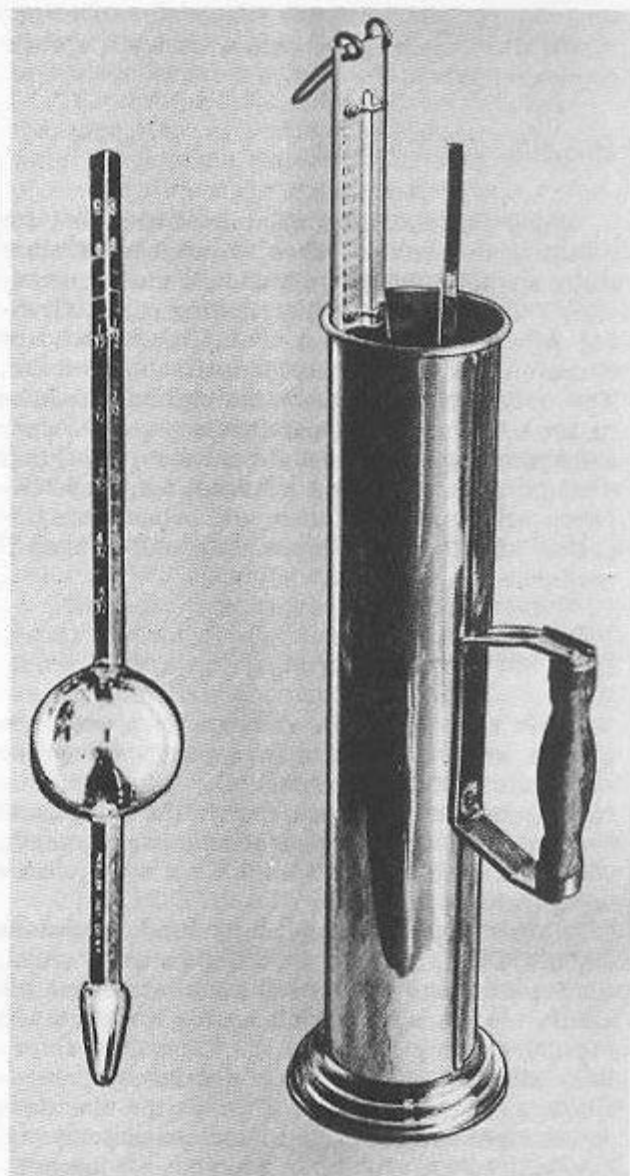
CARE AND MAINTENANCE OF DISTILLING PLANTS (GENERAL)

The care of strainers, miscellaneous cleaning of parts, inspection of zincs, and troubleshooting are factors which should not be overlooked in maintaining all types of distilling plants. These factors are discussed in the paragraphs which follow.

Care of Strainers

Quick-opening, flanged, basket type strainers are installed in the suction lines of the brine and circulating pumps, to prevent foreign matter from entering the pumps and piping systems of the distilling plant. The brine pump suction strainer should be inspected and cleaned when the plant is secured, and after any repairs that might cause scale to fall into the brine suction line.

The clogging of this strainer interferes with the operation of the pump, and, in a submerged



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Figure 11-13.—Salinometer and sampling pot.

tube distilling plant, makes it impossible to maintain the brine density at 1.5 thirty-seconds. A clogged strainer in a flash type plant will cause the last flash stage to flood.

The circulating pump suction strainer should be inspected about once a week when at sea, and more frequently when in port. Even partial clogging of this strainer will result in a reduction in the flow of circulating water, which in turn causes a reduced vacuum. Scale will then

form more rapidly on the evaporator tubes and inside the vapor feed heater and air ejector condenser tubes.

Miscellaneous Cleaning

When the distilling plant is dismantled for cleaning evaporator tubes, a number of other parts should be inspected, and cleaned if necessary. The feed water distributing pipes, flushing pipes, and separate drain lines should be removed and any scale deposits cleaned out. The hooks and troughs on the baffles should be cleaned to ensure proper drainage. The upper and lower gage glass equalizer lines, gage glass fittings, gage and sight glasses, feed lines between effects, brine lines, and brine pump impeller should all be inspected, and cleaned if necessary.

Inspection of Zincs

Zinc rods or plates are usually provided in all the salt water units of a plant (except the evaporator shell) to reduce the effects of galvanic action on structural parts. The zinc should be inspected and cleaned about once a month. When a zinc is more than half corroded, a new one should be installed.

A new type of high-purity zinc, known as ANODE ZINC, is being installed on naval ships. Zinc protectors made of this material have the ability to slough off corrosion products as rapidly as they are formed. This characteristic allows the zinc to give continuous protection against galvanic action, since the zinc does not become encrusted with corrosion products.

Troubleshooting

When distilling plant troubles occur, the first step to take is to check the readings of the various thermometers and gages. These readings should be checked against the previous hourly reading entered in the operating record. As a rule, an erratic or abnormal reading will indicate trouble in one of the seven different circulating systems, or in a component part of the distilling plant. Using the manufacturer's technical manual and drawings as guides, note all possible troubles that may occur in the isolated system, or part, and those

that will produce the same abnormal readings. Each item on this list of probable troubles should then be checked by means of a detailed inspection. The items that involve the least amount of work, or dismantling, should be inspected first. This procedure of inspections and tests of individual units of a system, or the major parts of a distilling plant, should be continued until the cause of the trouble has been located.

There may be times when all component parts of a system under investigation will be in good condition. This may be confusing to inexperienced personnel. However, the trouble shooter should start again and recheck the probable causes of the trouble. With the additional knowledge gained from the inspections and tests that were made, the trouble shooter can reconsider the symptoms of the trouble. It is possible that troubles existing elsewhere in the system may cause similar results.

One of the most common troubles with distilling plants is a low output. In many cases, this type of trouble is the most difficult to locate because it depends upon various factors. In any attempt to locate the causes for low output, both the operational procedures and the material conditions must be carefully investigated. Low output may result either from an accumulation of troubles or from unsatisfactory conditions. In checking on the numerous possibilities which may cause a low output of the distilling plant, a systematic procedure should be followed. The investigation should not be stopped when one unsatisfactory condition is found, but continued until all possible troubles have been carefully checked. Continuous trouble with a low distilling plant output can usually be traced to inexperienced operating personnel and to inadequate preventive maintenance procedures.

FLASH TYPE DISTILLING PLANTS

Flash type distilling plants have become the standard for all the larger surface ship installations. These plants use low pressure steam and operate on the principle of evaporation followed by condensation. The flash type unit may have two or more stages. For example, CVA-62 is equipped with five-stage units, each having a capacity of 50,000 gallons per day. Two-stage units of 12,000 gallons per day are being installed on new destroyer type ships.

PRINCIPLES OF OPERATION

Each stage of a flash unit has a flash chamber, a feed box, a vapor separator, and a distilling condenser. There is also a two or three stage air ejector, distillate cooler, and a feed water heater. Feed water passes through the tubes of the distillate cooler, the distilling (stage) condensers, and the air ejector condenser. In each of these heat exchangers the feed water picks up heat and the final heating is done by low pressure steam admitted to the shell of the feed water heater. From this heater the feed water enters the first stage feed box and comes out through orifices into the flash chamber. As the heated feed water enters the chamber, a portion flashes or vaporizes because the pressure in the chamber is lower than the saturation pressure corresponding to the temperature of the hot feed. This vapor condenses on the tubes of the first-stage distilling condenser. The feed which does not vaporize in the first chamber passes to the second chamber. The process is repeated in each stage and the brine remaining in the last stage is removed by the brine overboard pump. Vapor formed in each stage passes through a vapor separator and into the stage condenser where it is condensed to distillate. The distillate passes through a loop seal on its way to the condenser of the next stage. The distillate pump removes the distillate from the last stage.

PRINCIPAL PARTS

The unit discussed in this section is a five-stage plant in which feed water is flashed to vapor in five evaporator stages at successively lower pressures. The flash unit, shown in figure 11-14, consists of five evaporator-condenser stages in a single enclosure. Within each stage sea water is evaporated and condensed in a vacuum.

Connections, or passages, that exist between evaporator stages are the feed water and distillate loop seals, which permit the flow of feed water and distillate from stage to stage while preserving the varying degrees of vacuum in each stage.

The condensers are mounted on top of each stage between the front and rear water boxes. Feed water flows through the tubes in six passes, entering at the lowest tubes at the front of the condenser, reversing direction at the water boxes three times and leaving at the

top of the tubes in the condenser. Each condenser has a pet cock for venting entrained air or noncondensable gases.

The evaporator stages become larger in the direction of reduced pressure. The feed water loop seals which extend from the bottom of evaporator stage one through four are visible as cylinders. An evaporator drain is located in the center of the dished bottom of each loop seal. The flanged brine outlet from the evaporator is at the bottom of the fifth stage.

The distillate loop seal between the distillate collection trough of one stage and the condensers of the following stages also protrude below the bottom of the evaporator.

If the salinity of the distillate reaches .065 EPM per gallon a warning device indicates the high salinity. The salinity cell shutoff valves permit withdrawal and descaling of the salinity cells without securing the unit.

Although each stage condenser produces an equal amount of distillate, the amount flowing from each stage is larger than the preceding, as the distillate accumulates in its flow toward the distillate cooler. Consequently, the loop seal piping grows progressively larger.

The total distillate production of the five stages is withdrawn from the bottom of stage five and pumped into the shell of the distillate cooler, and on to the storage tanks.

THE DISTILLATE COOLER is a heat exchanger of the shell and tube type, in which the heat of the hot distillate flowing around the tubes is transferred by conduction to the cooler feed water flowing through the tubes.

Distillate flows into the shell space surrounding the tubes through an inlet near the feed water outlet. The distillate is retained in the cooler long enough to efficiently transfer its heat through the tubes by vertically placed baffles, as it flows from top to bottom of the cooler.

Thermometers are mounted on the inlet and outlet piping of the cooler. Another thermometer is mounted on the feed water inlet piping.

As the distillate leaves the cooler it is pumped to storage tanks, providing the salinity does not exceed .065 epm per gallon. (If the salinity exceeds .065 epm per gallon, a solenoid trip valve operated by a salinity indicating cell, dumps the distillate to the bilges or waste tank until the salinity is again back to or below .065 epm per gallon.)

Pet cocks are located on each end of the cooler so as to bleed off any accumulation of air or noncondensable gases.

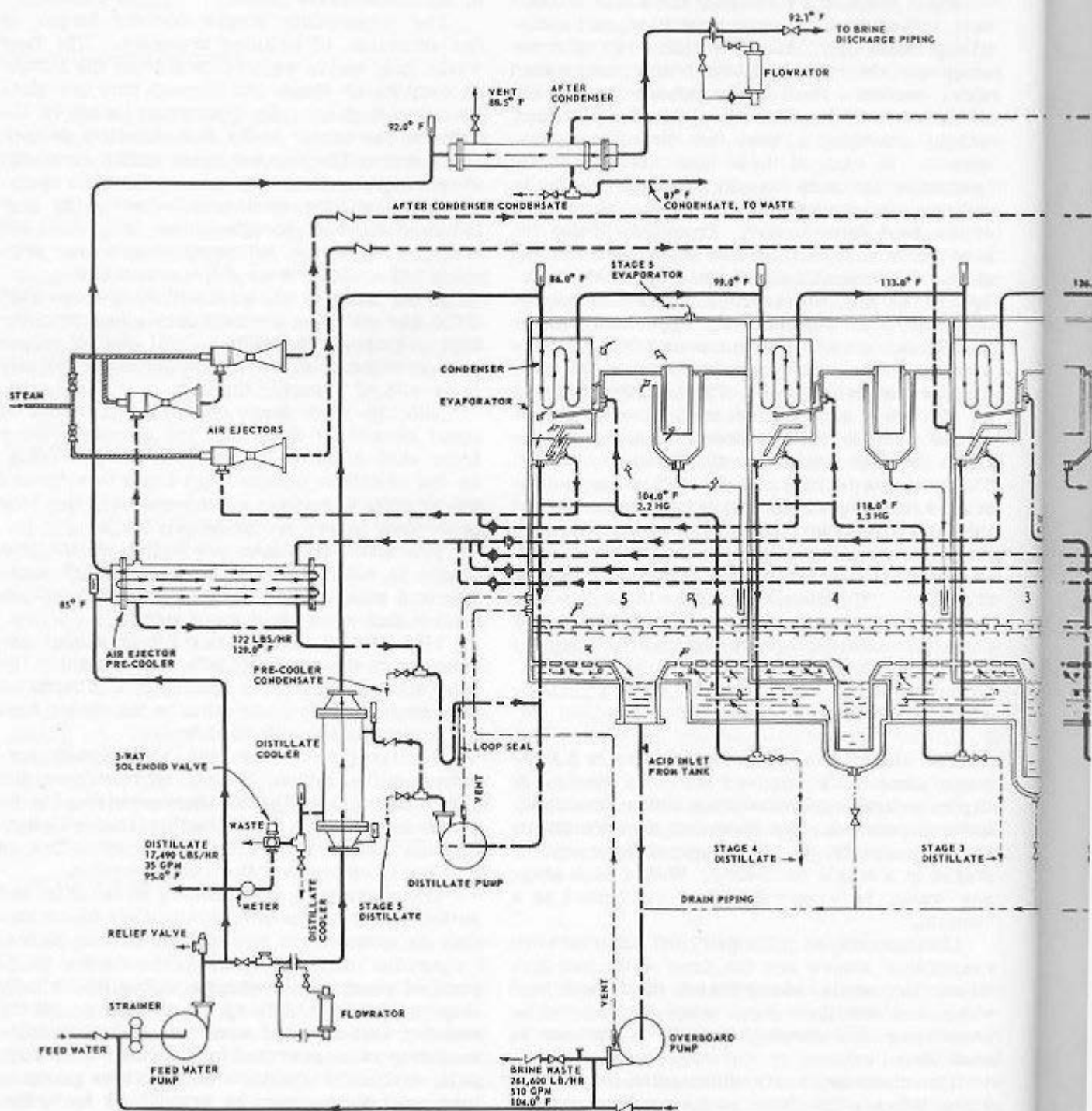


Figure 11-14.—Flow diagram for a five-stage flash type distilling unit.

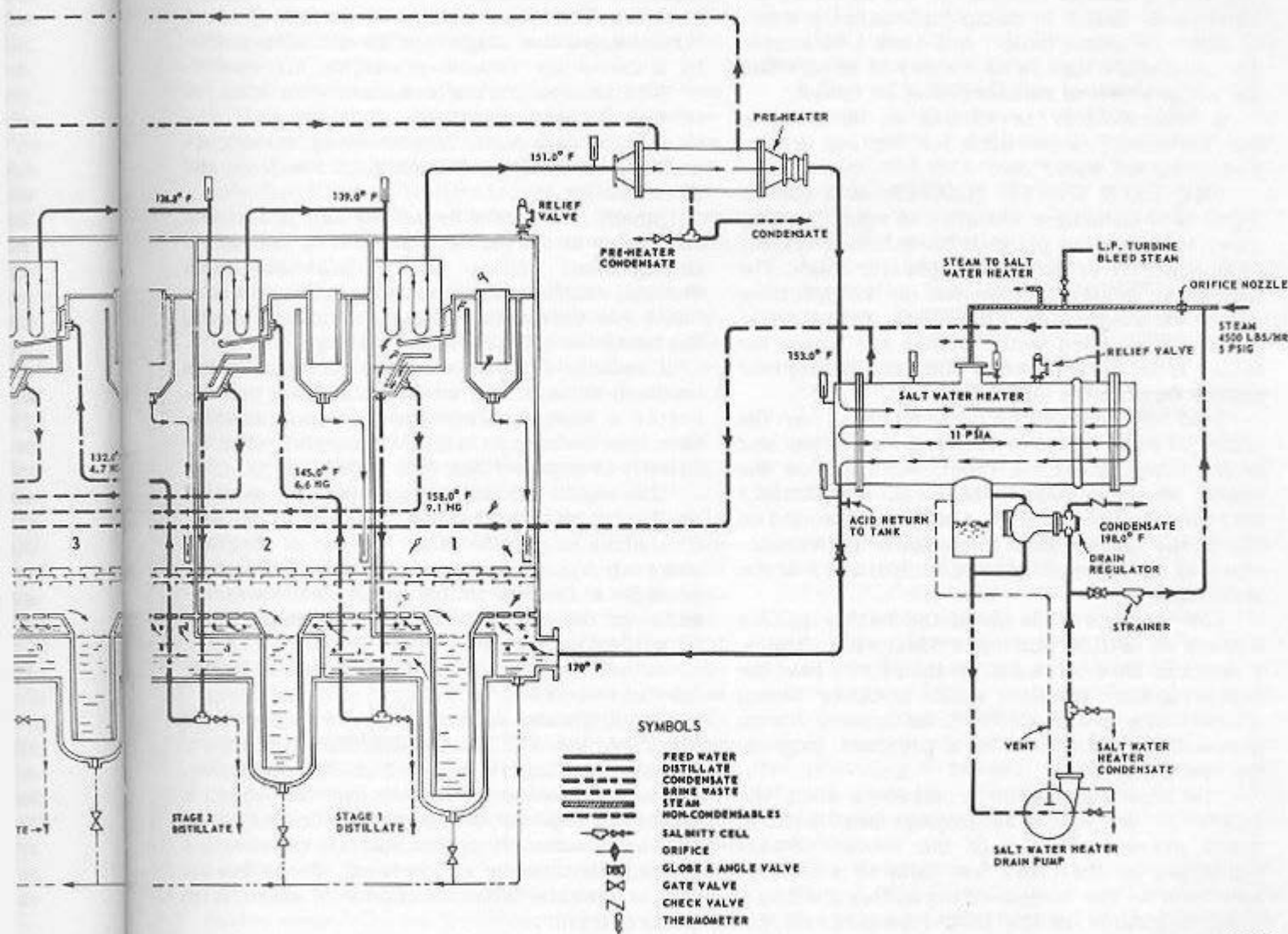


Figure 11-14.— Flow diagram for a five-stage flash type distilling unit—continued.

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THE FEEDWATER PREHEATER is a gas or liquid heat exchanger of the shell and tube type, similar in design to the distillate cooler. The preheater is located in the feed water line between the condenser of the first evaporator stage and the salt water heater (fig. 11-14).

High pressure ship's steam, first used by the air ejectors to evacuate the stage evapora-

tors, is piped into the preheater shell. A series of five baffles, spaced close together in the top steam outlet reduces the velocity of the steam which condenses on the outside of the heat transfer tubes.

Feed water that has already been partially heated in the tubes of the distillate cooler and the five-stage condensers flows through the

tubes of the preheater via the front water box in a single pass, acquiring the heat of condensation of the air ejector steam before leaving the preheater at the rear water box outlet.

A salinity cell, set to energize at 0.10 epm operates a shutoff valve in the piping below the condensate outlet to dump high salinity water to bilge or drain tank. A 6-inch loop seal in the condensate line is necessary to ensure that the salinity cell is submerged at all times.

A thermometer is located on the front of the preheater, a pet cock for venting is also located on the water box.

THE SALT WATER HEATER is a gas or liquid heat exchanger designed to raise the feed water temperature prior to its entrance into the flash chamber of the first evaporator stage. The salt water heater is mounted on the operating end of the evaporator and extends the full width of the unit. Feed water enters and leaves the heater from the front water box after making four passes through the heater.

Four thermometers are installed on the heater, two to measure the feed water inlet and outlet temperature; a third, mounted on the heater shell to measure the steam temperature surrounding the tubes; a fourth is mounted on top of the heater shell to measure the temperature of the desuperheating temperature in the steam side.

Low pressure steam in the heater passes through an orifice which provides, within limits, a uniform flow of steam. It then flows past the desuperheater nozzle, which reduces steam temperature in the shell of the heater. Steam pressure is indicated by a pressure gage on the operating panel.

The entering steam is directed along the length of the tubes by impingement baffles, which prevent erosion of the tubes. Steam condenses on the tubes and falls to a condensate well at the bottom of the heater shell. (A drain regulator of the float-type controls the level of the condensate in the well. A salinity cell, set to energize at 0.10 epm controls a shutoff valve located in the ship's piping between the drain pump and regulating valve.) The desuperheater atomizes the heater condensate in the low pressure steam side of the heater.

Since the function of the salt water heater is to provide feedwater to the inlet of the first evaporator stage flash chamber and the amount of heat from the steam is constant, the feed

water flow through the heater must be adjusted according to the inlet temperature so the feed water temperature may be constant. The feed water flow is controlled by a valve on the outlet side of the heater.

The air ejector PRECOOLER is a gas or liquid heat exchanger which cools noncondensables and condenses steam drawn from the first three evaporator stages and the salt water heater by a two-stage vacuum-producing air ejector.

The precooler receives its coolant from the feed water pumped into the distilling unit. The flow is through heat transfer tubes, making six passes, entering and leaving at the front end of the cooler.

Steam and noncondensables are drawn into the cooler at the top near the rear of the cooler. Impingement baffles at the inlet and seven vertical baffles through which the transfer tubes run direct the flow of hot gases around the tubes for efficient heat transfer.

Condensate collects on the tubes and drops to the bottom of the shell. A salinity cell operates a shutoff valve in the precooler condensate line to dump to bilge or drain tank when the salinity is greater than 0.65 epm.

The outlet for noncondensables is mounted on the top of the shell and flanged to the suction chamber of the first ejector of the two-stage air ejector system. The two air ejectors produce a vacuum in the precooler which results in the flow steam and noncondensables from the evaporator.

A thermometer is mounted on the feed water inlet of the cooler.

Cooling water from the air ejector precooler flows into the AFTER-CONDENSER, the fifth of the heat exchangers mounted on the evaporator. The after-condenser completes the condensation of any air ejector steam not condensed in the precooler and cools noncondensable gases before venting them to the atmosphere. It enables the unit to operate without emission of steam from the evaporator.

Cooling water enters and leaves the after-condenser through an inlet pipe in the front, and an outlet pipe in the rear of the condenser.

Air ejector steam and noncondensable gases enter the shell side through an inlet in the front of the unit. Noncondensable gases are vented through a valve on the rear of the unit. A series of vertical baffles direct the steam around the tubes on which it condenses. Condensate is removed through bottom outlets on both ends of the condenser.

A salinity cell set to operate at 0.10 EPM controls a shutoff valve below the condenser.

Three high pressure steam-operated vacuum-producing AIR EJECTORS are mounted on the precool side of the evaporator unit. The ejector system consists of a single-stage (booster) air ejector and a two-stage air ejector arrangement in which the steam outlet from one air ejector is flanged to the suction side of the other.

The single-stage ejector uses ship's steam to draw vapor and noncondensables from evaporator stages four and five. Gases are drawn from the evaporator through a vapor duct in each distillate collection trough so that a minimum of steam is withdrawn. Pipes from stages 4 and 5 lead to a bronze tee flanged to the ejector.

The single-stage ejector steam and entrained gases leave the ejector outlet tubing, flow through a check valve, and reenter the evaporator shell through the top of stage three, from which they are piped into the bottom of the stage three condenser section.

The purpose of this arrangement is to enable the single-stage ejector to produce the high degree of vacuum required in stages four and five. An ejector discharging into a vacuum is able to achieve a higher degree of vacuum than one discharging to atmosphere. A vacuum of 28 inches of mercury is required in stage five.

The two-stage ejector draws noncondensables from the salt water heater and the first three evaporator stages. Since the noncondensables from stages four and five are directed back into stage three, the two-stage ejector, therefore, actually handles all noncondensables within the unit.

The suction chamber of the second ejector is flanged to the noncondensables outlet of the precool side through which the gases pass before entrainment in the air ejector steam. The two-stage ejectors use ship's steam and produce a vacuum in the precool side slightly greater than in the first evaporator stage.

Orifice plates of varying size are flanged into the piping from the evaporator stages and salt-water heater leading to the air ejectors. These plates prevent the air ejectors from withdrawing an undue amount of steam from the evaporator along with the noncondensables.

The discharge of the second ejector is flanged to the suction chamber of the third ejector. The discharge of the third ejector is flanged to piping, containing a check valve,

which runs diagonally across the top of the evaporator shell to the air ejector steam inlet of the preheater shell near the front water box.

The pressure of ship's steam piped to the ejectors is indicated on the independently mounted pressure-gage panel. Line pressure to the air ejectors must be maintained at or above 135 psig, as a lower pressure will cause unstable operation of the ejector and will affect the vacuum in the evaporator.

A DUPLEX STRAINER, located in the ship's feed water inlet piping, removes solid matter from sea water by filtering through one of two perforated and screened bronze baskets. Basket wells are located in the body or housing of the strainer on either side of the centrally located flanged inlet and outlet.

A lever handle between the wells directs the feedwater into the left-or right-hand well. When one basket becomes clogged, flow is switched to the other and the clogged basket should be removed and cleaned.

An inlet and outlet angle-type RELIEF VALVE is flanged into the feed water inlet between the feed water pump and the air ejector precool side. The valve is set to open at 75 psig to prevent pressure buildup from an obstruction in the feed water lines or accidental operation of the feed water pump with the feed water control valve closed.

Two FLOWRATORS are mounted on the unit to measure the amount of feed water and cooling water pumped into the system. Since the amount of fluid to be measured in both cooling and feed water lines is large, the flowrators are mounted in bypass piping arrangements, measuring a small portion of the actual main stream flow but providing a reading on the graduated scale of the cylinder for the entire flow. Main stream and range orifices are provided for each flowrator.

The flowrators serve as manometers. The pressure drop across the manometer is equal to the pressure drop created by the constriction of the main stream orifice. The range orifice at the inlet of the flowrator constricts the bypass flow so that a maximum main stream flow will register a maximum reading on the flowrator scale.

MAINTENANCE

Many maintenance procedures for a flash type distilling plant are similar to the maintenance procedures required for a submerged

tube plant. Both types of plants are subject to air leakage, salt water leakage, and malfunctioning of pumps and other auxiliary equipment. Some of the more important maintenance problems will be discussed in the following paragraphs.

Air Leakage

Since all parts of the distilling plant are designed to operate under a vacuum except the circulating, feed, and fresh water lines, extreme care must be taken to prevent leakage of air which might seriously interfere with the proper operation of the plant.

The brine overboard and distillate pumps take their suction from points of relatively high vacuum. Air leakage in the piping to these pumps is particularly objectionable and must be eliminated. A small amount of air entering these lines, even though it is insufficient to affect the distilling plant vacuum, may cause the pump to lose suction. Leaks in the lines to the pump suction gages must not be overlooked.

An 8 to 10 psig, low pressure hydrostatic test should be applied to the entire system at least once a month, and at any other time when there is an indication that air leakage may exist. The salt water circulating pump can be used to apply the pressure.

Pumps

Proper operation of all pumps is essential for the successful operation of the distilling plant. The effect of air leakage into the suction line of the pumps has been discussed in the preceding paragraph. Proper operation of the water sealed gland lines and proper maintenance of the glands themselves are necessary

for dependable operation of the pumps. General information on operation and maintenance of pumps may be found in chapter 9 of this publication; however, for details of any specific pump, consult the manufacturer's technical manual.

Salt Water Leakage

Salt water to distillate or salt water to condensate leaks at any of the various tube bundles will be immediately indicated by an alarm bell and a red light which shows at which cell a conductivity increase has occurred. The cells are located downstream from each tube bundle. Tube leaks usually result from damaged or corroded tubes or from improper expansion of tubes into tube sheets.

Faulty tubes may be sealed with plastic tube plugs or may be removed and replaced in accordance with standard Navy procedures, as given in chapter 9460 (46) of BuShips Technical Manual.

Cleaning Heat Exchangers

The tubes of the distillate cooler, air ejector condenser, and the stage condensers operate with comparatively cool salt water inside them and will seldom require cleaning. The sea water in the salt water heater is at a higher temperature and these tubes will occasionally require cleaning to remove the hard scale on the inside of the tubes. A special tool is furnished for this purpose; this cleaning tool is shown in figure 11-15.

The procedure for cleaning salt water heaters is as follows: Remove the waterheads. Insert the special cleaning tool in the tube and drive it with a 250 to 300 rpm motor. The

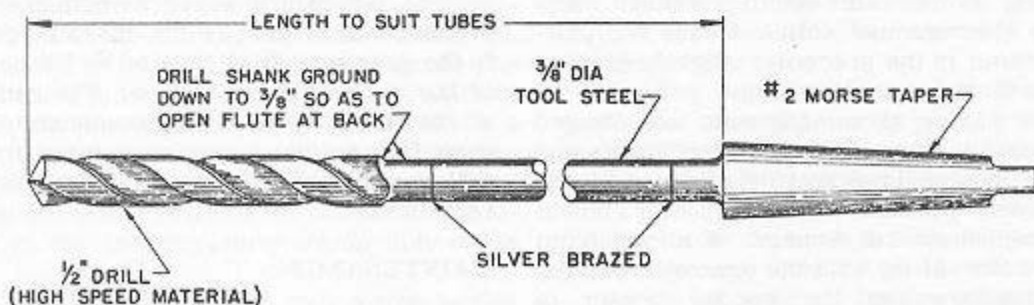


Figure 11-15.—Tool for removing scale inside tubes.

motor should be of the reversible type. Feed a light stream of water into the opposite end of the tube to wash the scale from the cutting tool and out of the tube. A light stream of compressed air may be substituted in place of the water. Care should be taken not to drive the tool too fast and to be certain that the tool is straight when inserted into the tube.

An 8 to 10 psig hydrostatic test should be performed on the shell of the salt water heater before replacing the heads. If a greater test pressure is used, the relief valve will have to be plugged or removed.

Cleaning Feed Boxes

If feed flow is below normal and the distiller feed pump discharge is normal, the first-stage flash orifices may be plugged. Fouling of the second-stage orifices may be evidenced by water backing up into the first stage; however, the second-stage orifices are larger and will not be as readily plugged. Water backing into the first stage may also be caused by insufficient pressure difference between the stages.

Since the temperatures that exist in the feed boxes are well below the range in which salt water scale forms, the only plugging or fouling expected at the orifices would come from the introduction of foreign matter into the system. Should the orifices in either stage become plugged, it will be necessary to remove the access plate at the front of the unit, remove the perforated plates from the feed box and remove the obstructing material from the orifices. The feed boxes are constructed so that the front can be readily removed for access to the orifices.

VERTICAL BASKET DISTILLING PLANTS

Vertical basket distilling plants are used on surface ships and nuclear submarines. The low pressure vertical basket type distilling plant (fig. 11-16) consists of single- or multi-effect evaporators with a condenser, vapor feed heaters, air ejectors and after condensers, and a distillate cooler. The notable difference between this type of distilling plant and the submerged-tube type is in the evaporators. The evaporator typically consists of a vertical shell enclosing a deeply corrugated vertical basket. (See fig. 11-17.) In very large units more than one basket may be installed per shell. Low pressure steam is admitted to the inside

of the first-effect basket and feed water is boiled in the space between the outside of the basket and the shell. The vapor formed from the boiling feed water passes through centrifugal-type vapor separators and the vapor feed heater into the inside of the second-effect basket. This boils the brine from the first-effect in addition to a certain amount of feed water in the space between the shell and the basket. The vapor thus formed passes through separators to the subsequent effects, or in the case of a two-effect plant, into the distiller condenser.

FLOW CIRCUITS

The flow circuits of a vertical basket distilling unit are illustrated schematically in figures 11-18, 11-19, and 11-20. Refer to these figures as you study the following descriptions of the flow circuits of the unit.

Steam Flow Circuit

Heating steam from the ship's auxiliary exhaust main is fed through a pressure-control valve to the steam chest of the first effect. The pressure-control valve is set to maintain a constant steam supply pressure; it should be set for 5 psig steam on the upstream side of the orifice plate for rated output, and lower for reduced output. The heating steam is condensed within the corrugated basket; the condensate is returned to the ship's condensate system or reserve feed tanks by the first-effect drain pump. (See fig. 11-18.)

A steady water level is maintained in the suction line of the first-effect drain pump by the drain controller; this ensures a positive submergence head for the pump. If the first-effect drain pump fails, the evaporator can be kept in operation by bypassing the drain controller and manually controlling the condensate discharge to the low pressure drain mains; at least 1 psig pressure in the steam chest is required, under these conditions, to drain the condensate.

Feed Flow Circuit

Sea-water feed is taken from a sea chest, through a strainer, by the sea-water circulating water pump, and is discharged through the distillate cooler. (The incoming feed serves to cool the distillate from the condenser to within a few degrees of the temperature of the feed.)

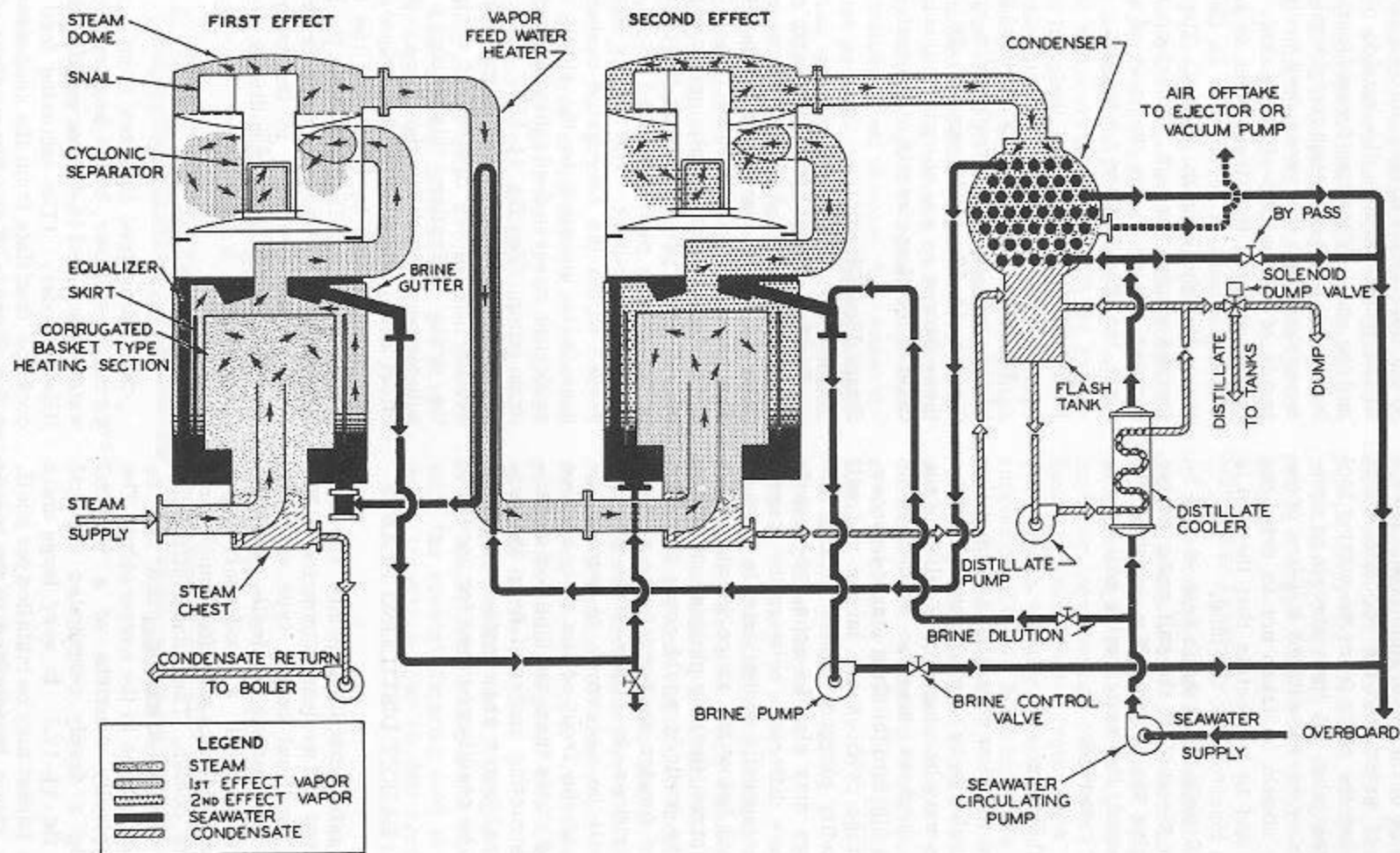
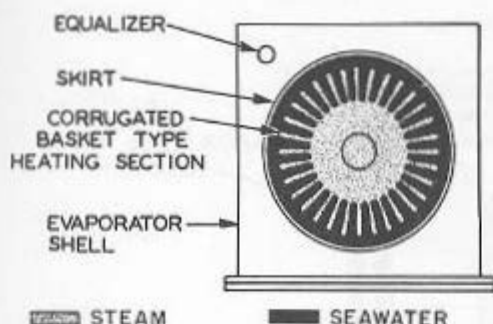


Figure 11-16.—Low pressure double-effect distilling plant (vertical basket type).



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Figure 11-17.—Section view of evaporator (vertical basket type).

The sea water then passes through the condenser; the major portion (about 75%) goes through the educator, combines with the brine (from the second effect), and is discharged overboard. (See fig. 11-20.)

The feed remaining in the condenser is directed through the after condenser and the vapor feed-water heater to the first effect, where it surrounds the basket. Violent boiling takes place and vapor forms within the first effect. The remaining brine serves as feed for the second effect. (Earlier models were equipped with a branch from the feed line, which lead from the heating section of the condenser to a connection on the bottom of the second effect; as a result, the second effect was supplied with brine from the first effect, and heated sea water from the heating section of the condenser as feed.) In current models, all feed enters the first effect.

The brine from the second effect is removed by the brine overboard-discharge pump; it is discharged overboard, through the eductor and control valve, after it has been combined (in the eductor) with the sea-water overboard discharge from the condenser. (See figs. 11-18 and 11-19.)

Vapor Circuit

The vapor which forms as a result of the boiling of the feed in the first effect passes through the uptake pipe and enters the cyclonic separator above the evaporation section. Most liquid particles which carry over with the vapor are removed by centrifugal force within the first-effect separator. The first-effect vapor

passes from the steam dome, through the vapor feedwater heater, to the steam chest and the evaporator basket of the second effect. Some of the vapor, in passing from the first effect to the second effect, condenses as it heats the feed water passing through the vapor feedwater heater. The major portion of the first-effect vapor, however, enters the second-effect steam chest and condenses as it heats the brine in the second effect. (See figs. 11-18 and 11-19.)

The vapor resulting from the boiling of the brine in the second effect passes through the second-effect uptake into the second-effect separator, where centrifugal force is utilized to remove water particles from the second-effect vapor. (Liquid particles from both stages drain downward and become part of the brine drains.) This two-stage separation results in distillate with less than 0.065 epm chloride, under normal operating conditions. From the second-stage separator, the vapor passes, through the steam dome, to the condenser, where the vapor is condensed as it is cooled by the incoming feed. (See figs. 11-19 and 11-20.)

Distillate Circuit

The condensate formed in the second-effect steam chest passes, through a loop seal, to the flash tank of the condenser, under the pressure differential existing between the second-effect steam chest and the flash tank. The loop seal permits only condensate to pass.

The vapor from the second-effect steam dome condenses in the condenser and collects in the flash tank at the bottom of the condenser. The distillate (combined condensate drains from the condenser and the second-effect steam chest) is removed from the flash tank by the distillate pump and is discharged through the distillate cooler and the solenoid-operated dump valve, to the ship's service tanks. (See fig. 11-19 and 11-20.)

In some vertical-basket units, the discharge rate of the distillate pump is controlled automatically by a drain controller. The drain controller maintains a positive water level in the flash tank so that the pump will not become vapor-bound. Later models of vertical-basket units have been equipped with a recirculating line (fig. 11-20) to the flash tank, instead of a drain controller. A throttle valve is included in the recirculating line. The recirculating line supplies relatively cold fresh water

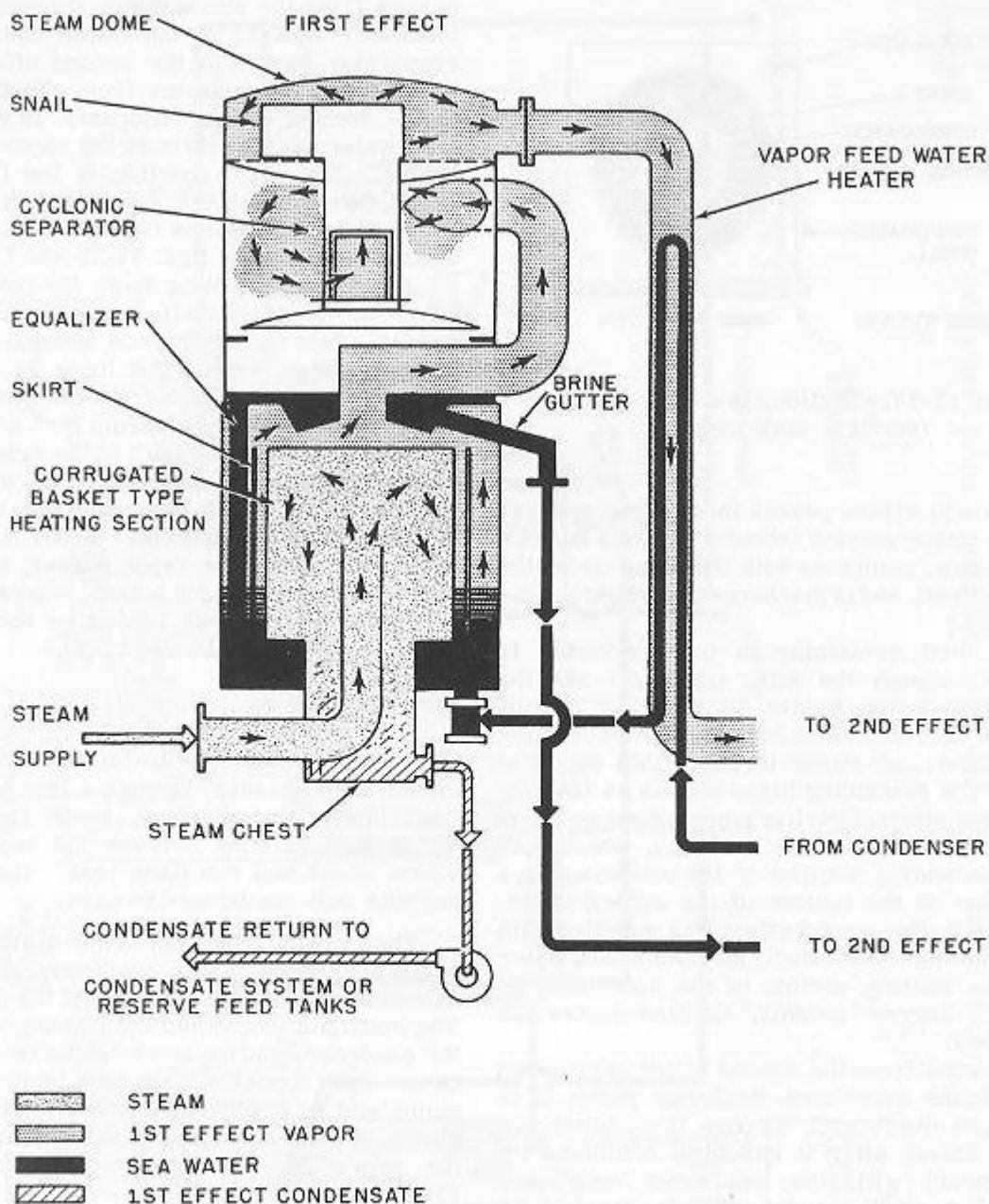


Figure 11-18.—Flow circuits of a vertical basket unit—first-effect section.

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to the flash tank. The cooling water reduces the temperature of the distillate below the flash point; thus vapor lock within the distillate pump is prevented. The recirculating line also ensures, through control of the throttle valve, a positive suction head on the distillate pump.

Under normal operating conditions, the vertical basket distilling unit produces distillate with less than 0.065 epm chloride (0.25 grains salt per gallon). If the unit is to produce relatively pure distillate, it is essential that salt water be prevented from entering the vapor and

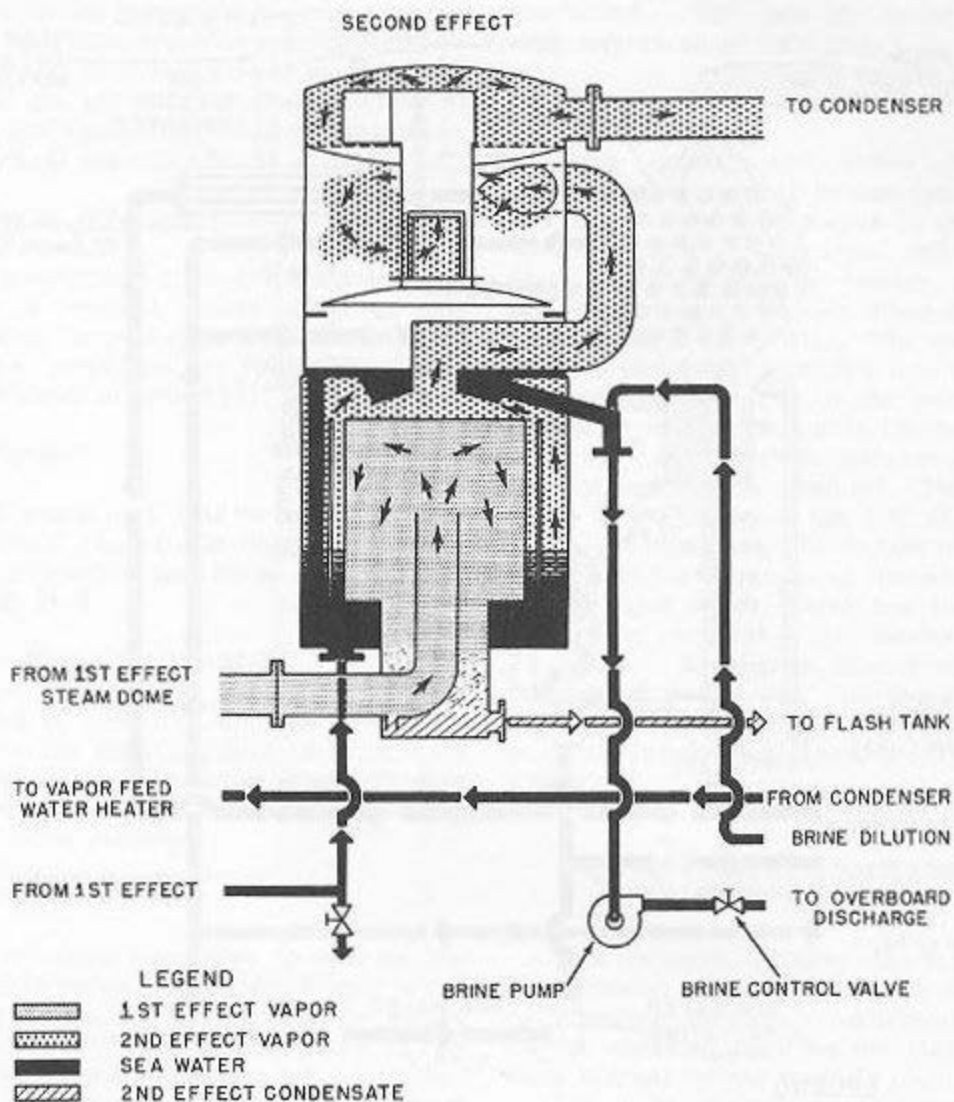


Figure 11-19.—Flow circuits of a vertical basket unit—second-effect section.

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condensate systems. To prevent saltwater contamination of the ship's freshwater supply, a salinity cell is provided in each of the unit's fresh-water lines. If a salt-water leak should develop in the distillate circuit, the salinity indicator actuates the solenoid dump valve, which diverts the contaminated water to the bilge until the unit can be secured and the leakage stopped.

Noncondensable Gases

Air and other noncondensable vapors in the condenser are removed and vacuum is maintained throughout the evaporator units by an air ejector. The ejector is of the single-nozzle, single-stage, steam-jet type. The ejector, mounted on the side of the condenser, takes its suction from a specially baffled section within the condenser. Vent lines and interconnecting vapor-piping

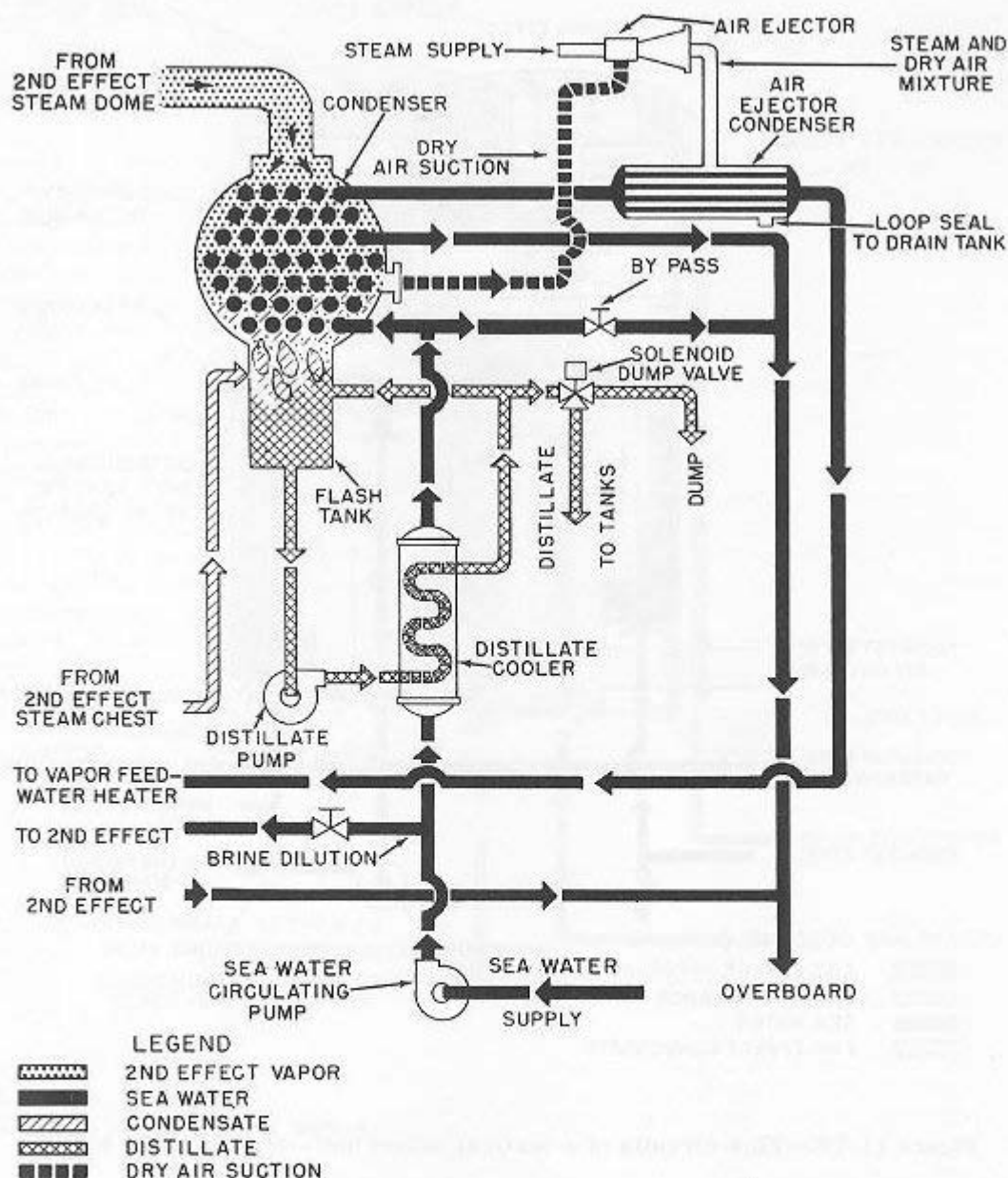


Figure 11-20.—Flow circuits of a vertical basket unit—condenser section.

47.130

connect components in which vacuum must be maintained.

The air ejector removes the air and other noncondensable vapors from the distiller condenser by utilizing the energy in steam at 150 psi. The gases entering the suction of the ejector are entrained by the

steam jet from the nozzle and are carried through the diffuser, where the pressure is raised to that of the atmosphere. The ejector discharges into a surface after-condenser, where the steam is condensed and the noncondensable gases are vented to the atmosphere.

OPERATION AND MAINTENANCE

The information provided in this section, dealing with operating troubles and maintenance of vertical basket distilling plants, supplements that given in the previous section. Additional information can be obtained from the manufacturer's technical manual for the specific unit.

Inability to Make Pure Water

There are a number of troubles which occur and prevent a vertical basket distilling unit from producing pure water. The causes and recommended remedies for some of these troubles are listed in table 11-1.

Low Water Output

Troubles which may lead to low water output in a vertical basket distilling unit and the causes and remedies for these troubles are listed in table 11-2.

Low Vacuum When Cold Shocking

It may not be possible to obtain 28 inch Hg vacuum when the distilling unit is being cold shocked. When this condition exists, it may be caused by air in the basket, open or leaking valves, or leaking gaskets.

Operating at Reduced Rates

When it becomes necessary to operate the unit at lowered rates, the steam supply pressure should be reduced by setting the steam reducing valve. It may be necessary to run the first-effect steam chest under a vacuum. Therefore, in order to keep the steam chest properly vented, it will be necessary to have the vent from the steam chest continuously opened to the shell of the first effect. At the same time the atmospheric vent valve should be closed.

Pump Failure

Should the sea water circulating pump fail, the discharge from the fire pump, when adequately reduced, can be used through the hose connection provided in the piping.

Should the brine pump fail, remove the orifice in the steam line. The unit can then be run with a steam supply of 10 psig steam

to the first effect, with the vacuum equipment secured. The eductor will discharge the brine overboard. The capacity under such conditions will be about 6000 gpd.

Scale Removal

Scale forms on the outside of the corrugations of the vertical basket-type evaporator. The scale can be removed by cold shocking. The shell should be drained and low pressure steam admitted into the basket. This expands the corrugations and also dries the scale, thus making the scale brittle. The steam is turned off and sea water admitted into the shell until the basket is covered by the sea water. Condensation of the steam in the basket creates a vacuum and the differential pressure causes the corrugations to contract. This loosens the scale which drops to the bottom of the shell. Clean-out holes near the bottom of the shell can be opened for removal of the scale particles.

The first effect, which has the most scale formation, is usually cold shocked about every 75 hours. Subsequent effects should be cold shocked at double this interval or more. In a quadruple-effect unit, the fourth effect will probably require cold shocking only once or twice a year.

VAPOR COMPRESSION DISTILLING PLANTS

This section covers the types of vapor compression plants, operation, and important maintenance factors. Additional information can be obtained from the manufacturer's technical manual for the specific plant.

The most common vapor compression unit in use is the Model X. This model is built in two sizes, 1,000 gpd (Model X-1) and 2,000 gpd (Model X-2).

In the Model X, the vaporizing and condensing of the feed is accomplished in the evaporator; the warming of the feed and the cooling of the condensate, however, are accomplished in an external heat exchanger of the double-tube type (tube within a tube). Cut-away and schematic views of the Model X-1 distilling unit are shown in figures 11-21 and 11-22, respectively.

Recent developments in vapor compression units include Models V-1 and the Y-1, each of which has the same rated capacity as the Model

Table 11-1.—Impure Water 2W-112D.

Trouble	Cause	Remedy
Priming	High water in separator Excessive feed rates Clogged equalizers or spillover (piping). Maloperating brine pump. Vacuum too high. Sudden changes of vacuum Drifting exhaust line pressures. Irregular steam supply to ejector. Wet steam supply to ejector. Dirt in ejector strainer or nozzle.	Adjust feed rates Clean. (Especially base of loop seal.) Service brine pump. Decrease vacuum by opening bypass valve at condenser or throttling valve at sea water pump or bleed air into the ejector suction. Correct fluctuations of exhaust steam system. Correct fluctuations of supply pressure to air ejector. Drain condensate from steam supply line and check system. Clean air ejector strainer and nozzle.
Brine density too high	Insufficient overboard discharge. Low feed rates. Fouled brine lines.	Increase rate of brine overboard to attain a density of 1.5 thirty-seconds. Increase feed rates. Clean brine line.
Leak in heat exchangers. (Unit leaking will be isolated by cell indicating high reading on salinity indicator.)	Defective tube or joint.	Test hydrostatically and reroll or replace defective tube.

X-1 unit. Two smaller models (300 gpd capacity) are also in use. These smaller units are similar to the Model X-1, but are far more compact. All of these vapor compression units have external heat exchangers.

OPERATION OF THE MODEL X-1 UNIT

It is beyond the scope of this chapter to describe all of the various vapor compression distilling units in detail. Since all these units operate on the same basic principles, however, the Model X-1 is described here as an example of vapor compression units. Refer frequently to figure 11-21 and 11-22 as you study the following information dealing with the

operation of the Model X-1 unit. Information concerning the construction of the Model X-1 unit can be obtained from the manufacturer's technical manual.

Consider briefly what happens to the sea water which enters a Model Y-1 unit. Pure water is distilled from sea water, when the unit is in operation, as described in the following paragraphs.

Cold sea water feed enters the heat exchanger; it is there heated to about 190° or 200°F. From the heat exchanger, the feed goes into the evaporator. Here it passes through the downtake; into the bottom of the evaporator shell; and up through the tubes, where boiling and evaporation take place at atmospheric pressure. Of the incoming feed, from 1/2 to 2/3 evaporates; the rest flows out through

Table 11-2.—Low Water Output (2W-112D).

Trouble	Cause	Remedy
Flooded chests.	Closed or throttled valves in discharge lines of first-effect condensate drain or second-effect loop seal drain. Maloperating first-effect drain pump.	Open applicable valves. Service first-effect drain pump.
Insufficient vacuum.	Steam supply pressure to ejectors too low. Wet steam supply to ejectors. High water temperature at distilling condenser.	Increase steam supply pressure to air ejector. Drain condensate from line; check system. Reduce air offtake temperature by increasing circulating water through condenser (throttle bypass valve at condenser).
Insufficient steam pressure in first-effect chest.		Increase supply pressure to 5 psig steam above orifice.
Air binding.		Vent air from steam chests.
Salt-water feed temperatures too low.		Increase by opening bypass valve at condenser. It may be necessary to supplement this by throttling the discharge valve of the sea water circulating pump. (Check feed rates.)
Scaling, heating section (basket).		Cold shock and remove all loose scale through provided door or handholes. (Acid cleaning, if required, must be done in accordance with instructions issued by the Naval Ship Systems Command.)

the brine overflow thus maintaining a constant water level within the evaporator.

The steam rises and enters the vapor separator, where any particles of moisture present are separated from the vapor. The moisture is drained from the bottom of the separator and out of the evaporator through the vapor separator drain. In units which are equipped with a room pound gage and a pressure-control switch instead of a manometer, the moisture separated from the vapor overflows with the brine.)

From the vapor chamber, the steam goes into the suction of the compressor; here distilled water is dropped onto the rotating impellers to

desuperheat the steam as it is compressed. The steam is compressed until a pressure of 3 to 5 pounds above atmospheric pressure is attained. The compressed, saturated steam is discharged to the steam chest (into the space surrounding the tubes). As the saturated steam condenses on the outside of the 3/4-inch tubes, the condensate drops down and collects on the bottom tube-plate. Every time a pound of compressed steam condenses, approximately a pound of steam is formed in the evaporator section; the compressor suction is thus kept supplied with the correct amount of steam.

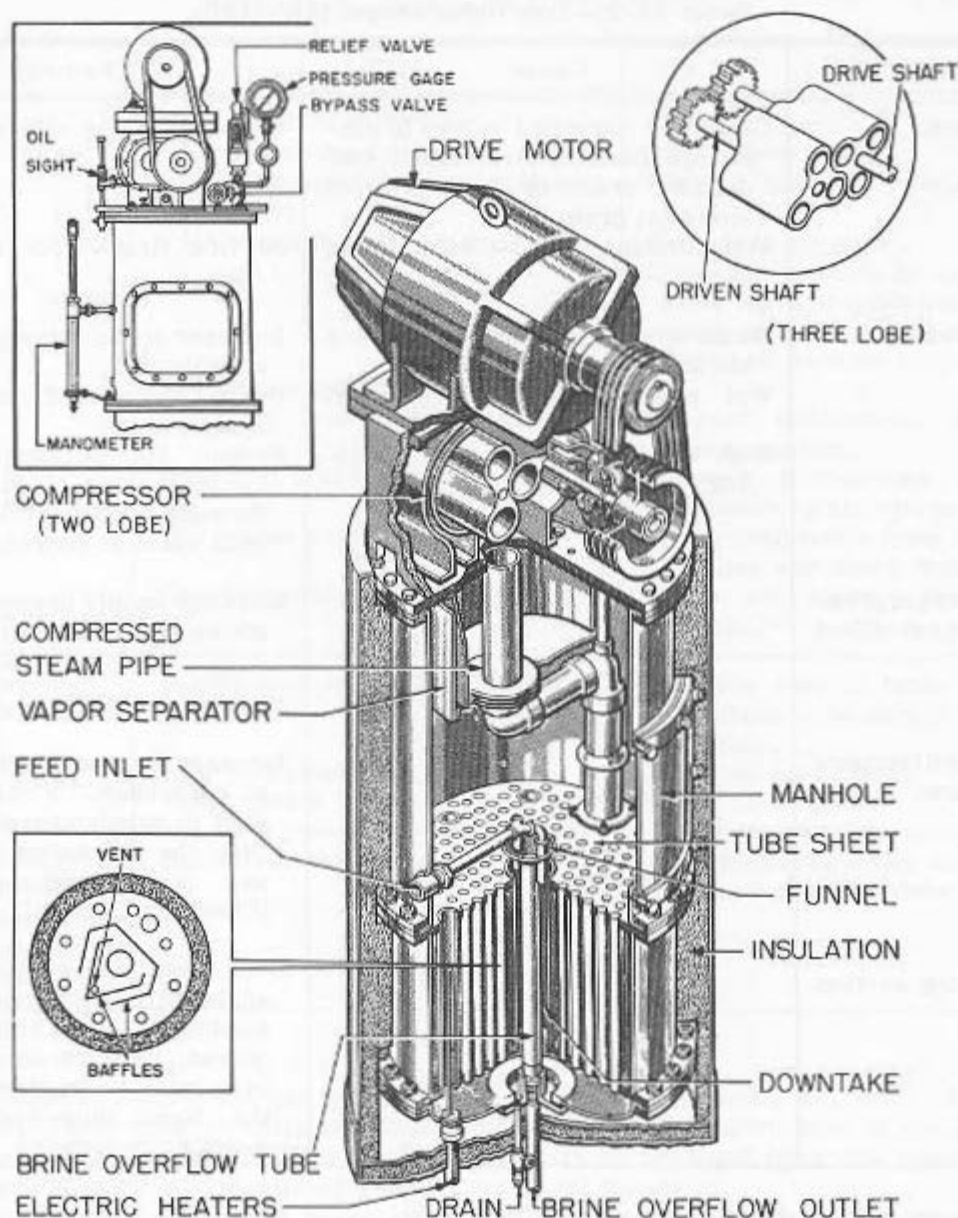


Figure 11-21.—Model X-1 vapor compression distilling unit.

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The condensate is drawn off through a steam trap; it flows into the heat exchanger at a temperature of about 220°F. As it flows through the heat exchanger, the condensate gives up its heat to the incoming feed and is cooled to within about 18°F of the cold feed water temperature. Noncondensable gases are vented from the steam chest, through a small

orifice. These gases, plus a small amount of steam, flow into the vent line; they carry the separated moisture into the heat exchanger. The steam condenses and gives up its heat to the feed.

The remaining feed which does not vaporize, flows continually into the funnel; out of the evaporator; and into the heat exchanger. The

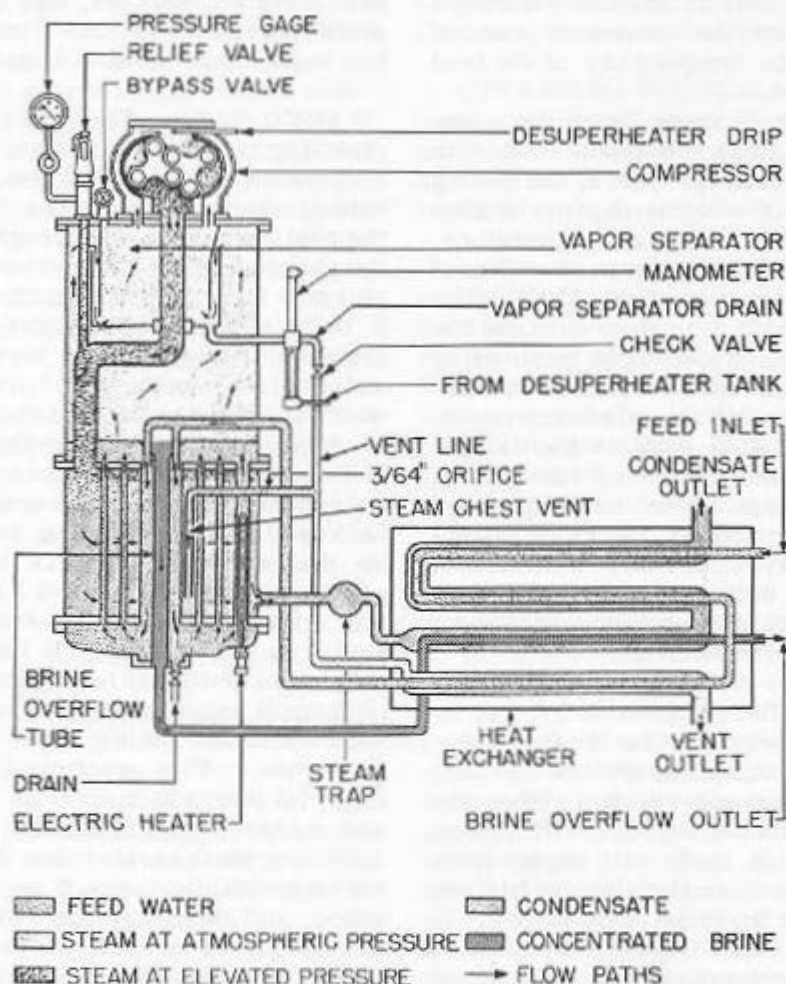


Figure 11-22.—Model X-1 distilling unit with heat exchanger.

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temperature of this brine which leaves the evaporator, through the overflow pipe, and then enters the external heat exchanger, is about 214°F. In passing through the heat exchanger, the hot brine raises the temperature of the sea water feed.

Factors Related to Distillation by Vapor Compression

There are a number of factors related to the efficient operation of a vapor compression unit. Many questions may come to mind: Why does the vapor have to be compressed? What starts the heat cycle? To what extent are heaters used in maintaining the heat cycle?

What about the loss of heat? How is heat balance maintained? These and other factors related to the operation of a vapor compression unit are considered briefly in the following paragraphs.

VAPOR COMPRESSION.—The need for compressing the vapor in a distilling unit involves several factors. The tubes of the steam chest serve two purposes: (1) to vaporize the feed and (2) to condense this vapor. The feed enters the heat exchanger at the temperature of sea water. The temperature of the feed is increased as the feed flows through the heat exchanger. The feed is already near its boiling temperature at atmospheric pressure when it enters the evaporator. As the feed passes through the

downtake, sufficient heat is absorbed from the compressed steam on the condenser side of the tubes to bring the temperature of the feed up to the boiling point.

As the compressed vapor from the compressor enters the steam chest, the vapor is condensed. For any given pressure, the boiling point of sea water is several degrees higher than the boiling point of fresh water. Therefore, the feed water passing up through the tubes of the steam chest is actually above 212°F. The vapor from this boiling feed does not have the characteristics of sea water; it is fresh water vapor, which, at atmospheric pressure, condenses at 212°F. When this vapor is compressed, however, its condensation point is higher than the temperature of the boiling feed water in the tubes of the steam chest. When the compressed vapor enters the steam chest, the vapor comes in contact with external surfaces of the tubes. The temperature of these tubes is lower than the condensation point of the compressed vapor; the vapor, therefore, condenses.

HEAT CYCLE.—The cycle is started up by utilizing electric heaters to bring the feed water up to the boiling point, and to generate enough steam for compressor operation. When the compressor is adequately supplied with steam, the normal distillation cycle will begin; from this point, direct heat from the electric heaters is required only to make up heat losses. In operation, the heat input from the heaters is relatively small compared with the total heat input.

HEAT SUPPLY.—Heat is supplied to the unit in two ways: by means of the electric heaters; and by the work done by the compressor, in compressing the steam. The amount of heat supplied by the heaters is proportional to the number of heaters in operation; it can be varied; at will, by the operator. The energy supplied by the compressor, however, cannot be varied by the operator.

Heat transfer is affected by scale. If the amount and location of the scale in the evaporator tubes were to remain constant, the problem would be simple. But, as scale accumulates the rate of heat transfer through the tube walls decreases. When the tubes are comparatively clean, an adequate amount of heat is transferred, the vapor is condensed, and space for additional vapor in the steam chest is made available at a constant rate. When scale formation retards the

heat transfer, however, less condensation takes place unless the steam from the compressor has been compressed to a higher gage pressure.

FEED RATE.—The matter of feed rate in a distilling unit is very important. The amount of heat which the feed can pick up depends on the rate at which the feed flows through the tubes of the heat exchanger and through the steam chest of the evaporator. If the feed rate is low, the water picks up more heat during that passage because it is in contact with the hot tubes for a longer period of time. If the feed rate is high, the water picks up less heat, for it is in contact with the hot tubes for less time.

Experience has shown that, with the Model X-1 unit, a minimum feed rate of 70 gph is necessary if the rate of scale formation is to be kept low. The unit is designed, therefore, so that sufficient heat is supplied, when the compressor speed is about 2,000 rpm, to maintain vaporization of the feed at a minimum feed rate of 70 gph. If the total heat supply decreases sufficiently to cause the feed to stop boiling, it is possible to bring the temperature back up to the boiling point by decreasing the feed rate. This practice, however, causes a material increase in the rate of scale formation; and a high degree of salinity in the evaporator. Lowering the feed rate below 70 gph is, therefore, not permissible, except perhaps in an emergency, and then only for a short period. If the heat input to the unit drops, the proper procedure is to increase the heat supply by turning on more electric heaters.

HEAT LOSS.—Heat is lost from the unit through the insulation, and in the hot-condensate and brine-overflow streams. The condensate is at a constant temperature for any given discharge pressure. The rate of flow of the condensate depends on the compressor speed; it is substantially constant at any given compressor speed. Therefore, the rate of heat loss in the condensate stream is substantially constant at any given compressor speed. The brine overflow is also at a constant temperature; its rate of flow depends, however, on the feed rate. The rate of heat loss in the brine overflow stream varies directly, then, with the feed rate.

HEAT BALANCE.—When more heat is supplied to the evaporator than is required to balance the heat losses, more steam is generated than the compressor can handle without change in

speed. This will tend to build up a pressure above the feed in the evaporator section. This condition can be corrected by increasing the feed rate; this will result in more brine overflow, which, in turn, will increase the heat loss in the brine overflow stream, and cause the pressure within the evaporator to decrease. (Changes of pressure within the evaporator are indicated on the manometer.) Turning off some of the electric heaters would produce the same effect; this would reduce the heat supply, of course, rather than increase the heat loss.

In this discussion, wherever reference is made to manometer pressure, it is to be remembered that some installations are fitted with a compound gage instead of a manometer. The pressure gage will register the same changes in the vapor pressure as the manometer.

Should the heat losses be greater than the heat supply, an insufficient amount of atmospheric-pressure steam will be generated. When this condition exists, the pressure in the evaporator above the boiling feed will decrease slightly; a partial vacuum will be produced in the vapor separator; and the manometer will fall. To correct this condition; reduce the feed rate to decrease heat loss; or turn on more electric heaters to increase heat input.

The Model X-1 unit is kept in balanced, operating condition solely by adjusting the feed rate and by varying the number of electric heaters in use. These adjustments are made until a satisfactory feed rate is obtained and a constant pressure is indicated by the manometer. (A steady manometer indicates a steady pressure in the evaporator.)

Operating Procedures

The following procedures apply to starting, operating, and securing the Model X-1 unit. With a few exceptions, which will be pointed out, the routine is the same whether the Type XB-1 compressor or the Model AAA-1 compressor is used. Information on difficulties related to starting and operating the unit is not included with the following procedures; such information is provided in the manufacturer's technical manual and in Bureau of Ships Technical Manual, chapter 9580 (58).

STARTING ROUTINE.—When a Model X-1 distilling unit is being placed in operation, the starting procedure should be performed in

accordance with either the Naval Ship Systems Command or manufacturer's instructions.

OPERATING ROUTINE.—After the unit has been started, adjustments will be required for some time, until the unit is balanced and the manometer is showing a constant reading between +2 inches and -4 inches.

1. To balance the unit, first set the feed rate at its minimum value. Then, cut out heaters until the manometer starts to drop; this indicates that the heat losses are exceeding the heat input. Cut in one heater switch; and gradually increase the feed rate until the manometer remains constant somewhere in the range between +2 inches and -4 inches. When a ship is in heavy seas, or when the voltage to the heaters and compressor motor is fluctuating, it is desirable to balance the unit at a somewhat higher pressure; and to operate with a manometer reading between +2 inches and +4 inches.

2. Adjust the desuperheater drip to give a minimum compressor-discharge pressure. Increasing the number of drops per minute lowers the discharge pressure to a certain point; beyond this point, increasing the desuperheater drip will raise the compressor-discharge pressure. The desuperheater drip should be kept adjusted to hold the low point of the compressor-discharge pressure. As the evaporator scales up, more drip will be required; a dirty unit, just before cleaning becomes necessary, may require a small steady stream through the sight glass.

3. Other operating adjustments:

- a. To increase the brine overflow, increase the feed.
- b. To decrease the brine overflow, decrease the feed.
- c. To make the manometer rise, either turn on additional heaters or reduce the feed rate.
- d. To make the manometer fall, either increase the feed rate or turn off electric heaters.
- e. To increase the condensate rate, increase the compressor speed.
- f. To decrease the condensate rate, decrease the compressor speed.

SECURING ROUTINE.—The procedure for securing the unit is as follows:

1. Fill the desuperheater tank.
2. Turn off the electric heaters.

3. Open the bypass valve.
4. Stop the compressor motor.
5. Secure the condensate pump.
6. Secure the desuperheater drip.
7. Open the flow-control valve wide; con-

tinue feeding for at least 15 minutes in order to flush the unit. An even longer flushing period is desirable from the point of view of retarding scale formation. (In submarine installations, where longer flushing periods are required, adjust the feed rate until it is the same as the overflow rate.)

8. Secure the flow control valve and the feed pump.

9. When the flow stops in the brine overflow rotameter, secure the brine overflow rotameter and the brine overflow pump. The unit must always be left full of sea water between operating periods.

10. Secure sea chest valves.

11. Pull main electrical switch.

READINGS AND LOG ENTRIES.—It is important that an accurate, up-to-date log be maintained on each distilling unit. The log should contain a record of readings taken hourly during the period of plant operation; and a statement of maintenance work performed.

It is recommended that the hourly readings include: time of reading; hours run since last cleaning; compressor pressure; compressor rpm; feed rate (gph); overflow rate (gph); gallons of condensate distilled; feed pressure; manometer reading; number of heaters in use; volts; amperes; and condensate salinity.

The following notations should be made under "remarks": time distillation started; time unit secured; time desuperheater tank filled; date evaporator cleaned; and date heat exchanger cleaned.

CLEANING THE MODEL X-1 UNIT

During normal operation, scale deposits will form on the distilling plant evaporator and heat exchanger tubes. The rate of scale formation depends upon the concentration of suspended matter and carbonate salts present in the sea water or fresh water used to feed the distilling plant. Excessive scale on the evaporator and heat exchanger tubes will reduce the capacity of the distilling plant. Therefore, steps must

be taken to periodically clean the evaporator and heat exchanger of the plant.

Cleaning the Evaporator

Under normal conditions, tubes must be cleaned every 250 hours of operation by the sodium acid-sulfate method or every 500 hours by the mechanical method. (Operation in some waters may require more frequent cleaning.)

When the evaporator is cleaned mechanically, the overflow pipe, the rotameter, the manometer, and the flow control valve should also be cleaned. (It may be necessary to clean the measuring devices more frequently in order to keep the markings clear and distinct.) Consult the manufacturer's technical manual and Bureau of Ships Technical Manual for procedures to be followed when cleaning the evaporator and related measuring devices.

The sodium acid-sulfate method requires minor piping changes and some additional equipment which is not issued by the Naval Ship Systems Command. When this method is used, it will effectively remove scale from all surfaces coming in contact with either the salt water feed, or the brine overflow. These are the surfaces likely to require cleaning.

Cleaning with sodium acid-sulfate solution is simple and quick as compared with the mechanical cleaning methods, and can be carried out without dismantling the unit. When using the sulfate method, the unit must be in normal operation, the only difference being that the cleaning agent is used in place of the sea water feed. (Hydrochloric acid cleaning of the Model X-1 unit is prohibited.)

When the evaporator is to be cleaned with sodium acid-sulfate solution, it should be cleaned in accordance with recommendations from the Naval Ship Systems Command.

Cleaning the Heat Exchanger

The heat exchanger should be cleaned after each 200 hours of operation, and **MUST** be cleaned after each 250 hours. In cleaning heat exchangers (AA or AAA types), refer to chapter 9580 (58) of the Bureau of Ships Technical Manual for the correct procedure.

CHAPTER 12

REFRIGERATION PLANTS

The purpose of refrigeration is to cool spaces or objects and to maintain them at temperatures below the temperature of the surrounding atmosphere. In order to produce a refrigeration effect, it is necessary to expose the object to a colder object or environment and allow heat to flow in its "natural" direction—that is, from the warmer body to the colder body. For example, a pan of hot water placed on a cake of ice will be cooled by the flow of heat from the hot water to the ice. This refrigeration effect can be maintained as long as the ice lasts; but no matter how much ice is available, a refrigeration effect greater than the cooling of the water of 32°F cannot be produced. For example, water cannot be made to freeze by this method, since freezing requires the removal of the latent heat of fusion (heat which must be removed from a liquid to change it into a solid without any change in temperature) from the water after it has cooled to 32°F; for this process a temperature difference is required which is not available when both the water and the ice are at 32°F. Therefore, when the purpose of refrigeration is the production of ice or the maintenance of temperatures lower than 32°F, it is obvious that ice is not a suitable refrigerant.

In order to understand the principles of refrigeration, it is essential to have a knowledge of the nature and effects of heat and the physical conditions affecting the refrigerant. Additional information concerning basic refrigeration principles and definitions can be obtained from chapter 9590(59) of the Bureau of Ships Technical Manual.

In accordance with the Naval Ship Systems Command policy, refrigerants used in the Navy are no longer identified by trade names. Instead, they are identified by the letter "R" followed by the appropriate number, or else they are identified simply as "refrigerants." For example, the refrigerant formerly known as

"Freon 12" (CCL_2F_2) now is identified either as "R-12", as "refrigerant 12", or simply as a refrigerant.

The refrigeration systems most commonly used in the Navy, utilize R-12 as the refrigerant. The information given in this chapter is, therefore, primarily concerned with R-12 systems. It should be noted that the cycle of operation and the main components of R-12 systems are basically the same for refrigeration and air conditioning plants

TYPES OF MECHANICAL REFRIGERATION SYSTEMS

The two basic types of mechanical refrigeration systems, where energy input is in the form of mechanical energy or work, used by the Navy are the steam-jet refrigeration system and the vapor compression cycle refrigeration system. Both types are used for naval shipboard refrigeration and air conditioning. The most generally employed type is the vapor compression cycle. Vapor compression cycle refrigerating systems with centrifugal compressors are often used—generally to cool a secondary refrigerant; for example, brine for cargo refrigeration and fresh water for air conditioning application.

STEAM-JET REFRIGERATION SYSTEM

The steam-jet refrigeration system is used on some naval ships for air conditioning. As shown in figure 12-1, the steam-jet plant consists of a flash tank, a booster ejector, a condenser, air ejectors, and the necessary pumps and piping. The flash tank (sometimes called the evaporator) is maintained under exceptionally high vacuum by a steam-jet booster ejector. As water is sprayed into the flash tank, part of each drop flashes into vapor and thereby cools the unvaporized portion of each drop to about 50°F or lower, depending upon the capacity of the unit. The cooled water

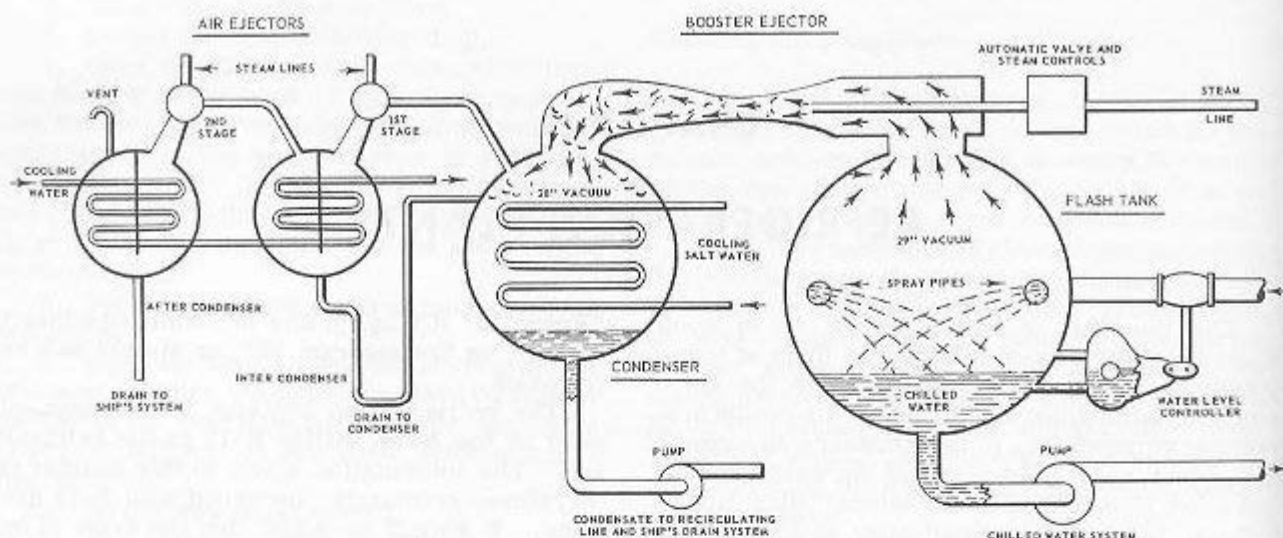


Figure 12-1.—Steam-jet refrigeration system.

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falls to the bottom of the shell; it is then pumped to the cooling coils, and returned to the flash tank at a temperature of about 55°F.

VAPOR COMPRESSION CYCLE REFRIGERATION SYSTEM

Vapor compression cycle refrigeration systems may have either centrifugal compressors or reciprocating compressors.

The vapor compression cycle—with reciprocating compressor—using R-12 is used for most naval refrigeration plants. Figure 12-2 gives a general idea of this type of refrigeration cycle. On studying this system, try to understand what happens to the refrigerant as it passes through each part of the cycle. It will be helpful to trace the refrigerant through its entire cycle, beginning with the thermostatic expansion valve.

Liquid refrigerant enters the expansion valve from the high pressure side of the system and passes through an orifice, which reduces the pressure of the refrigerant. Due to the reduction in pressure, the liquid refrigerant begins to boil and to flash into vapor.

From the thermostatic expansion valve, the refrigerant passes into the cooling coil (evaporator). The boiling point of the refrigerant under the low pressure in the evaporator is lower

than the temperature of the space in which the cooling coil is installed. As the liquid boils and vaporizes, it absorbs its latent heat of vaporization from the surroundings, thereby cooling the space. The refrigerant continues to absorb latent heat of vaporization until all the liquid has been vaporized. By the time the refrigerant is ready to leave the cooling coil, it has not only absorbed this latent heat of vaporization, but has also absorbed some additional heat—that is, the vapor has become superheated. As a rule, the amount of superheat is 10°F.

The refrigerant leaves the evaporator as a low pressure superheated vapor, having absorbed heat and thus cooled the space to the desired temperature. The remainder of the cycle is concerned with disposing of this heat and getting the refrigerant back into a liquid state so that it can again vaporize in the evaporator and thus again absorb heat.

The low pressure superheated vapor is drawn out of the evaporator by the compressor, which also keeps the refrigerant circulating through the system. In the compressor cylinders, the refrigerant is compressed from a low pressure, low temperature vapor to a high pressure vapor, and its temperature rises accordingly.

The high pressure R-12 vapor is discharged from the compressor into the condenser. Here

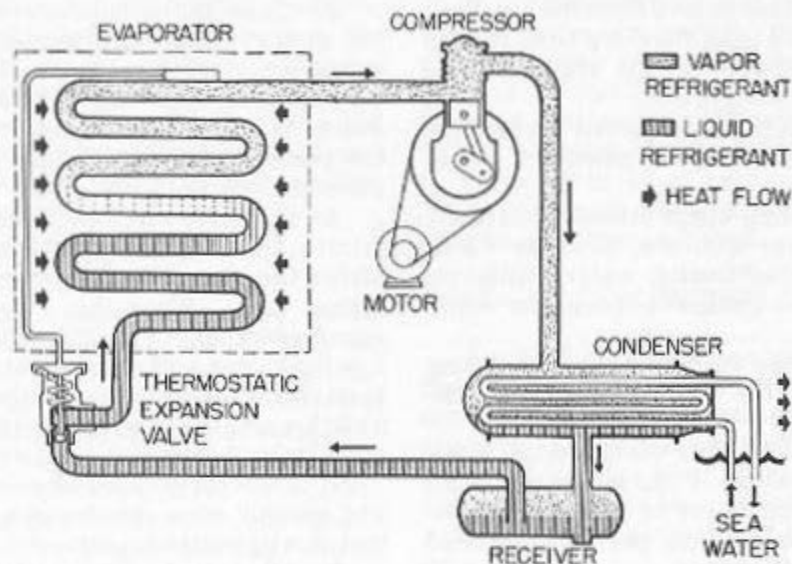


Figure 12-2.—R-12 refrigeration cycle.

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the refrigerant condenses, giving up its superheat (sensible heat) and its latent heat of vaporization to the ambient air in an air-cooled condenser or the cooling water in a water-cooled condenser. The refrigerant, still at high pressure, is now a liquid again.

From the condenser, the refrigerant flows into a receiver, which serves as a storage tank for the liquid refrigerant in the system. From the receiver, the refrigerant goes to the thermostatic expansion valve, and the cycle begins again.

As it can be observed from the description of the compression cycle, this type of refrigeration system has two pressure sides. The LOW PRESSURE SIDE extends from the orifice of the thermostatic expansion valve up to and including the intake side of the compressor cylinders. The HIGH PRESSURE SIDE extends from the discharge valve of the compressor to the thermostatic expansion valve.

OPERATING PROCEDURES FOR AN R-12 SYSTEM

Proper operation of any unit of machinery is an important part of maintaining it. To ensure proper operation of the refrigeration plant, it is necessary to make periodic inspections and tests.

The intervals of the time between plant inspections will vary depending upon the purpose for which the plant is used. The temperatures and pressures throughout the system and the oil level in the compressor crankcase are checked and the results recorded every two hours unless watchstanding instructions specify otherwise. The results of these checks can be used to determine whether or not the plant is operating properly. One of the best methods of checking plant operation is to compare the existing temperatures and pressures with those recorded during a period when the plant was known to be operating properly, under conditions similar to the present conditions.

The following information on prestarting procedures applies to refrigeration systems in general.

1. Open all refrigerant line valves except those which would release refrigerant to the atmosphere or those which are for bypassing components such as the dehydrator, the liquid control manifold or the liquid control piping assembly, and the evaporator pressure regulating valve. Shut off valves, which are in the interconnecting piping between the condensing units and the condenser cross-connecting piping (if installed), should be checked to ensure that they are tightly closed. The compressor shut

off and main liquid line valves from the receiver should remain closed until they are to be opened in their proper sequence in the starting procedure.

2. Start the fan motors on all forced air coolers; see that an adequate amount of air is being delivered.

3. On water cooling applications (soda fountains, drinking water coolers, process water coolers, and air conditioning water chillers), admit the water to be cooled and purge the water circuit of air.

4. See that all stop valves in the circulating water supply and in the discharge lines for the condenser are open.

5. If water is taken from the firemain, make certain that the pressure-reducing valve ahead of the water regulating valve is adjusted to provide a water pressure of 30 psi or less ahead of the water regulating valve.

6. When no pressure-reducing valve is installed, regulate the firemain connection stop valve manually so that the required water pressure ahead of the water regulating valve is maintained.

7. When an individual circulating pump is used to supply condenser circulating-water, be sure that any valves which permit transmission of pump discharge pressure to the water-failure switch are open.

8. If the compressor unit is equipped with an air-cooled condenser, make certain that the air flow passages to the condenser are unobstructed, and that the air circulating fans are clear.

9. Open the compressor discharge-line valve, the stop valve in the line connecting the condenser and the liquid receiver, and the main liquid-line valve.

STARTING THE COMPRESSOR

Too much emphasis cannot be placed on the need for thoroughness and care at the time the compressor is started. Bent crankshafts, distorted valves, and blown gaskets are a few of the casualties which may occur if proper procedures and applicable precautions are not followed. After accomplishing or checking the items listed under the posted prestarting instructions, the following procedure should be used:

1. Set the AUTOMATIC-MANUAL selector switch on the compressor motor controller in the MANUAL position.

2. Close the momentary-contact START button in the pump control circuit to prepare the pump motor for starting.

3. Close the momentary-contact START switch in the compressor control circuit to start the pump motor which also energizes the king solenoid valve circuit.

As the pump circulates the water, the water-failure switch closes automatically and completes the circuit to the compressor-motor contactor coil. When this circuit is closed, the compressor motor starts. In installations where a pump motor and a pump control circuit are not installed, closing the momentary-contact START switch energizes the compressor control circuit and starts the compressor motor.

4. Turn the compressor over by hand or start and quickly stop the compressor to determine that it will rotate freely.

5. After it has been determined that the motor and the compressor are in operating condition, crack the suction stop valve and set the controls on AUTOMATIC. This arrangement will eliminate the possibility of the pressure in the system decreasing below that of the atmosphere and drawing air into the compressor.

Open the compressor suction valve slowly, with the compressor running, so as to limit the quantity of suction gas handled by the compressor. The suction gage should be watched as the compressor suction valve is opened. The valve should be opened, gradually, at a rate such that there will be neither a rapid fluctuation in suction pressure nor a rapid drop of pressure in the compressor crankcase.

6. If lubrication of the compressor is by forced feed, check the pressure on the oil pressure gage.

Unless specific instructions indicate otherwise, the oil pressure should be between 15 and 30 psi above compressor suction pressure within a few seconds after the compressor is started. If the compressor is designed for automatic capacity control, oil pressure of 50 to 60 psi above suction pressure is required.

7. Make certain that the proper quantity of circulating water is flowing through the condenser before the compressor discharge pressure reaches 125 psi.

In systems not equipped with water regulating valves, normal operating conditions generally produce condensing pressures of less than 125 psi, since the condensing water temperature is usually less than 85°F. In systems equipped with water regulating valves, the valves should

be adjusted to maintain the condensing pressure at 125 psi; when the valves are so adjusted, the quantity of cooling water required decreases rapidly with decreasing circulating water temperatures. In systems equipped with air-cooled condensers, condensing pressures may exceed 125 psi when the temperature of the surrounding air is higher than normal.

OPERATING AN R-12 PLANT IN AUTOMATIC

After the prescribed operating pressures and temperatures have been established and the switch set in the AUTOMATIC position, the suction-pressure is so connected, by electrical means, that it starts and stops the compressor automatically, on the basis of load conditions. If the automatic control valves and switches are in proper adjustment, the operation of the plant, after proper starting, will be entirely automatic.

When the selector switch is set for automatic operation, the closing of the water-failure switch, the high pressure switch, or the low pressure switch through automatic operation will energize their respective circuits. Other control devices require the intervention of an operator before the compressor can be restarted. Some high pressure switches are provided with manual reset devices which must be reset by the operator after the switches have been opened by excessive pressure.

Some installations are designed so that the supply of condenser cooling water is available either from a centrifugal pump or from the fire and flushing main directly. If cooling water is obtained from the fire and flushing main instead of from the pump, the pump controller switch is opened manually. The water-failure switch remains closed regardless of the source of condenser cooling water.

SECURING THE COMPRESSOR

If a compressor is to be secured for only a short period, it is not necessary to pump down the system. The compressor, however, must be pumped down. To do this, first close the compressor suction valve slowly, to prevent too rapid a reduction in crankcase pressure. Then allow the compressor to run until it is stopped by the low pressure control switch; push the STOP button on the motor-control panel. Next, close the compressor discharge shutoff valve; shut off the water supply to the condensers. Finally, close the main liquid valve after the receiver.

If a refrigeration system is to be secured for an extended period, the system must be pumped down; the procedure involves pumping most of the R-12 out of the coils of the evaporator, and storing the refrigerant in the receiver. If the quantity of liquid refrigerant contained in the system is in excess of the capacity of the receiver, the surplus liquid must be drawn off into refrigerant drums.

NOTES ON COMPRESSOR OPERATION

An R-12 compressor should not remain idle for an extended period of time. When two or more compressors are installed for a particular plant, the compressors should be operated alternately so that the total operating time on each of the compressors is approximately the same. An idle compressor should be operated at least once a week.

In some cases it may be necessary to use two compressors such as for extensive stores brought aboard ship, the transferring of stores at sea, or any situation where the temperatures are excessively high and must be returned quickly to normal. However, one compressor should normally serve a refrigerant circuit. When compressors are operated in parallel on a common refrigerant circuit, lubricating oil may be transferred from one compressor to another. Such transfer of oil may result in serious damage to all compressors on the circuit.

If an emergency requires that two compressors be operated on a common refrigerating load, the amount of lubricating oil returned to each compressor must be determined by careful observation of the oil level in each crankcase. The proper oil level must be maintained in the crankcase of each compressor under all operating conditions.

A sight-glass is provided in the side of the compressor crankcase for checking the level of the lubricating oil. To check the oil level while the plant is in operation, wait until the compressor shuts down. It is not possible to check the oil level while the compressor is running, since the motion of the parts within the crankcase churns the oil and causes foam.

As soon as the compressor stops, push the STOP button on the control panel, so that the compressor will not start while you are checking the oil level. Turn the flywheel of the compressor through one revolution and observe the rise and fall of the oil in the sight-glass.

Record the AVERAGE oil level—that is, the midpoint between the highest and the lowest levels—as the observed oil level. Unless otherwise specified, an oil level covering between 1/4 and 3/4 of the area on the sight-glass is satisfactory. If the oil level is not within the specified range, oil will have to be added or removed. Do not attempt to do this unless you are qualified in the procedures to be followed and are thoroughly familiar with the applicable safety precautions.

MAINTENANCE OF R-12 SYSTEMS

Refrigeration plants are equipped with automatic controls and once the plant is in normal operation, very little attention is required. However, these plants are, like all units of machinery, liable to casualties, so periodic checks must be made to ensure that the plant is operating normally. The main purpose of the daily operating log for refrigeration equipment is to ensure that abnormal operating conditions do not go undetected.

Usually the personnel assigned to operate and maintain refrigeration plants are graduates of an air conditioning and refrigeration school. However, on small ships, the men assigned to make the periodic checks on the refrigeration plants may or may not have attended this school. These men must be properly indoctrinated as to how to take and record the temperatures and pressures in a refrigeration plant and also as to why these readings are important for the operation of the plant.

Some of the refrigeration maintenance procedures that you should be familiar with are: defrosting the cooling coils, pumping down a system and checking for air and noncondensable gases, purging a system of noncondensable gases, using a halide torch (discussed later in this chapter) to test for refrigerant leaks, charging the system, checking compressor oil, proper care of V-belts, and repairing crankshaft seals.

DEFROSTING OF COOLING COILS

The cooling coils should be defrosted as often as necessary to maintain the effectiveness of the cooling surface. Excessive accumulations of frost on the coils will result in such troubles as reduced cooling capacity, low compressor-suc-

tion pressure, and a tendency for the compressor to short-cycle. The maximum permissible time interval between defrosting operations depends on many factors, such as refrigerant evaporating temperature, free-moisture content of supplies placed in the refrigerated space, temperature of refrigerated spaces, frequency of opening of cold-storage compartment doors, and atmospheric humidity. In the average cold-storage refrigeration installation it is good practice to defrost cooling coils before the average frost thickness reaches 3/16 inch. This is not a hard and fast rule; sometimes the frost layer may become appreciably thicker without seriously interfering with plant operation; at other times it may be necessary to defrost more often to maintain satisfactory operation of the plant and proper compartment temperature.

The most COMMON METHOD OF DEFROSTING a cooling coil in the average refrigeration installation is (1) to shut off the supply of R-12 to the coil to be defrosted, by closing the liquid-line stop valve ahead of the expansion valve; and (2) to permit the temperature in the compartment to rise above 32°F, by leaving the entrance door open. The frost will melt off the coils or may be easily brushed off. Since the cooling coils are made of tinned copper or galvanized steel tubing, care should be taken not to damage the evaporator coil if a scraper is used to remove frost.

Most installations now in use are provided with HOT-GAS DEFROSTING LINES to facilitate defrosting where compartment temperatures are maintained at 32°F or less. The principal advantage of hot-gas defrosting is that this process permits defrosting of the freeze room coils while the rest of the plant operates normally. (In the following paragraphs, defrosting procedures will refer only to freeze room coils.)

A hot-gas defrosting line leads from the compressor, discharge piping to the suction end of the freeze room cooling coil. The hot-gas line joins the suction line, between the freeze room and the suction valve; therefore, hot gas admitted to the freeze room cooling coil flows "backwards" through the coil—that is, the hot gas flows in a direction opposite to the flow of refrigerant under normal operating conditions. In addition to the hot-gas line, the system is provided with a line which connects the inlet end of the freeze room cooling coil (just beyond the expansion valve) to the liquid supply line.

When it is desired to defrost the coils of the freeze room, the normal refrigerant-liquid supply and suction return-line valves of the freeze room cooling coil are closed. The valve in the hot-gas supply line is then opened; compressed refrigerant-gas is admitted to the coil. As the frost melts on the exterior coil surfaces, the gas is condensed in the coils and becomes a liquid. The liquid is led, from the inlet end of the freeze room cooling coil, to the liquid supply line and may be utilized normally in the other compartments.

Upon completion of the defrosting process, the system is returned to its normal operating condition by closing the defrosting valves and opening the valves in the refrigerant-liquid supply line to the freeze room coil and the suction return valve from the freeze room coil. Care must be taken that all liquid refrigerant has been discharged from the freeze room coil before the suction line valve from the compartment is opened. If all the liquid has not been discharged, liquid slugs may be returned to the compressor.

PUMPING DOWN A REFRIGERANT SYSTEM

The pumping-down procedure to be followed will depend on the maintenance to be done. In some cases, the necessary maintenance can be performed on the charged system after a part to be repaired or replaced has been isolated. Generally, it is possible to pump down any part of a charged system except the condenser, the liquid receiver, and the compressor discharge line. When repairs are to be made to a major portion of the system, the refrigerant system must be pumped down to return all refrigerant to the receiver. If repairs are to be made to the receiver, or receiver shutoff valves, the entire system must be drained into spare refrigerant drums. It may also be necessary to drain the system to make repairs to the compressor discharge line or the condenser. However, in systems having valves to isolate the compressor discharge line and condenser, and where it is not objectionable to release refrigerant (which may still be trapped in the condenser after the system has been pumped down to the receiver) to the atmosphere, repairs to the compressor discharge line and condenser may be made with this section isolated.

Whenever it is necessary to open a charged system in order to make repairs or replace-

ments or to clean strainers, the refrigerant pressure within the part of the system to be opened should be pumped down to a pressure slightly above atmospheric ($1/2$ to 2 psig) before any connections are broken. It is generally possible to pump down any part of the system (except the condenser, the liquid receiver, and the compressor discharge line) by proper manipulation of cutout valves. As a part of the system which contains liquid R-12 is pumped down, its temperature will decrease as a result of the evaporation of the liquid refrigerant. When the temperature of such a part of the system begins to rise to normal again, while the low pressure in the part is maintained, it is reasonably certain that all R-12 liquid within the part has been evaporated.

If, in the final evacuation of a part of the system, a pressure of less than 0 psig is reached, sufficient refrigerant should be immediately bled into the evacuated part of the system to raise the pressure to between $1/2$ and 2 psig. Connections may then be opened; and repairs, replacements of parts, or other necessary service operations may be accomplished.

When a refrigerant system is opened, the free ends of the refrigerant lines should be temporarily plugged in order to prevent the entrance of air and dirt. When the connections are remade, one connection is made tight while the other connection is left loose, temporarily, so that the air or other foreign gases in the section of the system which is serviced can be swept out through the free end as this section of the system is slowly purged with refrigerant-gas bled from the charge in the system. The other connection (or connections) is then quickly tightened. Refrigerant, oil-charging, gage, and control lines, although generally of small size and short length, should be purged with refrigerant-gas immediately before they are connected to the system. Where connecting lines which have been removed are to be used again, the ends of the lines should be capped to protect the connecting fitting and to ensure that the tube will be clean and dry when it is used again.

When MAJOR REPAIRS are to be made to a major portion of the system or when the system is to be secured for an extended period, the refrigerant system must be pumped down to return all refrigerant to the receiver. Sufficient refrigerant-gas should be retained within the system to create a positive pressure of approximately 2 psig throughout the circuit, except

within the compressor discharge line and the condenser, and between the receiver and the main liquid-line shutoff valve. To pump down the system, close the main liquid-line shutoff valve and the dehydrator-bypass valve, and open the cooling-coil solenoid valves. Allow the compressor to operate on manual control until the suction pressure reaches approximately 1/2 to 2 psig, then stop the compressor. Repeat the operation until the liquid refrigerant in the circuit has evaporated and the suction pressure remains relatively constant at 1/2 to 2 psig. During the pump-down period, the evaporation of liquid refrigerant can be traced on the liquid line back to the main liquid-line shutoff valve by the formation of frost and its subsequent melting as the liquid refrigerant is evaporated and superheated. Open the power-supply switch to the compressor; close the compressor suction and compressor discharge shutoff valves. Shut off the water supply to the condenser and drain the condenser water. Where the amount of liquid refrigerant contained in the system is in excess of the capacity of the receiver, the surplus liquid refrigerant must be drawn off into separate refrigerant drums.

To drain the refrigerant charge from the system when it is necessary to make repairs to the condenser, the liquid receiver, or the compressor discharge line, or for any other reason, the following procedure should be used:

1. Start the compressor and pump down the cooling coil and suction-line with the liquid-line valve at the receiver outlet closed, to the point at which the low pressure control switch (the control unit that causes the compressor to go on or off, as required for normal operation of the plant) stops the unit.

2. When the compressor is stopped by the low pressure cutout switch, restart the unit manually and continue the pumping-down until the suction pressure reaches approximately 1/2 to 2 psig and stop the compressor. Repeat the operation in periodic cycles until the liquid refrigerant in the circuit has evaporated and the suction pressure remains relatively constant between 1/2 and 5 psig.

3. Close the compressor discharge line valve; close all liquid valves at the cooling coils.

4. Connect an empty R-12 service drum to the refrigerant drain valve. (Before connecting the drum to the R-12 system, cool the drum thoroughly to permit rapid draining of the refrigerant into the drum). Always use a clean

R-12 service drum containing no air or water so that the drained R-12 may be kept in suitable condition for future use.

5. Purge the air out of the line connecting the drain valve and the drum by leaving the connection at the drum valve open as you slowly flush refrigerant through the line and out at the connection; then close the connection. The R-12 may now be drained into the cooled drum by opening the drain valve and the service drum valve.

6. When the service drum is full, close the drain valve and permit the R-12 liquid in the drain line to evaporate; then close the service drum valve and disconnect the drum from the system.

7. Weigh the drum to be certain that it has not been overcharged. The net and gross weights are stamped on the drum. (These weights include that of the cast iron protector cap which fits over the cylinder valve.)

CAUTION: Never fill a service drum beyond its rated capacity; drum rupture may result from hydraulic pressure upon rise in temperature.

8. Discharge the R-12 vapor, which remains in the condenser and receiver to the atmosphere through the purge valve.

TESTING FOR REFRIGERANT LEAKS

Refrigerant leaks mean the loss of refrigerating effect and loss of refrigerant. Various tests are used to determine the existence of leaks in refrigerant systems. Pressure tests are used after the installation of a system and after extensive repairs or replacement of parts have been made. Pressure tests are made before the system is charged with refrigerant. Charged systems are tested for leakage either with a halide leak detector or with soapsuds; which of the two methods is to be used will depend largely upon the size of the leak, and upon the type of space in which the test is to be performed.

In addition to those tests for leaks which are made at periodic intervals, tests should be made before the compressors are started and at any other time that a shortage of refrigerant in the system is suspected. Unusual operating conditions which indicate a shortage of refrigerant in the system are:

1. High suction-line temperatures.
2. Relatively high crankcase and cylinder temperatures.

3. Excessively high refrigerant temperature in the liquid line.
4. Bubbles in the refrigerant sight-flow indicator.
5. Liquid refrigerant is carried partially through the coil, with considerable superheat at the thermal element.
6. Compressor running continuously.
7. Excessive oil seepage at shaft seal connection.
8. Oil seepage at refrigerant-system piping and compressor connections.

A shortage of refrigerant in the system nearly always indicates the presence of leaks. When a shortage of refrigerant is found, the entire system should be tested for leaks by one of the following methods.

The use of a HALIDE LEAK DETECTOR is the most positive method of detecting leaks in a refrigerant system. Such a detector consists essentially of a torch burner, a copper reactor plate, and an exploring hose. (See fig. 12-3.)

Most detectors use either acetylene gas or alcohol as a fuel. Pressure for detectors which use alcohol is supplied by a pump. If a pump-pressure type of alcohol-burning detector is used, be sure that the air pumped into the fuel tank is pure.

Atmosphere suspected of containing R-12 vapor is drawn, by injector action, through the exploring hose into the torch burner of the detector. Here the air passes over the copper reactor plate, which is heated to incandescence. If there is a minute trace of R-12 present, the color of the flame will change from a blue (neutral) to green as the R-12 comes in contact with the reactor plate. The shade of green will depend upon the relative amount of R-12 present; a pale green indicates small concentrations and a darker green shows heavier concentrations. Excessive quantities of R-12 will cause the flame to burn with a vivid purple color. Extreme concentrations of R-12 may extinguish the flame by crowding out the oxygen available from the air.

When a halide leak detector is used, best results are obtained if the following precautions are observed:

1. Be sure that the reactor plate is properly in place.
2. Adjust the flame so that it does not extend beyond the end of the burner. (A small flame is much more sensitive than a large

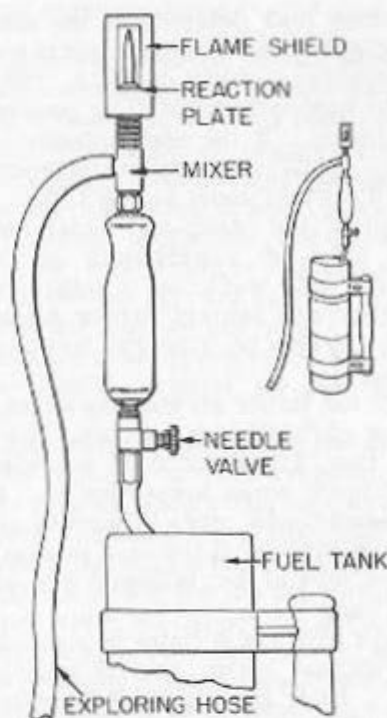


Figure 12-3.—Halide leak detector.

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flame. If difficulty is experienced in lighting the torch when it is adjusted to produce the necessary small flame, block the end of the exploring hose until the fuel ignites; then gradually open the hose.)

3. Clean out the exploring tube if the flame continues to have a white or yellow color. (A white or yellow flame indicates that the exploring tube is partially blocked with dirt.)

4. Check to see that air is being drawn into the exploring tube; this check can be made, from time to time, by holding the end of the tube close to your ear.

5. Hold the end of the exploring tube close to the joint being tested; this prevents dilution of the sample by stray air currents.

6. Move the end of the exploring hose tube slowly and completely around each joint being tested. (Leak testing cannot be safely hurried. There is a definite time lag between the moment when air enters the exploring tube and the moment it reaches the reactor plate; permit sufficient time for the sample to reach the reactor plate.)

7. If a greenish flame is noted at any time, repeat the test in the same vicinity until the source of the refrigerant is determined.

A halide leak detector is so sensitive that it is useless if the compartment is contaminated by excessive leakage of R-12. This is most likely to happen in a small or poorly ventilated compartment. If the compartment is contaminated by R-12 and cannot be ventilated, the SOAPSUDS TEST must be used.

Prepare the soap-and-water solution so that it has the consistency of liquid hand soap, and will work up a lather on a brush. (The lather will remain wet for a longer period if a few drops of glycerin are added to the solution.)

Apply the lather all the way around the joint; then look carefully for bubbles. If a joint is so located that a part of it is not visible, use a small mirror when inspecting it. Remember that it sometimes takes a minute or more for bubbles to appear, if the leak is small. Doubtful spots should be lathered and examined a second time.

Always follow a definite procedure in testing for refrigerant leaks, so that no joints will be missed. Even the smallest leak is not to be considered negligible. However insignificant the leak may seem, it eventually empties the system of its charge to the point of faulty plant operation. Because R-12 is practically odorless, the first indication that leakage exists is the loss of refrigerating effect. The extra time spent in testing all joints will be justified. A refrigerant system should never be recharged until all leaks are discovered and definitely repaired.

Never use oil to test for R-12 leaks. Oil is not reliable because of the capacity of the oil for absorbing R-12. If a small leak should exist where oil has been applied, the R-12 will be absorbed by the oil and will show no indication (bubbles) of the leak until the oil is saturated with R-12. Furthermore, if a halide leak detector is used to test a joint that has been tested previously with oil, the flame will give a false indication because of the R-12 released from the oil.

TESTING FOR AIR AND NONCONDENSABLE GASES

It is essential that every reasonable precaution be taken to keep air and noncondensable gases out of a refrigerant system. When air enters the system the condenser must be purged, with a resultant loss of refrigerant. Atmospheric air always contains some moisture, which will enter the system when air does.

A refrigerant system must be kept as moisture-free as possible to eliminate such troubles as the freezing of water at the expansion valves, internal oxidation or corrosion of parts, and emulsification or sludging of lubricating oils.

Air and noncondensable gases in a refrigerant system are pumped through the system and are discharged by the compressor into the condenser. These gases are trapped in the condenser by the liquid seal maintained over the receiver outlet. These gases are, in general, lighter than the relatively dense R-12 vapor; they tend to collect, therefore, in the upper part of the condenser when the compressor is stopped. The purge valve for discharging these gases to the atmosphere is located either in the upper part of the condenser shell or in the compressor discharge line above the condenser. While the compressor is in operation, any noncondensable gases in the system are thoroughly mixed with the R-12 vapor. This mixing is caused by the turbulence produced by the rapidly pulsating discharge of refrigerant into the condenser. Therefore, it is not advisable to attempt to purge noncondensable gases from the system while the compressor is in operation. Noncondensable gases in a condenser cause excessive condensing pressures with a resultant loss in plant efficiency.

The best time to check an R-12 system for noncondensable gases is immediately before the compressor is started after a shutdown period. When a condenser is to be checked for noncondensable gases, it is essential that the gages and thermometers used be accurate and that the system have sufficient refrigerant charge so that the liquid refrigerant present in the receiver will seal the liquid-line connection.

The following procedure should be followed when checking a refrigerant system for noncondensable gases:

1. Close the main liquid line shut off valve.
2. Secure the compressor so that it will not start during this check out operation.
3. If a discharge pressure gage is not permanently installed in the system, a service or test gage should be installed in the compressor discharge. Also, if a refrigerant liquid line thermometer is not installed, a thermometer should be fastened to the refrigerant liquid line adjacent to the receiver outlet. If a thermometer is not installed in a system having an air-cooled

condenser, one should be placed near the condenser to indicate the ambient temperature at that location.

4. When the discharge pressure gage is steady and no noticeable decrease in condensing pressure is noted, the liquid refrigerant temperature shown on the liquid line thermometer should be recorded. This is the refrigerant condensing temperature.

5. From the corresponding refrigerant temperature scale on the discharge pressure gage, or from a refrigerant pressure-temperature conversion chart, read and record the condensing temperature corresponding to the condensing pressure indicated by the discharge pressure gage.

6. Subtract the condensing temperature, taken from the liquid line thermometer, from the corresponding condensing temperature indicated by the pressure shown on the discharge gage. If the condensing temperature indicated by the discharge gage is greater by 5°F (or more) than the condensing temperature shown by the liquid line thermometer, the condenser should be purged of noncondensable gases.

If the preceding test indicates the need for PURGING, slowly release the noncondensable gases. When a purge valve is not provided, purge the gases by opening the discharge pressure gage connection.

The proportion of R-12 gas that will mix with the noncondensable gases and escape while the condenser is being purged will depend upon the rate of purging and upon the concentration of the noncondensable gases in the condenser. No practical test is available aboard ship to determine definitely when an excessively high proportion of R-12 gas is being purged with the noncondensable gases. To keep the R-12 loss to a minimum when the condenser is being purged, purge slowly; and frequently check the condenser for noncondensable gases.

R-12 is odorless in concentrations of less than 20 percent by volume in air; in heavier concentrations, however, it resembles carbon tetrachloride in odor. If you can get close to the purge-valve discharge, you may be able to determine by the odor of the purged gases when purging should be discontinued and when the check for noncondensable gases should be repeated. **PROTECT YOUR EYES WITH GOGGLES** when you are checking the odor of purged gases.

CHARGING THE SYSTEM

A refrigerating system should have an adequate charge of refrigerant at all times; otherwise its efficiency and capacity will be impaired. The amount of refrigerant charge must be sufficient to maintain a liquid seal between the condensing and evaporating sides. When the low pressure switch stops the compressor, the liquid receiver of a properly charged system is generally about 85 percent full of refrigerant. The refrigerant charge necessary for an individual plant is usually stated in the manufacturer's technical manual or on the ship's drawings.

The dehydrator, located in the liquid line between the receiver and the evaporator, should be put into service when charging (adding) R-12 to the system, or when the presence of moisture in the system is suspected. On systems that have moisture indicators the dehydrator should be used any time the indicator does not show completely dry. The dehydrator cartridges should be changed when the indicator continues to give an indication of moisture in the system after 36 hours of dehydrator use.

To charge additional R-12 into a refrigerating system, the entire system should be checked for leaks, and the following procedure used:

1. Weigh the service cylinders to be used to charge the system, and determine the weight of refrigerant contained in them by comparing the total weight with the weight stamped on each cylinder. It is important to know how much refrigerant is added to the system. The amount of refrigerant charged may be determined by mounting the charging drum on a scale and noting the loss of weight as charging progresses.

2. Connect one of the service drums to the system charging connection.

3. Open the cylinder valve slightly, and blow out the air in the charging line.

4. Close the cylinder valve and tighten the connection.

5. Open the cylinder valve slightly, and test the charging line and its connections for leaks.

6. Close the liquid line valves in the discharge lines from the receiver. Where the dehydrator is in a liquid line bypass arrangement, close the liquid line valve between the dehydrator connections to the main liquid-line and see that the valves in the dehydrator line are open.

7. Close the bypass valves around the liquid control valve assemblies and around the suction pressure regulating valves, if installed.

8. See that the coils of the solenoid valve are energized and that the automatic control equipment is working properly.

9. If the system is equipped with a cross-connecting line between the condenser inlet connections, close the stop valves in this line.

10. Start one of the compressors on AUTOMATIC control, and observe all starting precautions. (Avoid rapid pumping down of the crankcase pressure; rapid reduction in crankcase pressure will cause violent boiling and foaming of the lubricating oil as the R-12 absorbed by the oil is released.)

11. If the system is equipped with water-cooled condensers, see that there is sufficient circulating water to maintain the condensing pressure at 125 psig. In addition, see that the condenser water chests are properly vented.

12. Open the refrigerant cylinder valve and the charging valve. With the compressor operating, liquid refrigerant will flow into the system liquid line. After sufficient refrigerant has been added, check for system leaks; close the refrigerant cylinder valve and the system charging valve. Then open the receiver liquid line valve to place the system in operation.

13. If the system charging connection is located in the compressor suction line, gradually open the liquid valve at the discharge of the receiver of the compressor unit. Then open the valves in the charging line and operate the compressor until the required amount of refrigerant has been charged into the system. When charging into the suction (low side) of the system, keep the refrigerant cylinder upright and charge vapor only. (If additional service drums are required, the charging line should always be pumped down before the drum is disconnected.)

CHECKING COMPRESSOR OIL

If the apparent oil level observed immediately after a prolonged shutdown period is lower than normal, it is almost certain that the actual working oil level is far too low. After a sufficient quantity of oil has been added to raise the apparent oil level to the center of the bull's-eye sight-glass, the actual oil level should be checked as follows:

1. Operate the compressor on MANUAL control for at least one hour. Then slowly close the suction line stop valve. If the compressor is operating on a water cooler or other coil which is apt to freeze, observe the temperature and interrupt compressor operation as necessary to prevent freezing. Repeat cycling until the total running time (one hour) is obtained.

2. Stop the compressor. If the compressor is force lubricated, immediately observe the oil level in the sight-glass. If the compressor is splash lubricated, turn the flywheel until the crankshaft and connecting rod ends are immersed in the lubricating oil, then check the oil level.

When the compressor has been running on its normal cycle, with no abnormal shutdown period, the oil level should be checked as follows:

1. Wait until the end of a period of operation; if the operation is continuous, wait until the compressor has been in operation at least 1/2 hour, then stop the compressor.

2. As soon as the compressor stops, observe the oil level in the sight-glass on forced-lubricated compressors. If the compressor is splash lubricated, turn the flywheel until the crankshaft and connecting rod ends are satisfactorily immersed in the lubricating oil; then check the oil level.

Do not remove oil from the crankcase because of an apparent high level unless too much oil has been previously added, or unless it is apparent that oil from the crankcase of one compressor of the plant has been inadvertently deposited in the crankcase of another.

However, if the oil level is lower than its recommended height on the glass, a sufficient quantity of oil should be added to obtain the desired level. Do not add more oil than is necessary; too much oil can result in excessive oil transfer to the cooling coils.

Adding Oil

There are two common methods of adding oil to a compressor. In one type of installation, a small oil-charging pump is furnished for adding oil to the compressor crankcase. In another type, oil is placed in the compressor by means

of a clean, well-dried funnel. In either installation, care must be taken to prevent the entrance of air or foreign matter into the compressor.

When performing hourly checks of the compressors, it may be observed that there is no oil in the crankcase, or a very low oil level on the sight-glass. This indicates that the oil has left the compressor and is circulating in the system; and it will be necessary to add oil and operate the system. After the compressor has reclaimed the excessive oil in the system, the excess oil should be drained.

Removing Oil

To remove oil from the compressor crankcase, the pressure in the crankcase should be reduced to approximately 1 psi by gradually closing the suction line stop valve. Then the compressor should be stopped, and the suction and discharge line valves closed, the lubricating oil drain plug near the bottom of the compressor crankcase loosened, and the required amount of oil allowed to drain out. Since the compressor crankcase is under a slight pressure, the drain plug should not be completely removed from the compressor; the oil should be allowed to seep out around the threads of the loosened plug. When the desired amount of oil has been removed, the drain plug should be tightened, the suction and discharge line valves opened, and the compressor started. If an oil drain valve is provided in lieu of a plug, the required amount of oil may be drained without pumping down the compressor.

Renewing the Lubricating Oil Charge

When clean copper tubing is used for R-12 systems, and reasonable care has been taken to prevent the entrance of foreign matter and moisture during installation, the oil in the compressor crankcase will probably not become so contaminated that it requires frequent renewal. (NOTE: It is not necessary to change the oil unless the color or other indications of adverse conditions show that the oil should be changed.) When iron or steel pipe and fittings are used in the R-12 system, a sample of oil from the compressor crankcase should be withdrawn into a clean glass container every 3 months. If the sample shows contamination, the entire lubricating oil charge should be renewed. It is good practice to check the cleanliness of the lubricating oil after each cleaning of the compressor suction scale trap.

Care of V-belts

Belts must be properly tightened. Excessive looseness will cause slippage, rapid wear, and deterioration of V-belts. On the other hand, a belt that is too tight will cause excessive wear of both the belt and the main bearing of the compressor. In extreme cases it may cause a bad seal leak. When properly tightened, a belt can be depressed $1/2$ to $3/4$ inch, by the pressure of one finger, at a point midway between the flywheel and the motor pulleys.

When replacement of one belt of a multiple V-belt drive is necessary, a complete new set of matched belts should be installed. Belts stretch considerably during the first few hours of operation. Replacement of a single belt will upset the load balance between the new and old belts and will be a potential source of trouble. It is better practice to run the unit temporarily with a defective belt removed than to attempt to operate a new belt in conjunction with two or more seasoned belts.

V-belts, motor pulleys, and compressor flywheels should be kept dry and free of oil. Belt dressing should never be used.

TESTING AND RENEWING COMPRESSOR DISCHARGE AND SUCTION VALVES

An R-12 compressor **SHOULD NOT BE OPENED** for valve inspection or replacement until it has been determined that the faulty operation of the system is caused by improper functioning of the valves. Faulty compressor valves may be indicated by a gradual or by a sudden decrease in the normal compressor capacity. Either the compressor will fail to pump at all, or else the suction pressure cannot be pumped down to the designed value, and the compressor will run for abnormally long intervals (or even continuously). If the compressor shuts down for short periods (short cycles), the compressor valves may be leaking.

If the refrigeration plant is not operating satisfactorily, it will be best to first shift the compressors and then check the operation of the plant. If the operation of the plant is satisfactory when the compressors have been shifted, this indicates that the trouble was with the compressor.

The compressor discharge valves may be tested by pumping down the compressor to 2 psig, then stopping the compressor, and quickly

closing the suction and discharge line valves. If the discharge pressure drops at a rate in excess of 3 psi per minute and the crankcase suction pressure rises, there is evidence of compressor discharge valve leakage. If it is necessary to remove the discharge valves with the compressor pumped down, break the connection to the discharge pressure gage in order to release discharge pressure on the head. Then remove the compressor top head and discharge valve plate, being careful not to damage the gaskets.

If the discharge valves are defective, the entire discharge valve assembly should be replaced. Any attempt to repair the valve would probably involve relapping, and would require highly specialized equipment. Except in an emergency, such repair should never be undertaken aboard ship.

The compressor internal suction valves may be checked for leakage by performing these steps:

1. Start the compressor by using the manual control switch on the motor controller.

2. Close the suction line stop valve gradually, to prevent violent foaming of the compressor crankcase lubricating oil charge.

3. Pump a vacuum of approximately 20 inches of mercury. If this vacuum can be readily obtained, the compressor suction valves are satisfactory.

Do not expect the vacuum to be maintained after the compressor stops because R-12 being released from the crankcase oil will cause the pressure to rise. Do not attempt to check compressor suction valve efficiency of new R-12 units until after the compressor has been in operation for at least three days. It may be necessary for the valves to wear in.

However, if any of the compressor valves are defective, the compressor should be pumped down, opened, and the valves inspected. Defective valves or pistons should be replaced with spare assemblies.

CRANKSHAFT SEAL REPAIRS

On reciprocating compressors, the crankshaft extends through the compressor housing to provide a mount for the pulley wheel. At this point the shaft must be sealed to prevent leakage of lubricating oil and refrigerant. There are several types of crankshaft seals, depending on the manufacturer. The crankshaft seal is

bathed in lubricating oil at a pressure equal to the suction pressure of the refrigerant. A worn or defective seal will leak refrigerant prior to a noticeable oil leak.

When the seal requires replacement, or signs of abnormal wear or damage to the running surfaces are present, a definite reason for the abnormal conditions exists and an inspection should be made. It is very important to locate and correct the trouble or the failure will re-occur.

Seal failure is very often the result of faulty lubrication, usually due to the condition of the crankcase oil. Dirty or contaminated oil is generally caused by one or both of the following conditions:

1. Dirt or foreign material in the system or system piping. Dirt frequently enters the system at the time of installation. After a period of operation, foreign material will always accumulate in the compressor crankcase, tending to concentrate in the oil chamber surrounding the shaft seal. When the oil contains grit, it is only a matter of time until the highly finished running faces become damaged, causing failure of the shaft seal.

2. Moisture is frequently the cause of an acid condition of the lubricating oil. Oil in this condition will not provide satisfactory lubrication and will promote failure of the compressor parts. If the presence of moisture is suspected, a dryer should be used when the compressor is put into operation. At any time foreign material is found in the lubricating oil, the entire system (piping, valves, and strainers) should be cleaned thoroughly.

Removing and Installing a Shaft Seal

In the event a shaft seal must be repaired or renewed, the following procedures should be accomplished:

Drain the oil from the compressor crankcase. Since the oil contains refrigerant, it will foam while being drained. The oil drain valve or plug should be left open while working on the seal, so that refrigerant escaping from the oil remaining in the crankcase will not build up a pressure—and unexpectedly blow out the seal while it is being removed.

Remove the compressor flywheel (or coupling) and carefully remove the shaft seal assembly. If the assembly cannot be readily

removed, build up a slight pressure in the compressor crankcase by slightly opening the compressor suction valve, taking the necessary precautions to support the seal to prevent it from being blown from the compressor and damaged.

When the replacement is made, the entire seal assembly should be replaced. The parts should be clean and should be replaced in accordance with the manufacturer's instructions.

See that the shaft is clean, then unwrap the seal, being careful not to touch the bearing surfaces with the hands. Rinse the seal in an approved solvent and allow to air-dry. (Do not wipe the seal dry.) Dip the seal in clean refrigerant oil. Insert the assembly in accordance with manufacturer's instructions and bolt the seal cover in place, tightening the bolts evenly. Replace the flywheel and belts and test the unit for leaks by opening the suction and discharge valves and using a halide leak detector.

Lapping a Shaft Seal

On some compressors, it is possible to lap in a seal. Due to the difficulty of properly lapping the rubbing surfaces of a shaft seal, a seal leak should be corrected by renewing the assembly. If, however, a new shaft seal is not available, and it is possible to use the existing seal by refinishing the rubbing surfaces, the seal can be lapped as follows: Thoroughly clean the surfaces of the shaft shoulder and seal collar, and lap the back of the shaft seal collar to the crankshaft shoulder. This point must form an absolute seal so the importance of this lapping cannot be overemphasized. Only jeweler's rouge or the equivalent should be used for the lapping. The abrasive must be used sparingly to avoid getting it into the shaft bearings or crankcase. As the lapping proceeds, use less and less abrasive and finish the lapping with compressor lubricating oil.

After the lapping has been completed, thoroughly clean the shaft shoulder and permit it to dry without wiping. With the shaft seal shoulder and collar dry and clean, lap the two surfaces together as a final lapping operation. The surfaces are properly lapped when the surface of both the shaft shoulder and the shaft seal collar form a perfect contact and are free of all marks, scratches, or other imperfections. It is good practice to make the final examination with the aid of a good magnifying glass.

In some instances, a molded synthetic rubber gasket is provided instead of the metal-to-metal joint between the shaft seal collar and the crankshaft shoulder. In any case, it is extremely important that these parts be properly fitted and that the gasket be kept in good condition in order that a tight seal be maintained at this point.

When a shaft seal is lapped in, it should be regarded as a temporary repair and a new assembly should be installed as soon as possible.

SETTING CONTROL AND SAFETY DEVICES

A refrigeration plant cannot operate **EFFICIENTLY** and **SAFELY** unless the control and safety devices are in good working order and set properly. When a new control or safety device is installed in a refrigeration system, it must be adjusted or set to function at pressures or temperatures in accordance with the plant design. Periodic tests and inspections may indicate faulty plant operation that is due to improperly adjusted control or safety devices.

This section contains information on some of the more common types of control and safety devices used by the Navy.

The methods of setting the low pressure switch, the water-failure switch, and the thermostatic switch are similar; however, these switches differ as to operating range, purpose, and setting. Also, the high pressure switch and the water-failure switch are safety devices while the low pressure switch and the thermostatic switches are control devices.

For detailed information, consult BuShips Technical Manual and the manufacturer's technical manuals.

The **HIGH PRESSURE SWITCH** has an operating range of 60 to 350 psig and an adjustable differential (difference between the cut-in point and cutout point). The switch should be set to cut out at 160 psig and to cut in at 140 psig. To set the switch, first remove the cover plate. Then the two adjusting screws; one labeled differential, the other labeled range, are easily accessible. Turning the range adjusting screw to the right raises both the cut-in point and cutout point. Turning it to the left lowers these points. The differential adjustment affects only the cutout point. Turning it to the right raises the cutout point and turning it to the left lowers the cutout point. Start

the compressor and control the discharge pressure by throttling the circulating water through the condenser. Turn the differential screw all the way to the left and turn the range screw all the way to the right. Raise the compressor discharge to 150 psig. Turn the range screw to the left until the contactor in the switch opens, thereby stopping the compressor. When the discharge pressure drops to 140 psig, turn the range screw to the right until the contacts close, starting the compressor. The cut-in point is now set. With the compressor running, turn the differential screw all the way to the right, then raise the discharge pressure to 160 psig. Turn the differential screw to the left until the contacts open, stopping the compressor. The cutout point is now set.

The LOW PRESSURE SWITCH has an operating range of 20 inches of vacuum to 80 psig and an operating differential of 9 psig to 30 psig.

To set the low pressure switch, start the compressor and control the suction pressure by throttling the compressor suction valve. Turn the range and differential adjustment screws to the left. Lower the suction pressure to about 10 psig below the desired cut-in pressure and turn the range screw to the right until the switch contacts open, stopping the compressor. Allow the suction pressure to rise to the desired cut-in pressure and turn range screw to the left until the switch contacts close, starting the compressor. The cut-in point is now set. Turn the differential screw all the way to the right, throttle the suction valve to lower the suction pressure to the desired cutout pressure. Turn the differential screw to the left, until the switch contacts open, stopping the compressor. The cutout point is now set.

The WATER-FAILURE SWITCH should be set to cut in at 15 psig and to cut out at 5 psig. To set the water-failure switch, turn the differential screw to the left limit for minimum differential since the required differential (difference between cut-in and cutout points) is 10 psig. Throttle water overboard valve until a pressure of 15 psig is maintained at the condenser inlet. Turn range screw clockwise until the switch contacts open, then turn counterclockwise slowly until contacts close. Slowly shut off water supply, decreasing the pressure. The contacts should open at 5 psig.

The THERMOSTATIC SWITCH which operates the solenoid valve is similar to the low pressure switch. Tubing connects a bellows in the thermostatic switch to a thermal bulb in

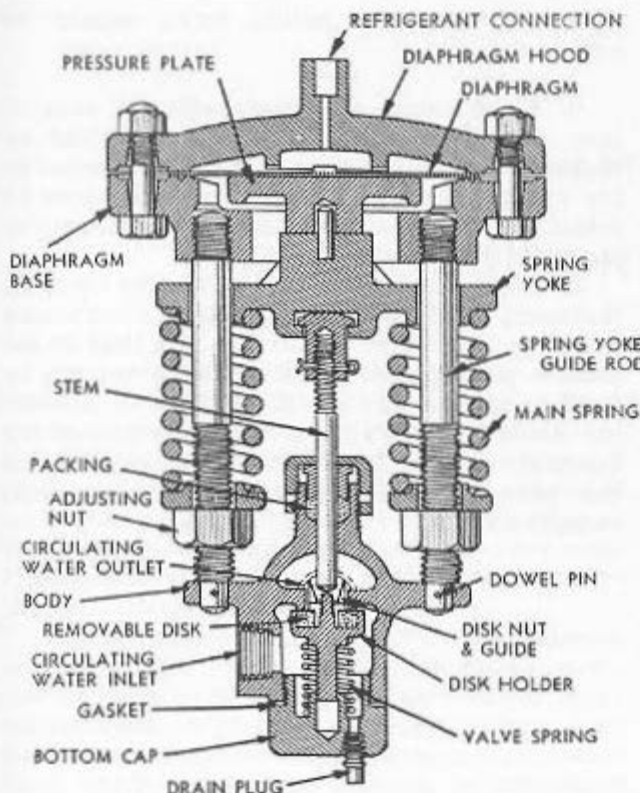
the compartment being cooled. The thermal bulb and tubing are charged with R-12 or some other volatile liquid. Temperature changes in the refrigerated compartment cause corresponding pressure changes of the actuating medium in the thermal bulb. These pressure changes are transmitted to the thermostatic switch, through the connecting tubing. To set or adjust the cut-in and cutout points of the thermostatic switch, the same procedure is used as in setting and adjusting the low pressure switch.

In actual practice, the refrigerant is superheated as well as subcooled during the process of the refrigeration cycle. Superheating occurs in the cooling coil and suction refrigerant line due to the absorption of heat after evaporation between the cold vapor and warmer piping. Superheating is advisable in practice because it assures complete vaporization of all of the liquid refrigerant before it enters the compressor. As far as the superheat setting of the THERMAL EXPANSION VALVE is concerned, the valve is factory set and seldom needs adjustment. To change the superheat setting, remove the cap on the external superheat adjustment. By using a screwdriver, the adjusting screw can be turned to the right to increase the superheat or turned to the left to decrease the superheat. One complete turn of the adjusting screw will raise or lower the superheat approximately 2°F.

The WATER REGULATING VALVE should be adjusted to maintain a compressor discharge pressure of approximately 125 psig. To raise the valve opening point, turn the adjusting nuts (see fig. 12-4) clockwise, increasing tension on the main springs. Increasing main spring tension increases the amount of pressure required to open the valve. Turning the adjusting nuts counterclockwise decreases the main spring tension, therefore decreasing the amount of pressure required to open the valve. If the ambient temperature is high, pressure (gas) in the compressor discharge line and condenser may remain high and cause the water regulating valve to partly open when the compressor is idle. In such instances, the point of valve opening should be raised just enough to cause the valve to close during compressor shutdown.

The valve may be flushed by opening it with an outside force; a screwdriver or similar tool may be used to force the spring yoke.

When condenser circulating water is obtained from the firemain, the pressure must be reduced.



47.100

Figure 12-4.—Water regulating valve.

For this pressure reduction, an **AUTOMATIC REDUCING VALVE** is installed in the branch line leading from the firemain to the condenser. The reducing valve is installed just ahead of the regulating valve. The outlet pressure can be varied by turning the adjusting screw, which is located under the cap. Turning the adjusting screw clockwise increases the pressure applied by the spring to the top of the diaphragm, thus opening the valve wider and increasing the outlet pressure. Turning the adjusting screw counter-clockwise decreases the spring pressure on the top of the diaphragm, thus tending to decrease the discharge pressure.

SAFETY PRECAUTIONS

Refrigerants are furnished in cylinders for use in shipboard refrigeration systems. The following precautions must be observed by personnel handling, using, and storing these cylinders:

1. Never drop cylinders nor permit them to strike each other violently.

2. Never use a lifting magnet or a sling (rope or chain) when handling cylinders. A crane may be used if a safe cradle or platform is provided to hold the cylinders.

3. Caps provided for valve protection must be kept on cylinders except when the cylinders are being used.

4. Whenever refrigerant is discharged from a cylinder, the cylinder should be weighed immediately and the weight of the refrigerant remaining in the cylinder should be recorded.

5. Never attempt to mix gases in a cylinder.

6. **NEVER** put the wrong refrigerant into a refrigeration system! No refrigerant except the one for which the system was designed should ever be introduced into the system. In some cases, putting the wrong refrigerant into a system may cause a violent explosion.

7. When a cylinder has been emptied, close the cylinder valve immediately to prevent the entrance of air, moisture, or dirt. Also, be sure to replace the valve protection cap.

8. Never use cylinders for any purpose other than their intended purpose. **DO NOT** use them as rollers, supports, etc.

9. **DO NOT** tamper with the safety devices in the valves or cylinders.

10. Open cylinder valves slowly. Never use wrenches or other tools except those provided by the manufacturer.

11. Make sure that the threads on regulators or other connections are the same as those on the cylinder valve outlets. Never force connections that do not fit.

12. Regulators and pressure gages provided for use with a particular gas must **NOT** be used on cylinders containing other gases.

13. Never attempt to repair or alter cylinders or valves.

14. Never fill R-12 cylinders beyond 80 percent of capacity.

15. Whenever possible, store cylinders in a cool, dry place, in an upright position. If the cylinders are exposed to excessive heat, a dangerous increase in pressure will occur. If cylinders must be stored in the open, take care that they are protected against extremes of weather. **NEVER** allow a cylinder to be subjected to a temperature above 125°F.

16. **NEVER** allow R-12 to come in contact with a flame or red-hot metal! When exposed to excessively high temperatures, R-12 breaks

down into PHOSGENE gas, an extremely poisonous substance. Because R-12 is such a powerful freezing agent that even a very small amount can freeze the delicate tissues of the eyes, causing permanent damage; it is essential that goggles be worn by all personnel who may be exposed to a refrigerant, particularly in its liquid form. If refrigerant does get in the eyes, the person suffering the injury should receive medical treatment immediately in order to avoid permanent damage to the eyes. In the meantime, put drops of clean olive oil, mineral oil, or other nonirritating oil in the eyes, and make sure that the person does not rub his eyes. CAUTION: Do not use anything except clean, nonirritating oil for this type of eye injury. (NOTE: If large leaks are indicated, the soap method should be used to detect leaks; for

minute leaks, the halide torch should be employed.)

If R-12 comes in contact with the skin, it may cause frostbite. This injury should be treated as any other case of frostbite. Immerse the affected part in a warm bath for about 10 minutes, then dry carefully. DO NOT rub or massage the affected area.

R-12 is considered a fluid of low toxicity. However, in closed spaces, high concentrations displace the oxygen in the air and thus do not sustain life. If a person should be overcome by R-12 remove him IMMEDIATELY to a well-ventilated place and get medical attention at the earliest opportunity. Watch his breathing. If the person is not breathing, give artificial respiration.

CHAPTER 13

AIR CONDITIONING EQUIPMENT

Air conditioning is a field of engineering dealing with the design, construction, and operation of equipment used in establishing and maintaining desirable indoor air conditions. It is the science of maintaining the atmosphere of an enclosure within specified limits of temperature, humidity, and purity. As such, air conditioning involves the cooling, heating, dehumidifying, ventilating, and purifying of air.

One of the chief purposes of air conditioning is to keep the ship's crew comfortable, alert, and physically fit. The air of various compartments must be of the right temperature, have the proper moisture content, have contamination held within an acceptable level, be circulated properly, and have the correct proportion of oxygen. It must be remembered that the human body cannot long maintain a high level of efficiency under adverse conditions.

However, the comfort and fitness of the crew is not the only immediate purpose of air conditioning. Mechanical cooling or ventilation must also be provided for ammunition spaces to prevent deterioration of ammunition components; for gas storage spaces, to prevent excessive pressure buildup in containers and contamination from leakage in the space; and for electrical equipment spaces, to limit ambient (encompassing) temperature to that specified for the equipment.

This chapter covers general information concerning the operation and maintenance of air conditioning equipment used by the Navy. Additional information may be obtained from chapter 9380 (38) of BuShips Technical Manual.

VENTILATION EQUIPMENT

Since proper circulation is the basis of all ventilating and air conditioning systems and of related processes, information dealing with means of circulating air will be considered first. The sections which follow contain information

on equipment used to supply, circulate, and distribute fresh air, and to remove used, polluted, and overheated air.

Fans used on Navy ships in conjunction with supply and exhaust systems may be divided into two general classes: axial flow and centrifugal. Most fans in duct systems are of the axial flow type because axial flow fans generally require less space for installation.

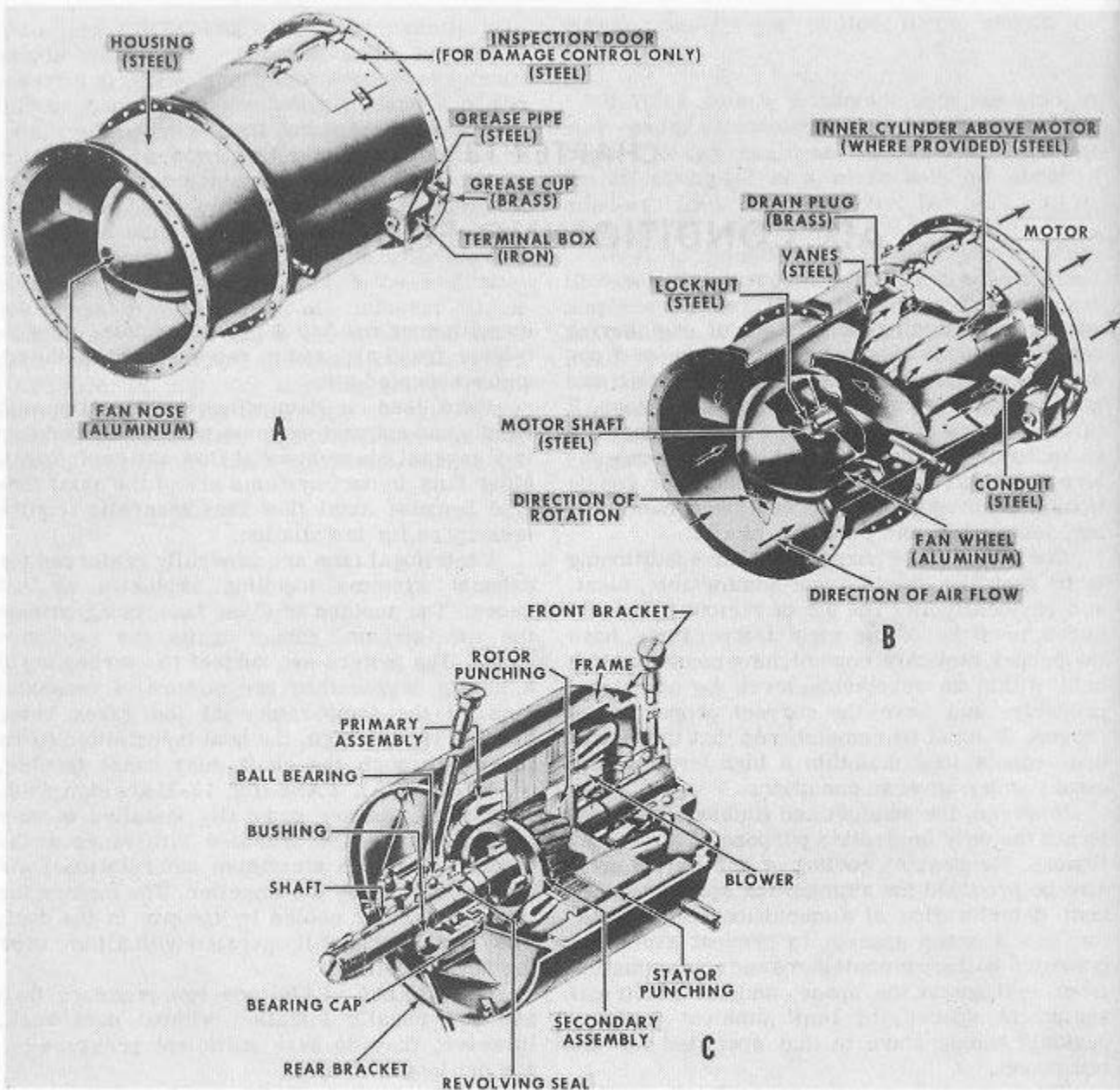
Centrifugal fans are generally preferred for exhaust systems handling explosive or hot gases. The motors of these fans, being outside the air stream, cannot ignite the explosive gases. The motors are subject to overheating to a lesser degree than are motors of vaneaxial fans. If the temperature of the gases being handled is very high, the heat transmitted to the motor, through the shaft, may cause trouble.

VANEAXIAL FANS (fig. 13-1) are high pressure fans and are generally installed in duct systems. They are provided with vanes at the discharge end to straighten out rotational air motion caused by the impeller. The motors for these fans are cooled by the air in the duct. They will overheat if operated with all air over the fan shut off.

TUBEAXIAL FANS are low pressure fans and are usually installed without duct work. However, they do have sufficient pressure for a short length of duct.

CENTRIFUGAL FANS (part A of fig. 13-2) are used primarily for exhausting explosive or hot gases. However, they may be used in lieu of axial flow fans if they work in better with the arrangement or if their pressure-volume characteristics suit the installation better than an axial flow fan would.

The PORTABLE FANS (part B of fig. 13-2) with flexible airhoses, are used aboard ship to ventilate compartments after painting, to exhaust flammable or toxic gases from closed spaces and tanks, and to cool hot spots around machinery during repairs.



47.106

Figure 13-1.—Vaneaxial ventilating fan: A. Exterior view. B. Cutaway view. C. Cutaway view of the fan motor.

Most of the portable fans are of the axial flow type, driven by electric, explosion-proof motors. On ships carrying gasoline, a few air turbine-driven centrifugal fans are normally provided. Greater confidence is placed in the explosion-proof characteristics of these fans.

BRACKET FANS are used in hot weather to provide local circulation. These fans are usually installed in living, hospital, office, commissary, issuance, and berthing spaces on ships which are not air conditioned. Where mechanical cooling is employed, bracket fans are sometimes

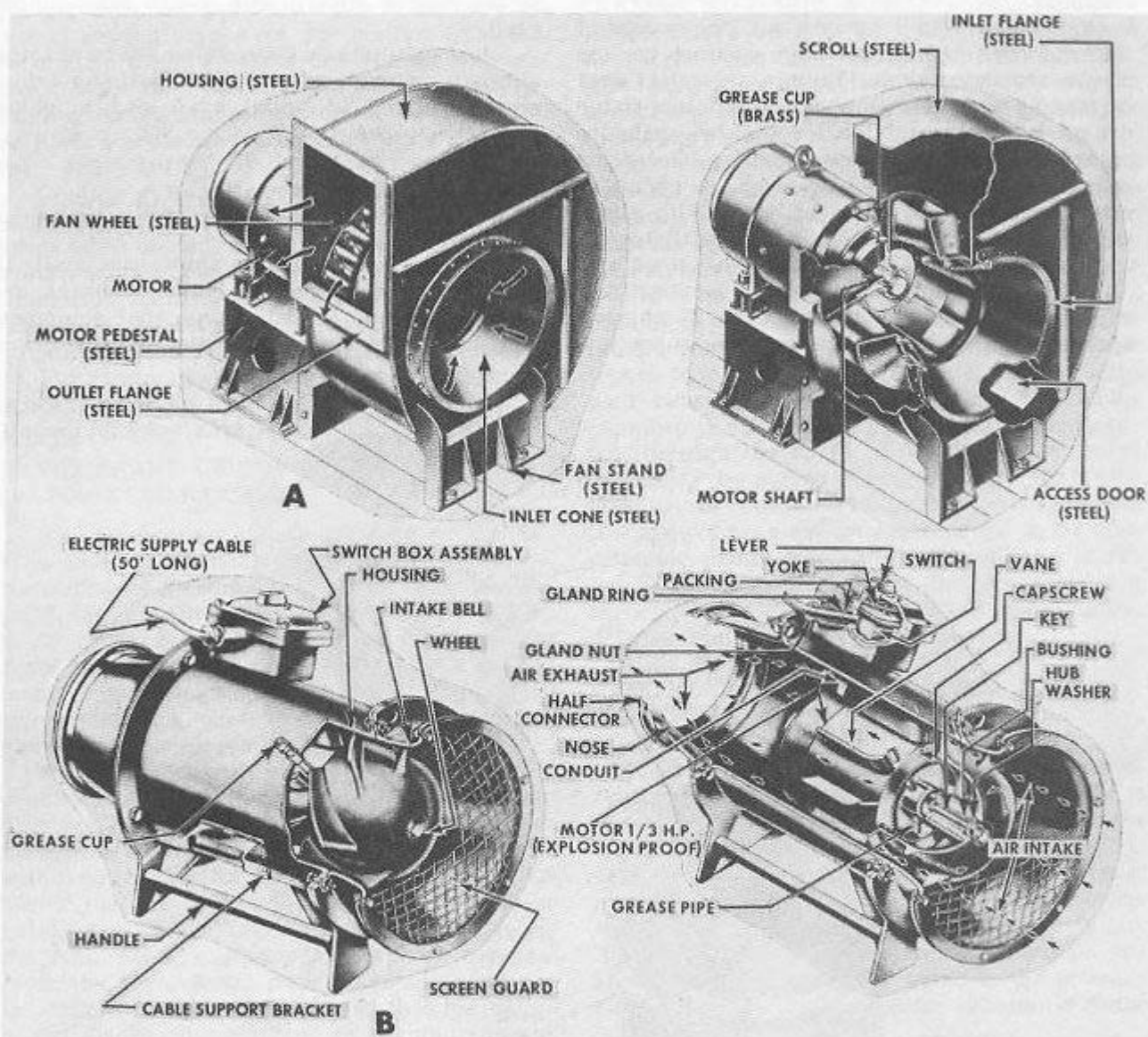


Figure 13-2.—Ventilating fans: A. Centrifugal fan. B. Portable axial fan.

47.107

used to facilitate proper circulation and direction of cold air.

When it is necessary to locate ventilation intakes in exposed locations on weather decks to serve spaces requiring continuous ventilation, a bucket type WATERPROOF VENTILATOR is installed to exclude water. The waterproof ventilator, shown in figure 13-3 consists of an outer housing, an inner ventilator shaft extending up to the outer housing, and a bucket-type closure

supported over the ventilator shaft by a compression spring. The bucket is provided with drain tubes extending into a sump between the ventilator shaft and the outer housing. The sump is provided with scupper valves, which drain onto the weather deck.

The ventilator operates automatically, and is normally open. Small quantities of water which enter the ventilator fall into the bucket and drain out through the drain tubes and

scuppers. In heavy seas, when water enters the bucket faster than it drains out, the weight of water forces the bucket down against the top of the ventilator shaft. Thus, a watertight seal is formed and maintained until sufficient water drains out to permit the force of the spring to raise the bucket to the open position. Operating gear is generally provided, also, to permit a manual closing of the ventilator. With slight variations in construction, this ventilator is used for both the supply and exhaust of air.

EXHAUSTS are used to remove heat and objectionable odors at their source. Machinery spaces, laundries, and galleys are but a few

of the spaces aboard ship where exhausts are used.

Most exhausts on Navy ships are mechanical although natural exhaust is sometimes extensively utilized on small craft and in ships' superstructures.

MECHANICAL COOLING EQUIPMENT

On the latest combatant ships, practically all parts of the ship, except machinery spaces, are air conditioned. To determine what equipment will most effectively lower the temperature of

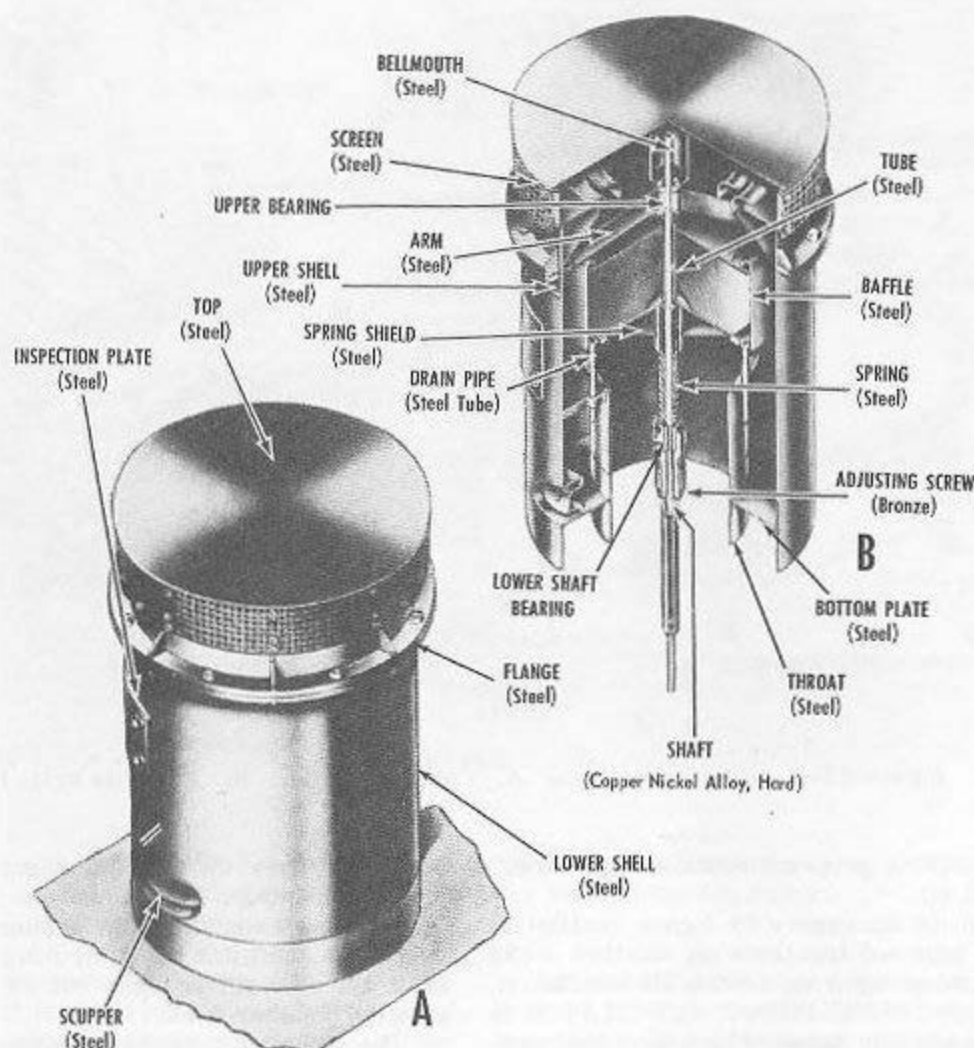


Figure 13-3.—Waterproof ventilator: A. Exterior view. B. Cutaway view.

compartment air and dehumidify it, the Navy has tested several types of air cooling systems. Basically, these systems are refrigerant systems, with their design and construction depending on the characteristics of the COOLING AGENT circulated through the system and on the PRINCIPLE OF OPERATION utilized.

Cooling systems can be broadly classified, according to the cooling agent circulated to the space to be cooled, as chilled-water circulating systems and as refrigerant circulating systems. Classified according to the principle of operation, the systems are: thermocompression (steam jet), absorption, and vapor compression.

For recommended temperatures for specific spaces, refer to the Bureau of Ships Technical Manual (chapter 9380).

REFRIGERANT CIRCULATING SYSTEM (VAPOR COMPRESSION)

The refrigerant circulating system (fig. 13-4) is essentially a shipboard refrigerating plant, consisting of a compressor, condenser, cooling coils, fan, air filter, and the necessary controls. R-12 is used as the refrigerant and cooling agent in systems of this type. R-12 is inflammable, nontoxic, and has suitable operating characteristics, particularly for shipboard reciprocating compressors.

Starting from the space to be cooled, the air conditioning cycle (see fig. 13-5) is as follows: The hot, moist air from the space is drawn through a duct or passage way, where it mixes with fresh air drawn in from the outside. The fan blows the air over the cooling coil, and the refrigerant inside the coil cools the surface of the coil. These cold surfaces absorb the heat from the air passing over them and condense the excess moisture. The moisture drips off into a pan below the coil and is carried away by piping. The cool, dry air leaving the coil is blown into the compartment that is being air conditioned, where it absorbs the excess heat and moisture in the space, and is then returned to the cooling coil. Air is exhausted from the space to allow for fresh air being drawn into the space. The cooling coils are installed in duct systems leading to the spaces to be air conditioned. Automatic and manual controls are added to regulate the operations of the air conditioning equipment.

In general, the machinery and piping arrangements of the ship's refrigerant system and of the refrigerant-circulating air conditioning system are similar.

Operating suction pressures and evaporator temperatures used in air conditioning systems are higher than those in refrigeration systems. The difference in suction pressure results in a corresponding effect on the rated capacity of the compressor.

In refrigerant-circulating air conditioning systems, the thermostatic expansion valves are normally of the external equalizing type. (An external equalizing connection is required where the refrigerant pressure loss through the cooling coil is of any consequence, such as, above 2 1/2 pounds of air conditioning, 1 1/2 pounds for middle range refrigeration, and 1/2 pound for frozen food applications.) The internal equalizing port between the valve outlet and the spring chamber is eliminated; instead there is an opening, through the valve, directly into the spring chamber. By means of copper tubing the spring chamber is connected to the cooling coil, beyond the point of greatest pressure drop. In air conditioning plants, the external equalizer is required in instances where the pressure drop through the cooling coil is 2 1/2 psi or more, or when multicircuit coils are used.

CHILLED WATER CIRCULATING SYSTEMS

There are two air conditioning systems currently in use, which circulate chilled water to the spaces to be cooled. One type operates on the vapor compression cycle and R-11 or R-12 is used as the primary refrigerant; the type of primary refrigerant used will depend on the size of the unit and the type of compressor installed. The other type of system operates on the absorption cycle and uses water as the primary and secondary refrigerants; lithium bromide is used as an absorbant.

Chilled-Water Circulating System (Vapor Compression)

The vapor compression chilled-water circulating system differs from a direct expansion air conditioning system in that the air conditioning is accomplished by a secondary refrigerant (chilled water) which is circulated to the various cooling coils. Heat from the air conditioned space is absorbed by the chilled water and is removed from the water by the primary refrigerant system in the water chiller. In larger capacity air conditioning systems, the compressor may be a centrifugal type that uses

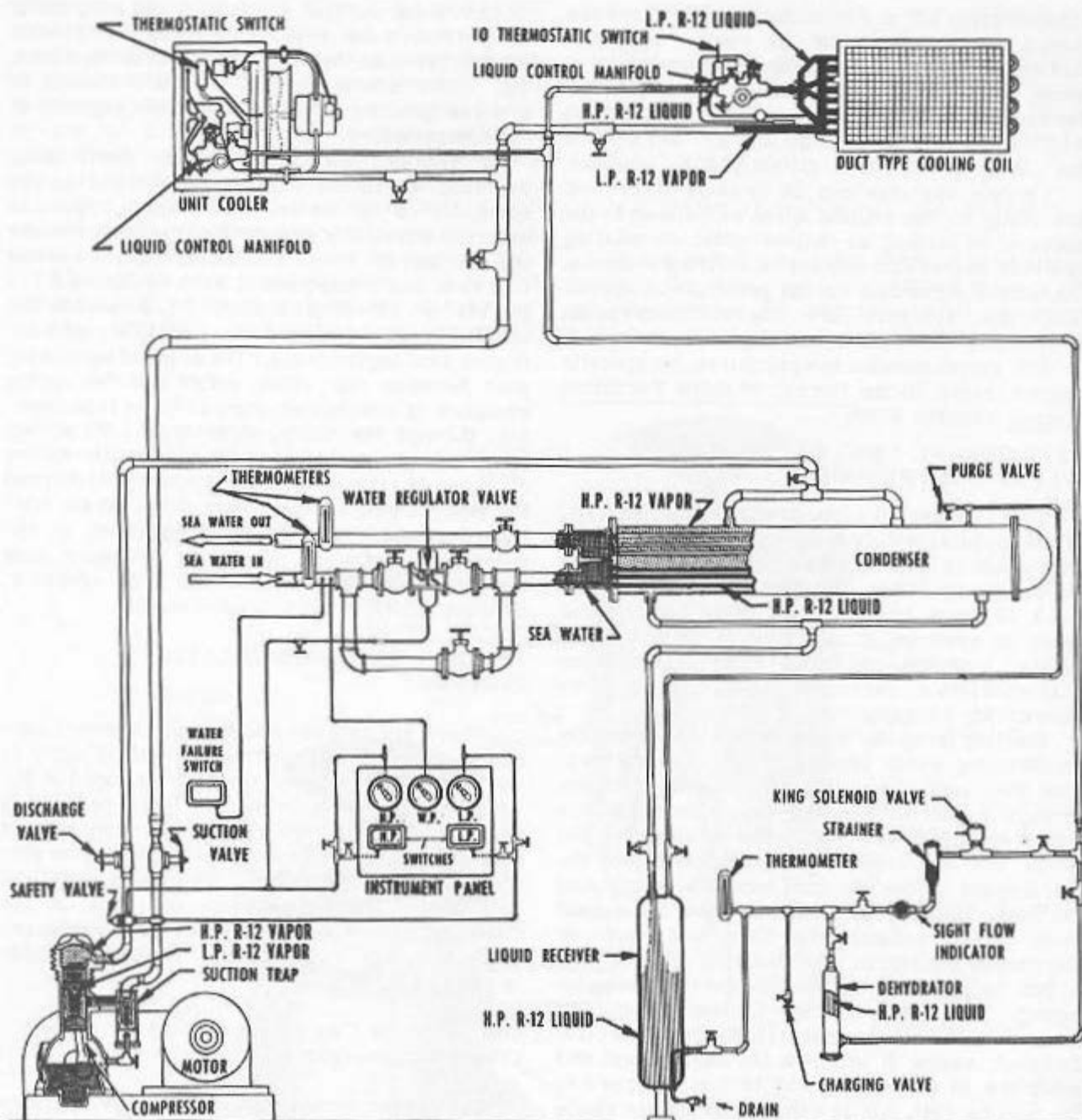


Figure 13-4.—Typical shipboard refrigerant-circulating air conditioning system.

47.109

Refrigerant-11 as the primary refrigerant rather than a reciprocating type that uses R-12.

The operating cycle of the centrifugal refrigerating machine (fig. 13-6) is basically the same as most refrigerating machines except for the method of compression. The refrigerant

vapor coming from the cooler goes into an opening around the hub of an impeller wheel. The blades in the rapidly rotating wheel impart velocity and compress the vapor. In a multi-stage compressor, the vapor is then directed to the hub of an additional wheel or wheels. The

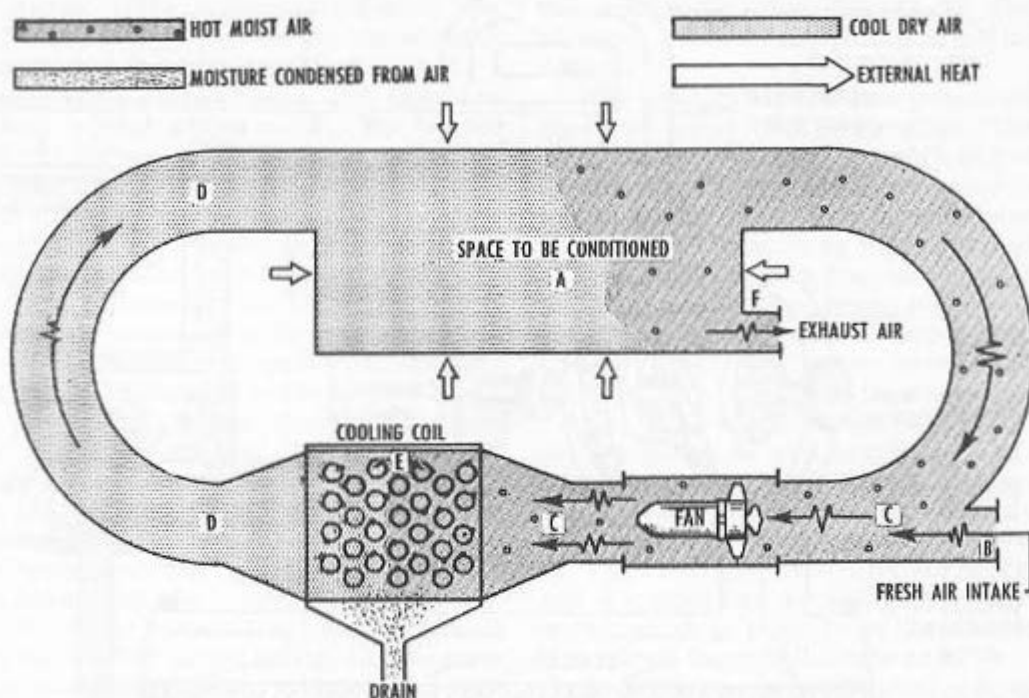


Figure 13-5.—Mechanical air-cooling cycle.

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vapor is compressed to about 12 psi and discharged to the condenser.

Between the condenser and the cooler on multistage units, the liquid refrigerant passes through an economizer. A float in the upper chamber of the economizer allows the passage of refrigerant into the lower chamber. By connecting the economizer to the second stage of the compressor—the pressure in the lower chamber is greatly reduced. This reduction of pressure causes some of the liquid refrigerant to flash into vapor and cools the remainder of the refrigerant. Thus, the economizer acts as an interstage flash cooler and increases the efficiency of the plant. A float in the lower chamber of the economizer allows the passage of the refrigerant into the cooler. In the cooler, the liquid refrigerant changes its state to a vapor and in so doing absorbs heat from the water.

Water is pumped through the cooler (fig. 13-6) where it loses heat to the refrigerant. The water leaves the cooler at 45°F to 50°F and is directed to the compartments to be cooled.

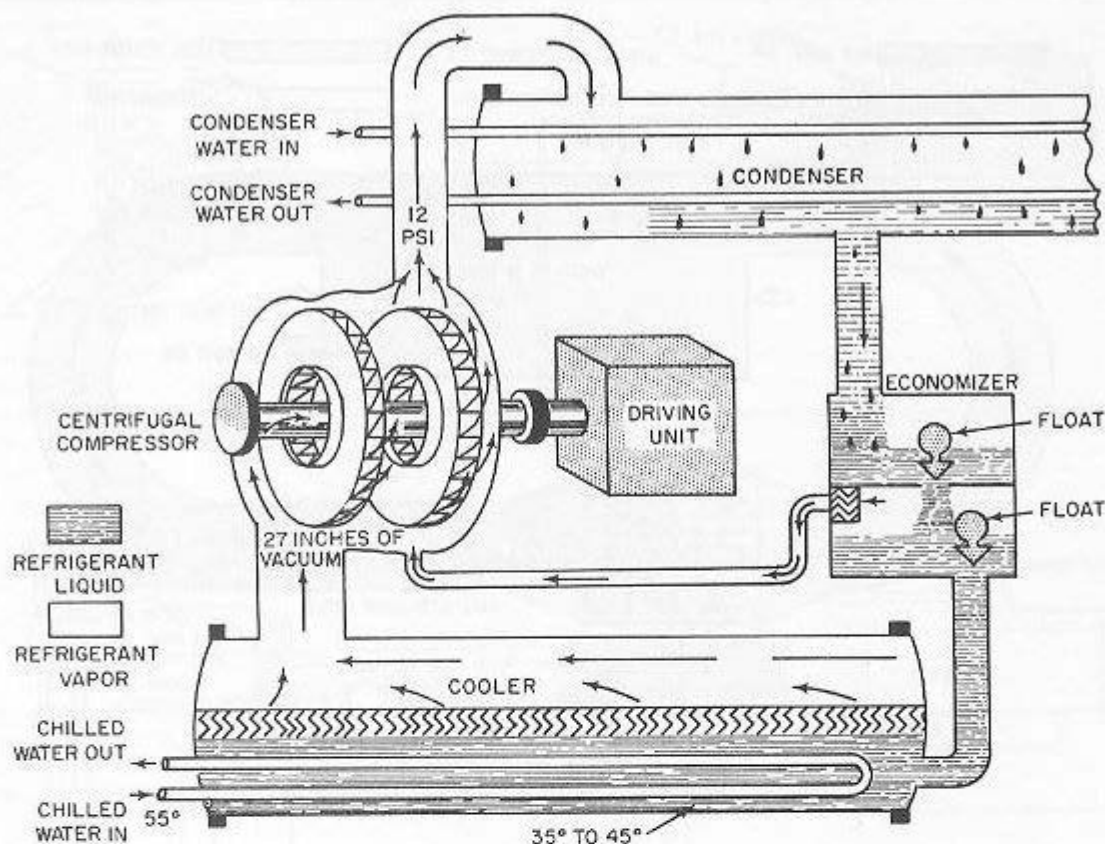
The centrifugal compressor (fig. 13-6) is of the two-stage type and consists of the casing, rotor, bearings, shaft, impellers, and shaft

seal. Centrifugal compressors are usually motor driven through a speed increasing gear which ensures proper compressor speed with a standard speed motor. The speed increasing gear is of the double-helical type, pressure lubricated by a gear-type oil pump, which is driven from the compressor shaft.

Some centrifugal compressors are turbine driven; in these compressors, a speed increasing gear is not necessary. On recently built warships, single-stage centrifugal compressors are used.

The chilled-water cooler is of the shell and tube type. A gas baffle is installed above the tubes to prevent the carryover of liquid refrigerant into the compressor suction. When the plant is shut down, the normal refrigerant charge covers about 50 percent of the tubes; however, when the plant is in operation, the boiling refrigerant covers all of the tubes.

The following controls and safety devices are typical of those installed on a centrifugal refrigerating system: (Control settings are approximate since they will vary with differences in design.)



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Figure 13-6.—Chilled water circulating system, with a centrifugal compressor.

1. The CONDENSER GAGE indicates the pressure corresponding to the condensing temperature.

2. The COOLER GAGE indicates the pressure corresponding to the evaporator temperature.

3. The OIL GAGE indicates the lube oil pressure within the lubricating system.

4. The HIGH PRESSURE SWITCH is actuated by the condenser pressure and is set to cut in at 5 psig and to cut out at 15 psig.

5. The COMPRESSOR LOW LUBE OIL PRESSURE SWITCH is actuated by the compressor oil pressure and is set to cut in at 12 psig and to cut out at 6 psig.

6. The GEAR LOW LUBE OIL PRESSURE SWITCH is actuated by the gear oil pressure and is set to cut in at 15 psig and to cut out at 6 psig.

7. The CONDENSER WATER PRESSURE FAILURE SWITCH is actuated by the sea water pressure and is set to cut in at 15 psig and to cut out at 5 psig.

8. The CHILLED WATER DIFFERENTIAL PRESSURE FAILURE SWITCH is actuated by the chilled water pressure and is set to cut in at 20 psig and to cut out at 16 psig.

9. The REFRIGERANT TEMPERATURE CONTROL SWITCH has its thermal bulb located in the cooler. It is set to cut out at 30°F and to cut in at 40°F.

10. The CHILLED WATER TEMPERATURE CONTROL SWITCH has its thermal bulb located in one of the tubes in the chilled-water cooler. It is set to cut out at 42°F and to cut in at 50°F.

11. The OIL HEATER START AND STOP BUTTON controls the electric heater located in the oil pump chamber of the compressor. The oil heater limits the amount of refrigerant absorption during shutdown. The heater should be turned on when the compressor is not running and turned off when the plant is operating.

The contacts of all safety devices are closed when normal conditions exist. Opening the contacts of any safety device stops the compressor.

After the cause of the abnormal condition has been determined and corrected, the compressor must be started in the usual way.

The centrifugal refrigerating unit operates on the usual compression cycle. The cycle, starting at the cooler, is as follows:

The water flowing through the cooler tubes is warmer than the refrigerant on the outside of the tubes. The heat transfer is from the water to the refrigerant. The heat evaporates the refrigerant. The evaporated refrigerant (vapor) is drawn into the compressor by the first-stage impeller. The first-stage impeller compresses the vapor and discharges it to the second-stage impeller. Here it joins a stream of vapor coming from the economizer. Compression of the two streams is completed by the second stage and the compressed vapor is discharged to the condenser.

In the condenser, the vapor condenses to a liquid and drains into the condenser float chamber. The rising refrigerant level opens the float valve and allows the liquid refrigerant to pass into the economizer chamber which has a connection to the second stage of the compressor. Enough of the liquid evaporates to cool the remainder to the temperature corresponding to the pressure in the economizer. As the liquid collects in the economizer float chamber, the rising level opens the float valve and allows the liquid to pass to the cooler.

Chilled-Water Circulating System (Absorption)

The chilled-water circulating system which operates on the absorption cycle differs from that which operates on the compression cycle in that it employs heat energy instead of mechanical energy to effect the change in conditions necessary to complete the refrigeration cycle. The compressor is supplanted by a heater or generator. Gas, steam, or an electric heating element may be employed as a heat source. In the system which operates on the absorption cycle, a solution of lithium bromide serves as an absorbant that maintains the necessary vacuum to evaporate and chill the water; the water is then pumped to the cooling coils. The lithium bromide-chilled water circulating system is currently being used on some naval ships.

The major parts of the system are two shell units, a heat exchanger, an eductor, and pumps. One unit contains the evaporator and the absorber; the other unit contains the generator and

the condenser. (See fig. 13-7.) The heat exchanger, eductor, and pumps are of conventional design.

The evaporator consists primarily of a spray pipe and water tank or receiver. The incoming water is sprayed into the upper half of the shell. Chilled water which has not vaporized is collected by the receiver part and returned to the chilled water system by means of a pump.

The absorber unit consists of a lithium bromide liquid solution spray pipe and sea water cooling coils. Salt water is pumped through these coils to cool the lithium bromide. The liquid solution is collected in the bottom of the shell.

The generator consists primarily of a steam coil, located in the bottom half of the shell. Steam, supplied by the ship, is passed through the tube nest to boil the liquid lithium bromide in which the tubes are submersed.

The condenser unit consists of a cooling coil and a condensate receiver or drain tank. Salt water which is piped from the absorber cooling coil, flows through the tube nest.

In a lithium bromide plant, chilled water is sprayed into a chamber within the evaporator in much the same manner as in the steam-jet refrigeration system (described in chapter 12 of this publication). The shell being under vacuum causes a small part of the water to flash into vapor, which cools the remaining water.

The vacuum in the shell is obtained by spraying a lithium bromide solution over the cooling coils of the absorber unit. The amount of vacuum maintained in the unit depends upon the concentration and temperature of the solution. This solution absorbs the water flashed in the evaporator. The salt water cooling coil functions to remove the heat of condensation and lower the temperature of the solution. The proper operation of the shell unit, containing the evaporator and the absorber, depends upon a high vacuum, a strong concentration of the lithium bromide solution, and a low temperature of the solution and shell space.

The preceding process would very quickly result in the dilution of the lithium bromide solution with the absorbed water from the chilled water system—a dilution which would reduce the absorbing action of the solution. Therefore, the water must be removed in order to keep a concentrated solution. This removal is accomplished by continuously draining part of the liquid from the primary lithium bromide solution system, and sending this liquid to the

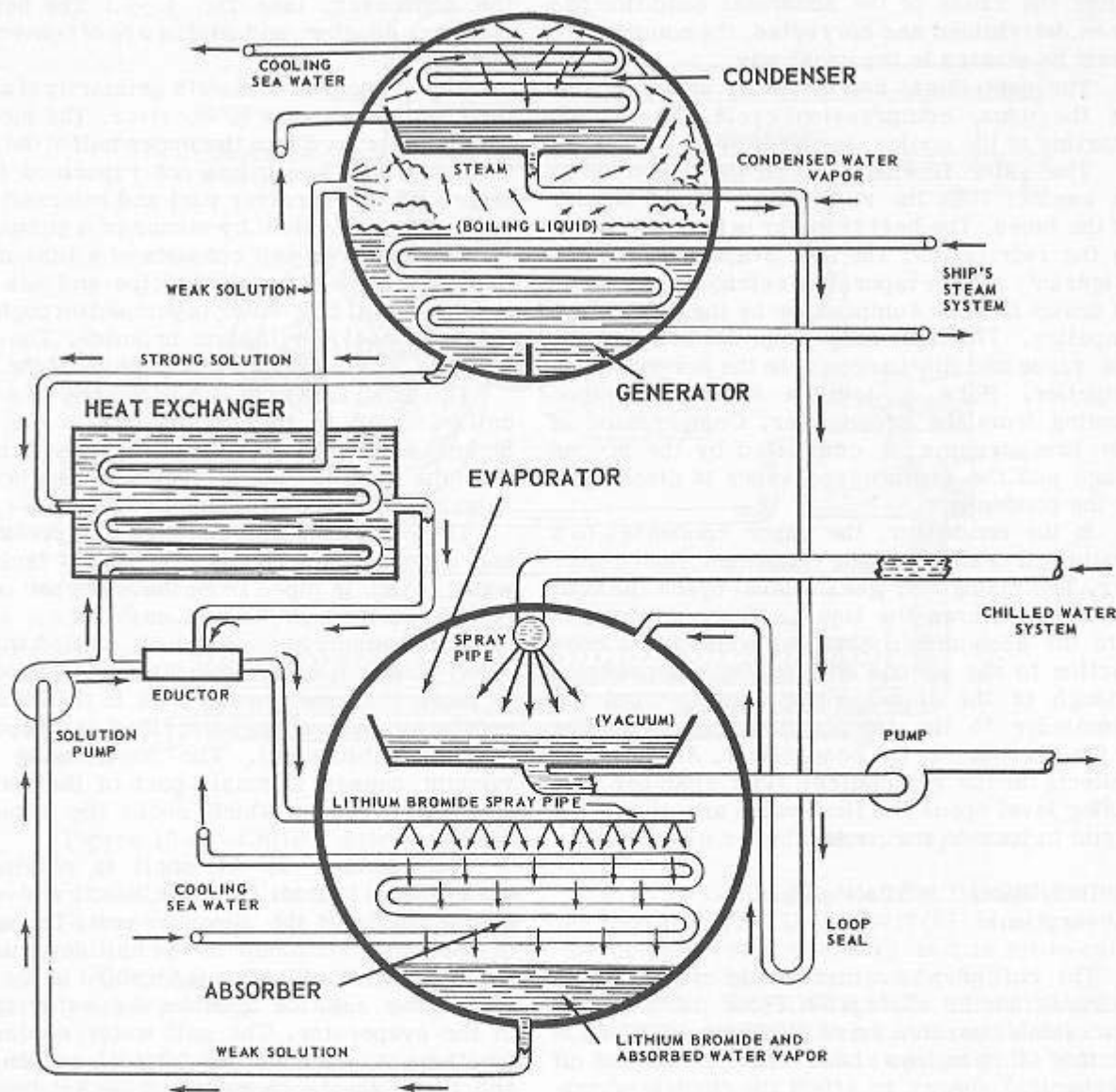


Figure 13-7.—Schematic drawing of the lithium bromide plant.

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generator, where the diluted or weak solution is boiled to remove the excess water. Steam coils are used to heat the liquid in the lower part of the generator shell.

The steam from the boiling liquid is condensed in the upper part of this shell. Salt water is circulated through the condenser to cool the steam and transform it back into water, which is then returned to the evaporator section. The concentrated lithium bromide is returned to the primary circulating system. The loop seal

maintains a difference in pressure between the two shells.

The heat exchanger is added to the plant to improve the efficiency and to reduce cooling water consumption. The strong solution will transfer its heat to the cool, weak solution which is to be boiled in the generator. The strong solution must be cooled to prevent it from carrying heat to the absorber unit.

Automatic devices and controls are added to operate or control the various piping systems.

Relief valves, gages, and thermometers are also included. A purge system, not shown in figure 13-7, is installed to remove air and noncondensable gases from the plant.

PACKAGED UNIT AIR CONDITIONERS

Packaged unit air conditioners are now being installed on some ships that were built without air conditioning. This type of air conditioner is built with the entire unit in one metal cabinet. Installation is simple; only the mounting brackets, electrical leads, and the cooling water lines are necessary for complete installation.

Compressing elements in packaged unit air conditioners are usually of the hermetic type (motor and compressor are contained in a welded steel shell). Repairing the compressor or motor aboard ship is not feasible; the assembly should be replaced as a unit.

Compressor discharge pressures vary from 120 psig to 200 psig, suction pressures vary from 30 psig to 65 psig. The temperature DROP of the air across the cooling coil is usually about 16°F to 18°F.

Some packaged unit air conditioners use a thermal expansion valve, similar to the type used on the ship's refrigeration plant; many types utilize one or more capillary tubes.

A capillary tube is a small copper tube with about 1/16-inch inside diameter. The tube acts as a restriction (or orifice) to reduce the pressure of the liquid refrigerant, just prior to its entering the cooling coil. The effect on the refrigerant is the same as when it passes through an expansion valve. Some air conditioners use as many as 11 capillary tubes to ensure an even flow of refrigerant throughout the cooling coil.

The high pressure and low pressure switches are set and sealed at the factory. The only adjustable controls are the water regulating valve and the thermostat. The principle of operation and the adjustment of the water regulating valve are the same as for the one used on the ship's refrigerating plant.

To set the thermostat, the following procedure may be used:

1. In the air conditioned compartment, place a thermometer at a point where the desired room temperature is of most importance.
2. Turn thermostat control to the coldest position.

3. When the desired temperature is reached, slowly turn the thermostat control toward the "warmer" position until the compressor stops.

HEATING EQUIPMENT

VENTILATION HEATERS (fig. 13-8) are installed in duct systems and are used wherever feasible, because of savings in weight, space, and piping. These heaters are built to withstand considerable shock and have standard connections to simplify piping. The copper tubes, through which the steam flows, are arranged in a single row.

Two different types of coil arrangements are employed. Part B of figure 13-8 shows the "S" arrangement with the tubing serpentine. The S-type is used in small size heaters. For large size heaters the S-type tube is not efficient.

Part C of figure 13-8 shows a "T" arrangement which has a copper tube within a tube (a 3/8-inch distributing tube inside a 5/8-inch outer tube). Steam pressures up to 150 psi may be used in these heaters.

Large ventilation supply systems, excepting those serving machinery spaces, are provided with a PREHEATER at or near the weather intake. By locating the heater near the intake, the duct temperature is kept high enough to avoid condensation during cold weather operation.

In systems employing the preheater, a REHEATER (or reheaters) is also provided. In recirculating cooling systems, reheaters are usually provided to maintain specified space temperatures during cold weather operation.

Reheaters supply either single spaces or zones. Zones are made up of spaces that are expected to have similar heat loads. Reheaters are controlled by room thermostats. In recirculating cooling systems on the newer ships, the reheaters are supplied from constant steam lines and reheat air to any zone which would be overcooled.

In small ventilation systems employing short duct runs where one heater will produce the required temperature rise, the COMBINATION HEATER is used alone. Combination heaters may also be used with reheaters where it is desired that the system supply more than one space but where the combination heater is sufficient to maintain the required temperature rise in one of the spaces.

CONVECTION HEATERS (fig. 13-9) are installed in small spaces or in spaces which are not fitted with mechanical supply ventilation. These heaters have a high heating capacity for their size and weight, are considerably smaller than radiators or pipe-coils of the same capacity, and will withstand severe shock. A steam pressure up to 150 psi may be used in the heaters, or a forced hot water system may be employed. When they are used with steam pressure between 25 and 50 psi, temperature differentials at different levels in the room are reduced. The heating is regulated with the air bypass damper in the front part of the heater. The cabinets are generally of steel, though they may be (if desired) of nonmagnetic stainless steel, copper, or aluminum.

UNIT HEATERS (see fig. 13-10) are actually ventilation heaters installed separately with their own fans. They are used in special cases such as when the amount of supply ventilation is too small to provide sufficient heat through ventilation heaters, or where there is no mechanical ventilation supply and the heat requirements exceed the capacity of convection heaters. They can be used with either steam pressure up to 150 psi or with forced hot water systems. Composite parts of the heaters include the tubing, heat transfer fins, fan, thermostatic con-

trol valve, strainer, trap, and heat direction blowers.

ELECTRIC HEATERS are used for spaces located at a considerable distance from the steam piping system. They are built in many types and designs.

MAINTENANCE OF AIR CONDITIONING EQUIPMENT

To ensure proper operation of any air conditioning system, periodic inspection and maintenance is absolutely necessary. Each ship should have an organization responsible for the maintenance of ventilating, heating, and cooling equipment.

VENTILATION EQUIPMENT

Shipboard ventilation must serve not only to supply, circulate, and distribute fresh air, but also to remove the used, contaminated, and overheated air from the various spaces. If the ventilation equipment fails to perform its functions properly, conditions may be created which will jeopardize the health or life of crew members. Therefore, the individuals responsible for inspection and maintenance must be thoroughly familiar with the ventilation equipment.

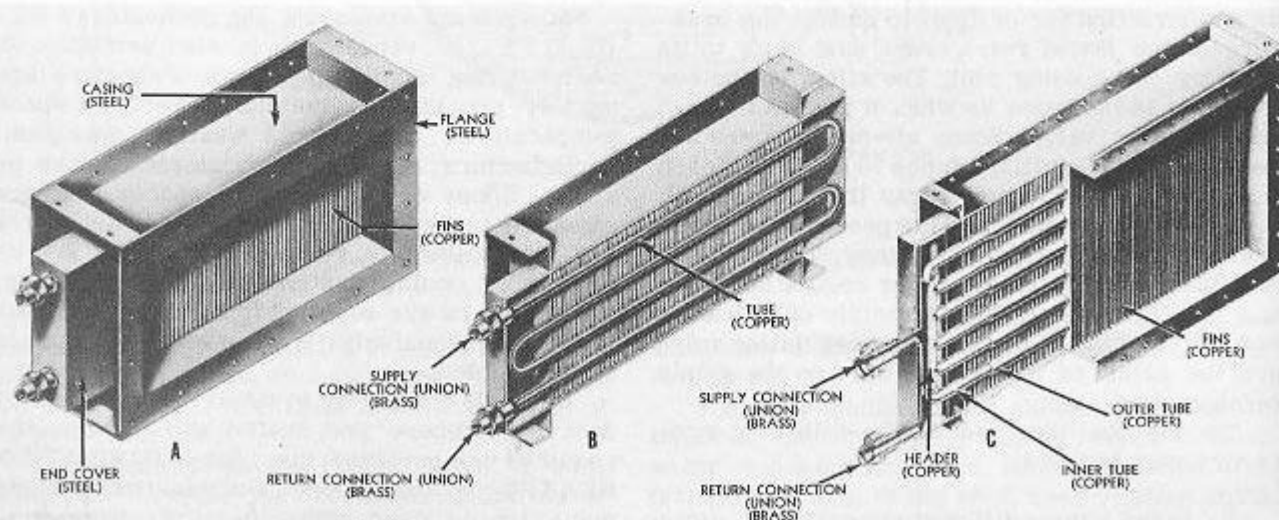


Figure 13-8.—Ventilation heaters: A. Exterior view of S-type heater. B. Tube arrangement of S-type heater. C. Tube arrangement of T-type heater.

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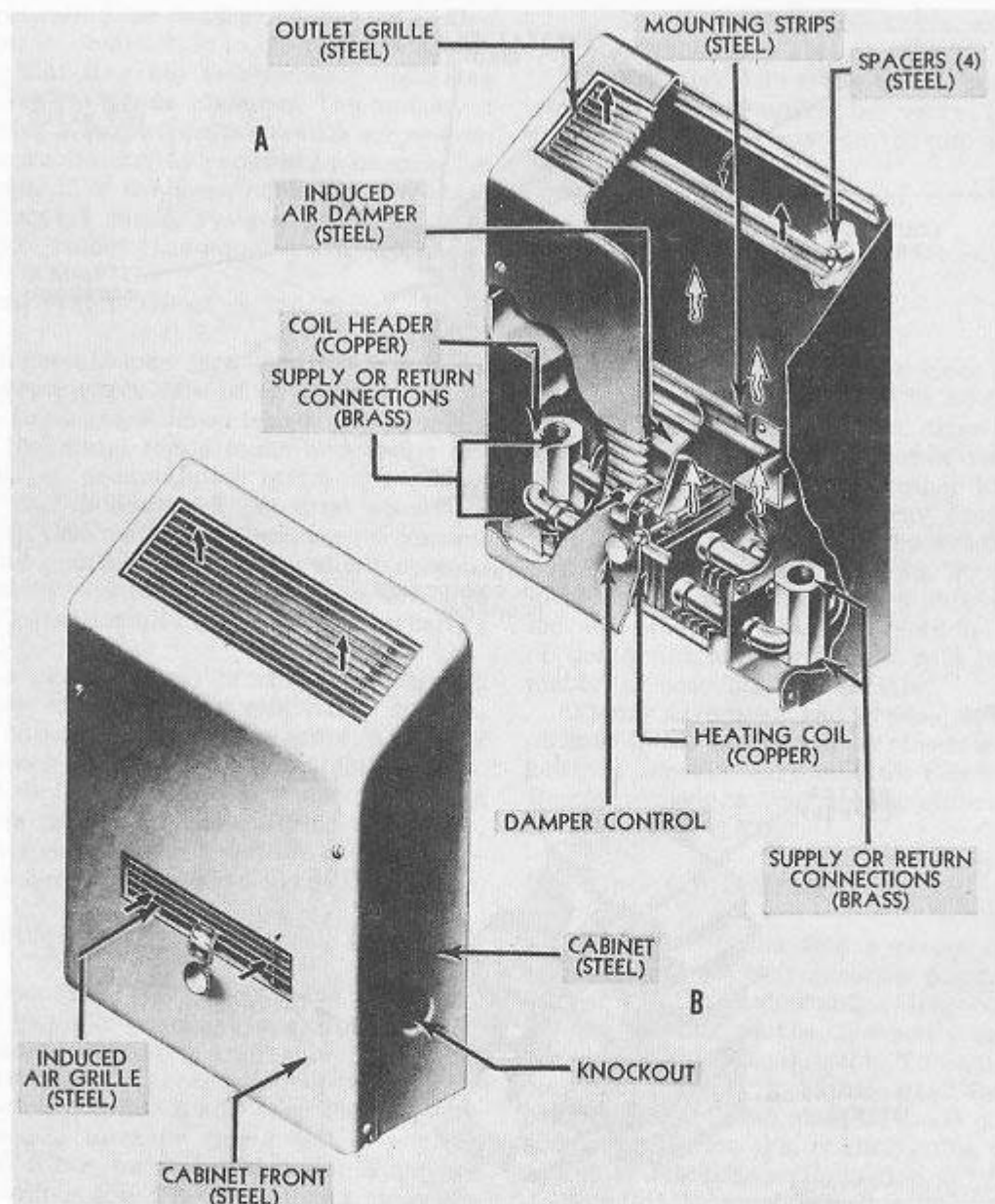


Figure 13-9.—Convection heater: A. Cutaway view. B. Exterior view.

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A shipboard ventilation system and its constituent parts cannot be isolated and separated from other component systems in a complete air conditioning system. For example, the air duct distribution system of a ship may be utilized for other systems used in cooling, heating, and dehumidifying the ship's atmospheric air. In addition to ducts, a ventilation system may include

weather openings, screens, filters, fans, gratings, closures, heaters, cooling coils, venturi tubes, dampers, and terminals. Obviously, if a ventilation system is to function effectively, it is essential that all of its various units be kept clean and in satisfactory operating condition. To maintain a ventilating system in the best condition requires the observance of applicable

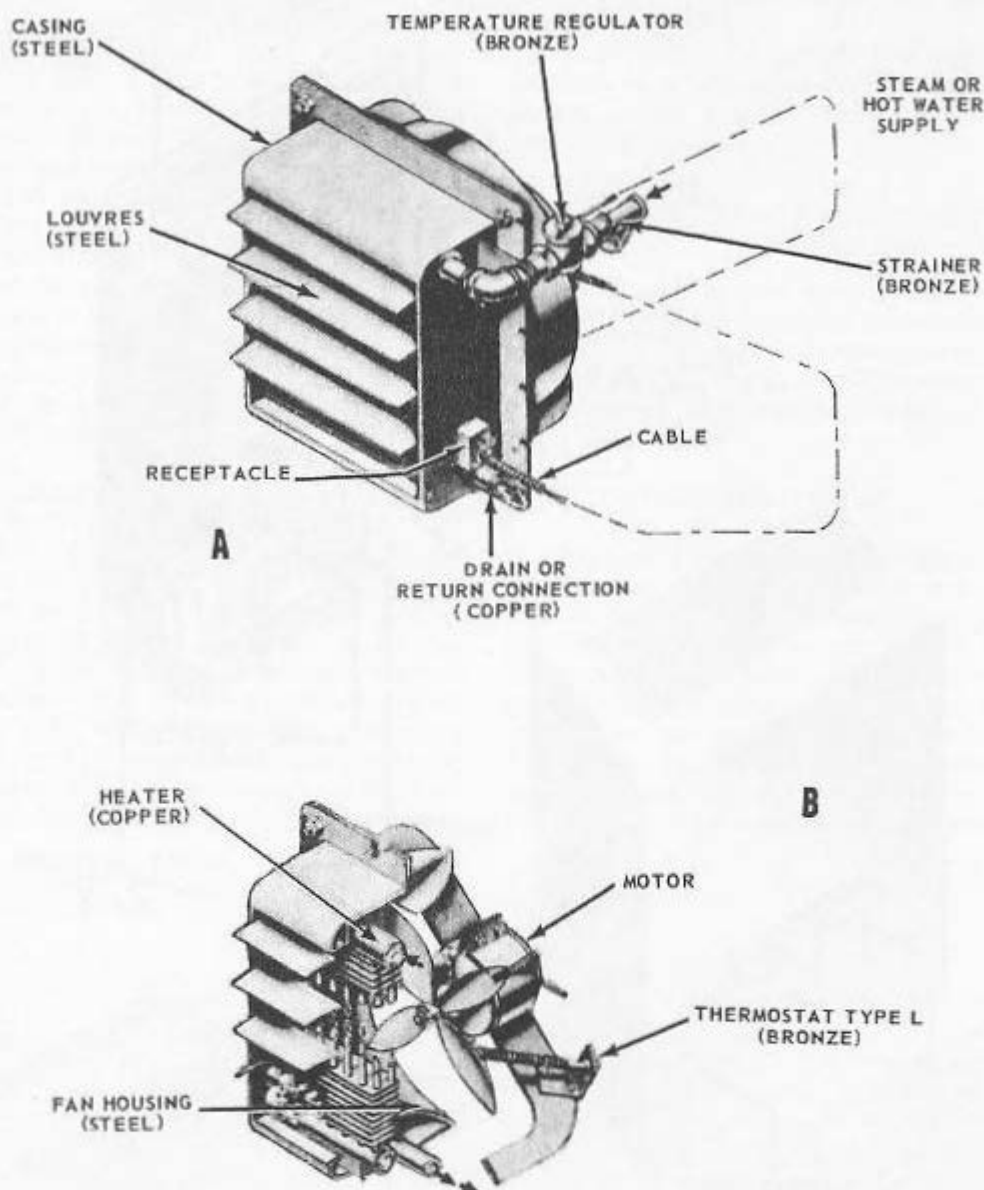


Figure 13-10.—Unit heater: A. Exterior view. B. Cutaway view.

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precautionary measures, and the adherence to prescribed maintenance procedures.

Guarding Against Obstructions To Ventilation

Such items as swabs, deck gear, and trash stowed in fan rooms or ventilation trunks not only restrict air flow but also increase dirt and

odors taken on board. Ventilation terminals must never be used for stowage. Wet clothing secured to ventilation terminals increases the moisture content of the compartment air, and restricts the air flow. Stowage arrangements should be such that ventilation weather openings are never restricted.

Do not use gauze or similar material as a filter over an air supply terminal. Gauze may

aid in preventing the passage of dirt but it also serves as an obstruction to the passage of air. The fact that filtering is necessary indicates that the system needs cleaning. The amount of dirt entering a space from the ventilation system can be most effectively reduced by keeping the ducts clean. If it becomes necessary to place a filter in an air supply system, place the filter at the intake rather than supply terminals.

Keeping the System Clean

Dirt accumulations in a ventilation system not only restrict the flow of air but also create a serious fire hazard. In a clean duct the cooling effect of the metal tends to act as a flame arrester, but an accumulation of foreign matter within a duct becomes a potential source of combustion. One method of reducing the amount of dirt and combustible matter which may be carried into a ventilation system is to wet down the areas in the vicinity of the air intakes before sweeping.

Since a great volume of air passes through or over the elements of a ventilation system, dirt will collect in the various units in spite of precautionary measures. The greatest accumulations of dirt will be within trunks and ducts where it is not readily noticeable. Therefore, periodic inspections and a definite service procedure are necessary to keep the system clean.

Cleaning Filters

Navy standard air filters have automatic filter load gages or pressure taps on each side of the filter bank. By use of a portable differential pressure gage, the pressure drop across the filter may be quickly read. When the pressure drop increases to three times that of a clean filter, the filter must be cleaned. Ships are provided with spare filters so that a clean one may be substituted for the dirty one. A systematic procedure may be set up for cleaning all filters on the ship.

Where there are only a few filters aboard ship, they may be cleaned in the galley dishwashing machine. Ships having a sufficient number of filters to justify the space, expense, and weight are supplied with special cleaning sinks. In either case, filters are washed with dishwashing compound, used in accordance with the current dishwashing instructions.

If a special cleaning sink is used, the following procedure should be performed:

1. Place filters in the wire basket, one filter deep, with the dirty side up.
2. Fill sink with fresh water, cut steam into sink to heat and agitate the water. (Most of the lint and dirt will rise to the top and pass off with the overflow.)
3. When filters are clean, cut off the steam and drain the sink.
4. Refill sink with fresh water, cut steam into sink and rinse filters.
5. Recoil filters.

Navy standard air filters have a thin film of oil applied to the wires. The oil film retains fine particles of dirt and lint. After each washing, the filters may be recoiled by spraying with 2075 oil or a filter adhesive other than the type in pressurized (aerosol) spray cans, provided it is nontoxic, odorless, water soluble, and has a flash point greater than 350°F. Spray guns furnished for oiling air filters must not be used for any other purpose, to avoid the possibility of contaminating the filters with toxic, flammable, or odor laden materials.

Flame arresters and grease filters may be cleaned in the manner prescribed for air filters, however, special care must be taken in rinsing. Flame arresters and grease filters **SHOULD NEVER BE OILED.**

COOLING EQUIPMENT

Since air conditioning systems are in many ways similar to refrigeration plants, much of the information concerning refrigeration, given in this training course, is equally applicable to air conditioning equipment. To ensure proper operation of any R-12 air conditioning plant, periodic inspections must be made of compressors, valves, motors, cooling coils, air filters, and other installed equipment.

Some of the most important inspections necessary for air conditioning plants are listed in the following paragraphs. (Note: On ships where the Planned Maintenance System is in effect, inspection schedules are observed in accordance with that system.)

Daily Inspections

The following inspections should be performed daily:

1. Check all motors for overheating.
2. Check oil level in the crankcases of the compressors every 2 hours.

3. Check for excessively high and low refrigerant pressures.

4. Check crankcases for low temperatures or excessive liquid R-12 returning to the crankcase.

Weekly Inspections

Weekly inspections and maintenance should be performed as follows:

1. Check all fans for unusual noise and vibration.

2. Check all regularly operated valves and compressor seals for leaks.

3. Check V-belts for proper tension.

4. Check flywheels, pulleys, and flexible couplings.

5. Clean evaporator coils which are not protected by filters.

6. Clean and dust all equipment.

7. Clean air filters.

8. Check all systems for refrigerant leaks.

Monthly and Quarterly Inspections

Every month, a check of the system should be made, as follows:

1. Check V-belts for wear, and clean off all oil and dirt.

2. Check and clean all automatic control and safety devices, also all switch contacts.

3. Check and clean condenser tubes when refrigerant or water temperatures indicate the need.

4. Inspect evaporator coils; clean them at least every 3 months, and more often if necessary.

5. Inspect the zinc fingers in the condensers; replace the zinc when deterioration amounts to 50 percent or more.

Yearly Inspections

The following inspections should be made at least once a year:

1. Disassemble motors and inspect and clean motor windings, as required.

2. Inspect motor bearings; clean and lubricate as necessary.

3. Wash out fan bearings, unless they are of the new type that requires no cleaning or oiling; check clearance; refill with new oil.

4. Check rusting of metal parts on all equipment.

5. Check all ball bearings; add grease when necessary.

6. Test all gages at least once each year, more often if necessary.

7. Inspect all insulation coverings of cold pipes, especially seams. Replace all rusted binding wires and rotted covering cloths; add seam filler where necessary.

In addition to inspections, safety precautions must be observed. Refer to the section on safety precautions in chapter 12 (Refrigeration Plants) of this publication. These precautions are equally applicable to air conditioning plants.

CHAPTER 14

AIR COMPRESSORS

Compressed air has many uses aboard ship. Some of the common uses of compressed air are as follows:

1. Operation of pneumatic tools.
2. Cleaning electrical machinery, fuel oil atomizer tips, and CO₂ indicator systems.
3. Ejecting gas from ship's guns.
4. Starting diesel engines.
5. Charging and firing torpedoes.
6. Operating pneumatic control systems.
7. Control air for boiler combustion control systems.

Compressed air is supplied to the various systems by high pressure, medium pressure, or low pressure air compressors, as appropriate. Reducing valves reduce a high pressure to a lower pressure for a specific system.

AIR COMPRESSOR CLASSIFICATIONS AND COMPONENTS

There are a number of variations in the design and construction of air compressors. The construction and principles of operation of some of the most common types of air compressors, used on Navy ships, are discussed in this section. The remaining sections of the chapter cover operating procedures, care and maintenance, inspections and tests, and safety precautions for compressors.

COMPRESSOR CLASSIFICATIONS

Air compressors are classified in various ways. A compressor may be single-acting or double-acting, single stage or multistage, and horizontal, angle, or vertical, as shown in figure 14-1. A compressor may be designed so that ONLY one stage of compression takes place within one compressing element, or so that more than one stage takes place within one compress-

ing element. In general, compressors are classified according to the type of compressing element, the source of driving power, the method by which the driving unit is connected to the compressor, and the pressure developed.

Types of Compressing Elements

Air compressor elements may be of the centrifugal, rotary, or reciprocating types. Most of the compressors used in the Navy have reciprocating elements (fig. 14-2). In this type of compressor the air is compressed in one or more cylinders, very much like the compression which takes place in an internal combustion engine.

Source of Power

Compressors are driven by electric motors, internal combustion engines, steam turbines, or reciprocating steam engines. Most of the air compressors in naval service are driven by electric motors.

Drive Connections

The driving unit may be connected to the compressor by one of several methods. When the compressor and the driving unit are connected on the same shaft, and mounted on a common base, they are close coupled. Another means of close coupling is with the use of a flexible coupling. Flexible couplings are normally used when the driving unit and the compressor are not mounted on a common base.

V-belt drives are commonly used with small, low pressure, motor-driven compressors, and with some medium pressure compressors. In a few installations, a rigid coupling is used between the compressor and the motor. In a steam turbine drive, compressors are usually driven through reduction gears.

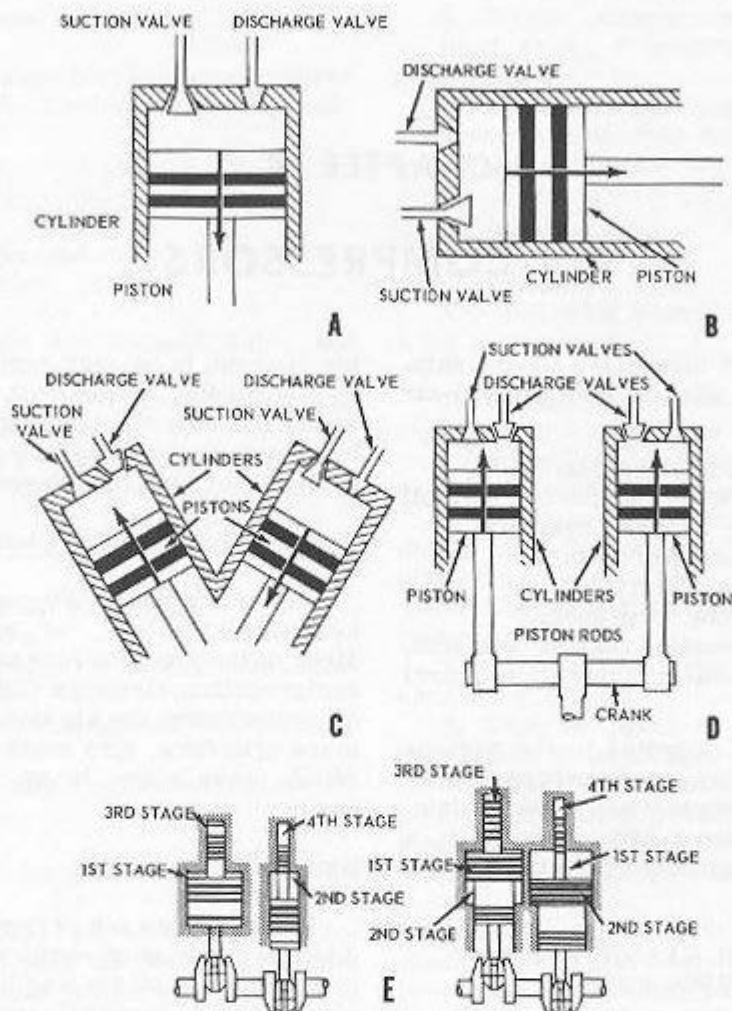


Figure 14-1.—Types of air compressors: A. Vertical. B. Horizontal. C. Angle. D. Duplex. E. Multistage.

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Pressure Classification

Compressors are classified as low pressure, medium pressure, or high pressure. Low pressure compressors are those which have a discharge pressure of 150 psi or less. Medium pressure compressors are those which have a discharge pressure of 151 psi to 1000 psi. Compressors which have a discharge pressure above 1000 psi are classified as high pressure.

Most low pressure air compressors are of the two-stage type with either a vertical V (see fig. 14-2) or a vertical W arrangement of cylinders. Two-stage, V-type low pressure com-

pressors usually have one cylinder for the first (low pressure) stage of compression, and one cylinder for the second (high pressure) stage. W-type compressors have two cylinders for the first stage of compression, and one cylinder for the second stage. This arrangement is shown in figure 14-3A.

Compressors may be classified according to a number of other design features or operating characteristics.

Medium pressure air compressors are of the two-stage, vertical, duplex, single-acting type. Many medium pressure compressors have differential pistons; this type of piston has more

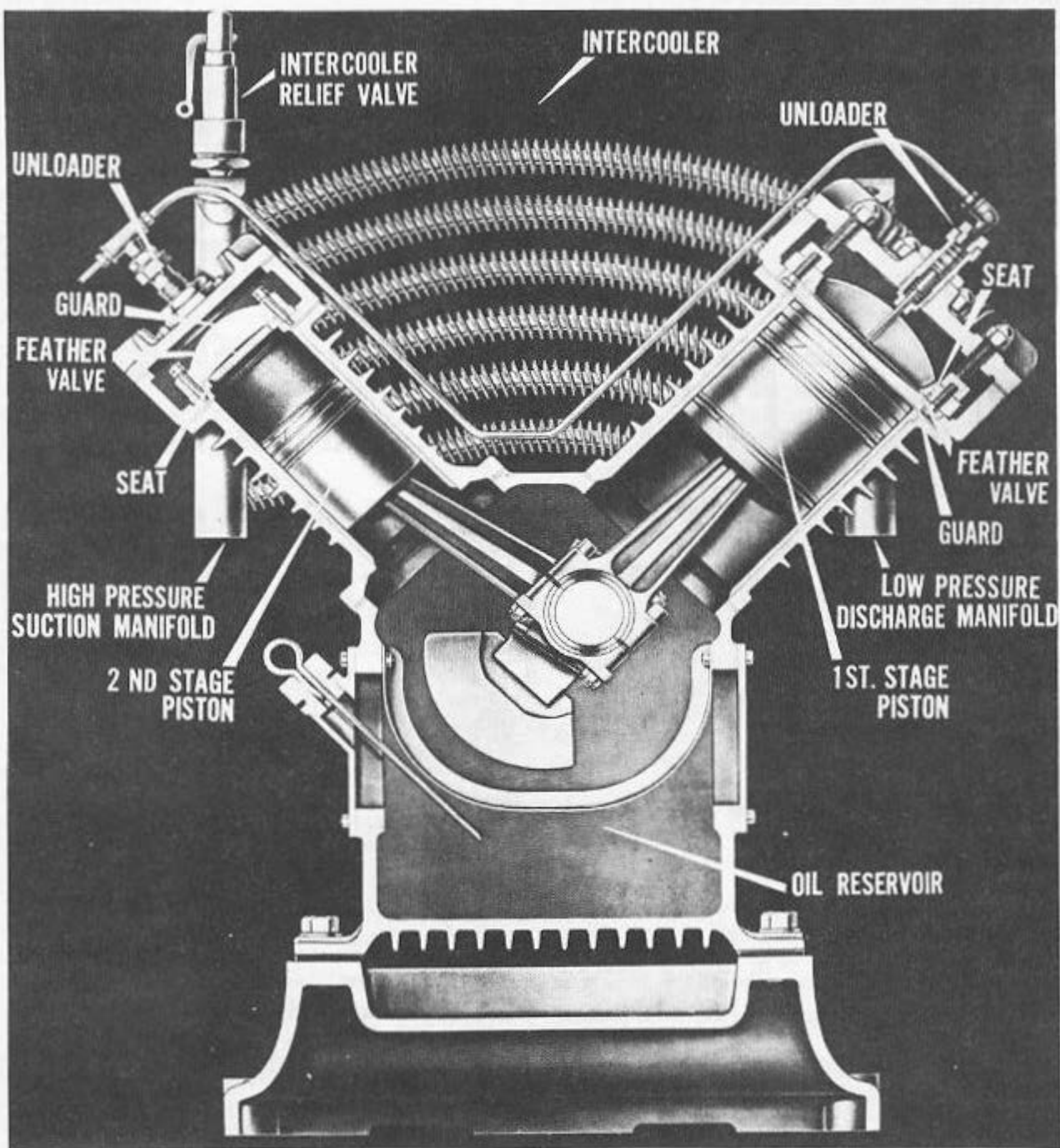


Figure 14-2.—A simple two-stage reciprocating low pressure air compressor.

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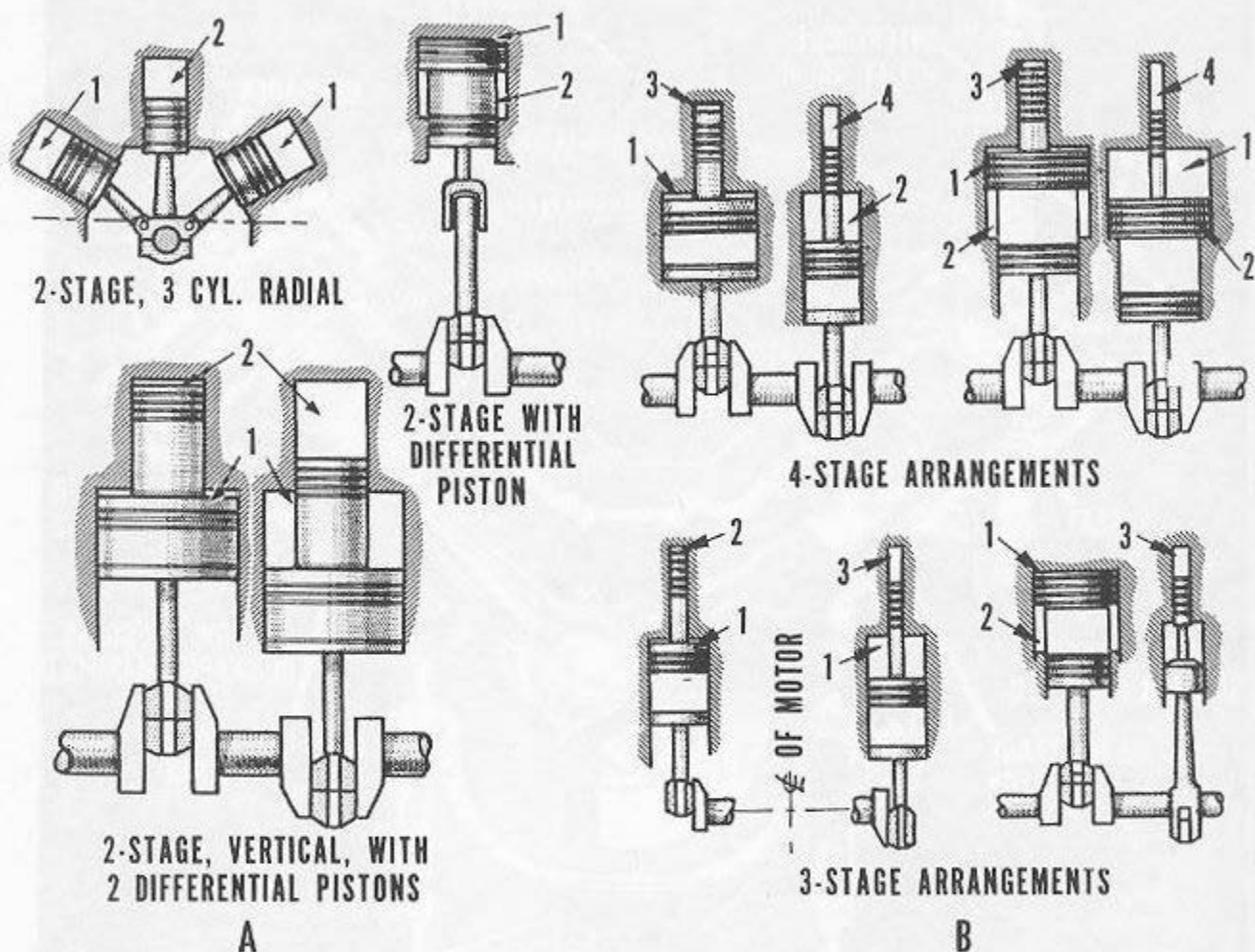


Figure 14-3.—Air compressor cylinder arrangements:

- A. Low and medium pressure cylinders.
B. High pressure cylinders.

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than one stage of compression on each piston. (See fig. 14-3A.)

Modern air compressors are generally motor-driven (direct or geared), liquid cooled, four-stage, single-acting units with vertical or horizontal cylinders. Cylinder arrangements for high pressure air compressors installed on Navy ships are illustrated in figure 14-3B. Small capacity high pressure air systems may

have three-stage compressors. However, high pressure air systems usually are equipped with four- to six-stage compressors.

OPERATING CYCLE OF RECIPROCATING AIR COMPRESSORS

Before proceeding with the components of air compressors, it will be most helpful for you

to be familiar with the operating cycle of air compressors. Since most of the compressors used by the Navy have reciprocating elements, the sections which follow deal with the operating cycle and component parts of reciprocating air compressors.

Reciprocating air compressors are usually similar in design and operation. The following discussion relates to the operating cycle during one stage of compression in a single-stage, single-acting compressor.

The cycle of operation, or compression cycle within an air compressor cylinder includes two strokes of the piston: a suction stroke and a compression stroke. The suction stroke begins when the piston moves away from TOP DEAD CENTER (TDC). The air under pressure in the clearance space (above the piston) expands rapidly until the pressure falls below the pressure on the opposite side of the inlet valve. At this point, the difference in pressure causes the inlet valve to open; and air is admitted to the cylinder. Air continues to flow into the cylinder until the piston reaches BOTTOM DEAD CENTER (BDC).

The compression stroke starts as the piston moves away from BDC; compression of the air begins. When the pressure in the cylinder equals the pressure on the opposite side of the air inlet valve, the inlet valve closes. Air is increasingly compressed as the piston moves toward TDC, until the pressure in the cylinder becomes great enough to force the discharge valve open against the discharge line pressure and the pressure of the valve springs. (The discharge valve opens a few degrees before the piston reaches TDC.) During the balance of the compression stroke, the air which has been compressed in the cylinder is discharged, at an almost constant pressure, through the open discharge valve.

The basic operating cycle just described is repeated a number of times in double-acting compressors and in other stages of multistage compressors. In a double-acting compressor, each stroke of the piston is a suction stroke in relation to one end of the cylinder, and a compression stroke in relation to the other end of the cylinder. In a double-acting compressor, therefore, two basic compression cycles are always in process when the compressor is operating; but each cycle, considered separately, is simply one suction stroke and one compression stroke.

In multistage compressors, the basic compression cycle must occur at least once for each stage of compression. If the compressor is designed with two compressing elements for the first (low pressure) stage, two compression cycles will be in process in the first stage at the same time. If the compressor is designed so that two stages of compression occur at the same time in one compressing element, the two basic compression cycles (one for each stage) will occur at the same time. In each stage, air is compressed to the designed working pressure of that particular stage and is then discharged to the stage having the next highest working pressure, with the last stage discharging to the receiver.

COMPONENT PARTS OF RECIPROCATING AIR COMPRESSORS

Reciprocating air compressors consist of a system of connecting rods, crankshafts, and flywheels used to transmit the power developed by the driving unit to the pistons; and also consist of compressing elements, lubrication systems, cooling systems, control systems, and unloading systems.

Compressing Element

The compressing element of a reciprocating compressor consists of the air valves, the cylinder, and the piston.

The VALVES of modern compressors (except for some high pressure compressors aboard submarines) are of the automatic type. The opening and closing of these valves is caused solely by the difference between (1) the pressure of the air in the cylinder and (2) the pressure of the external air on the intake valve or the pressure of the discharged air on the discharge valve. On most compressors, a thin plate, low lift type of valve is used (fig. 14-4.)

Various designs of CYLINDERS and PISTONS are used, depending primarily upon the number of stages of compression which take place within a cylinder. The three most common cylinder arrangements for low and medium pressure air compressors are shown in figure 14-3A. High pressure compressors with four-stage arrangements and three-stage arrangements are shown in figure 14-3B. The numbers 1 through 4 in figure 14-3 represent the stages of compression. Five- and six-stage compressors have the same basic stage arrangements.

The PISTONS may be of two types, trunk pistons and differential pistons. TRUNK PISTONS (fig. 14-5A) are driven directly by the connecting rods. Since the upper end of a connecting rod is fitted directly to the piston wrist pin, there is a tendency for a piston to develop a side pressure against the cylinder walls. To distribute the side pressure over a wide area of the cylinder walls or liners, trunk pistons with long skirts are used. This type of piston tends to eliminate cylinder wall wear. DIFFERENTIAL PISTONS (fig. 14-5B) are modified trunk pistons having two or more different diameters. These pistons are fitted into special cylinders which are arranged so that more than one stage of compression is served by one piston. The compression for one stage takes place over the piston crown; compression for the other stage(s) takes place in the annular space between the large and small diameters of the piston.

Lubrication System

Lubrication of air compressor cylinders is generally accomplished by means of a mechanical force-feed lubricator, which is driven from a

reciprocating or a rotary part of the compressor. Oil is fed from the lubricator, by a separate feed line, to each cylinder. A check valve is installed at the end of each feed line to keep the compressed air from forcing the oil back into the lubricator. Each feed line is equipped with a sight-feed glass. Lubrication begins automatically as the compressor starts up. The amount of oil that must be fed to the cylinders depends upon the cylinder diameter, the cylinder wall temperature, and the viscosity of the oil.

On small low pressure and medium pressure compressors, the cylinders are lubricated by the splash method, from dippers on the ends of the connecting rods, instead of by a mechanical lubricator.

Lubrication of the running gear of a modern compressor is accomplished by an oil pump, which is attached to the compressor and is driven from the compressor shaft. This pump (usually of the gear type) draws oil from the reservoir (fig. 14-6) in the compressor base and delivers it, through a filter, to an oil cooler (fig. 14-7). From the cooler, the oil is distributed to the top of each main bearing, to spray nozzles for reduction gears, and to outboard bearings. The crankshaft is drilled so that oil fed to the main

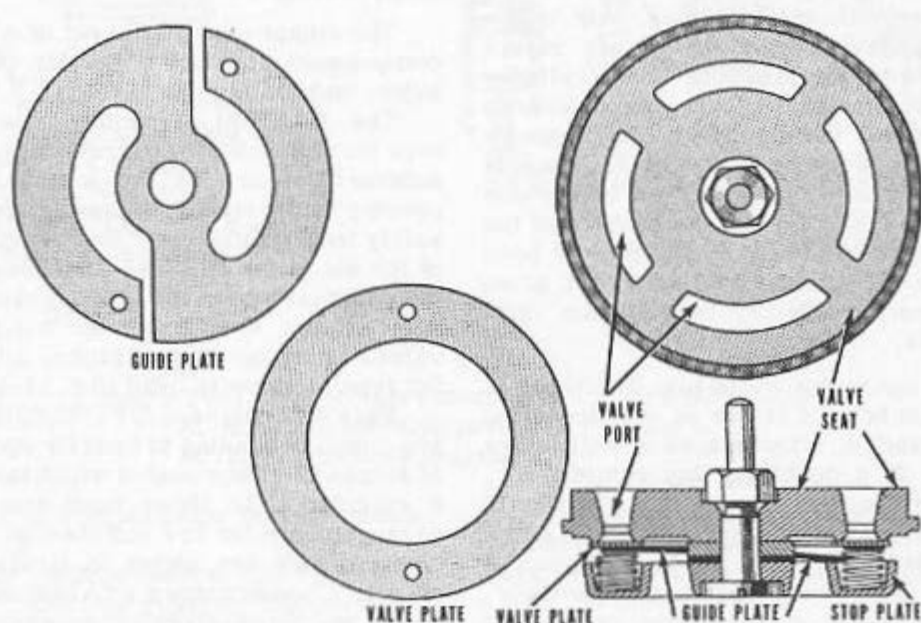


Figure 14-4.—Diagram of a thin plate air compressor valve.

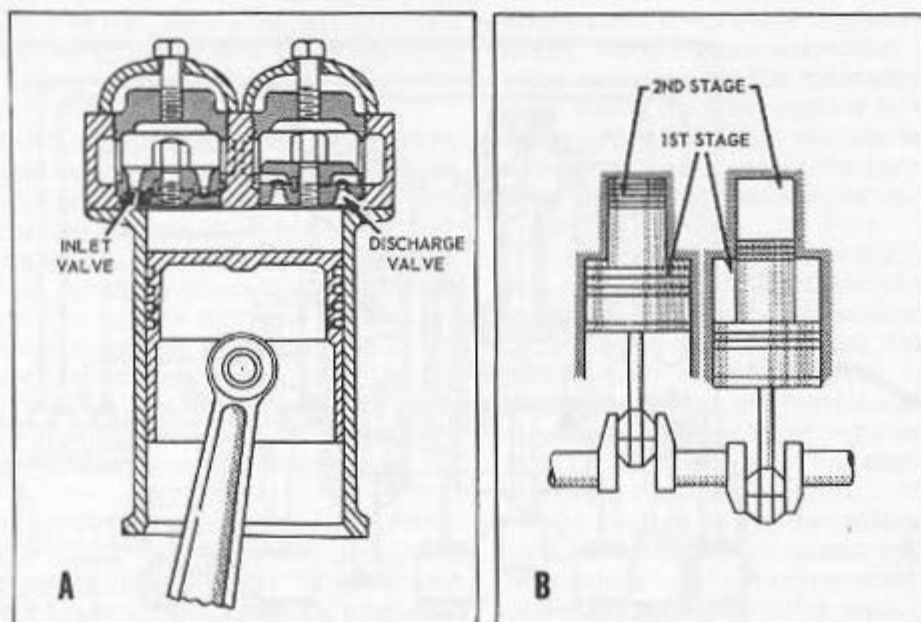


Figure 14-5.—Air compressor pistons: A. Trunk type. B. Differential type.

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bearings is picked up at the main bearing journals and carried to the crank pin journals. The connecting rods contain passages which conduct lubricating oil from the crank pin bearings up to the wrist pin bushings. As oil leaks out from the various bearings, it drips back to the reservoir (in the base of the compressor) and is recirculated. Oil from the outboard bearings is carried back to the base by the drain lines.

The discharge pressure of lubricating oil pumps varies with different pump designs. A relief valve, fitted to each pump, functions when the discharge pressure exceeds the pressure for which the valve is set. When the relief valve functions, excess oil is returned to the reservoir.

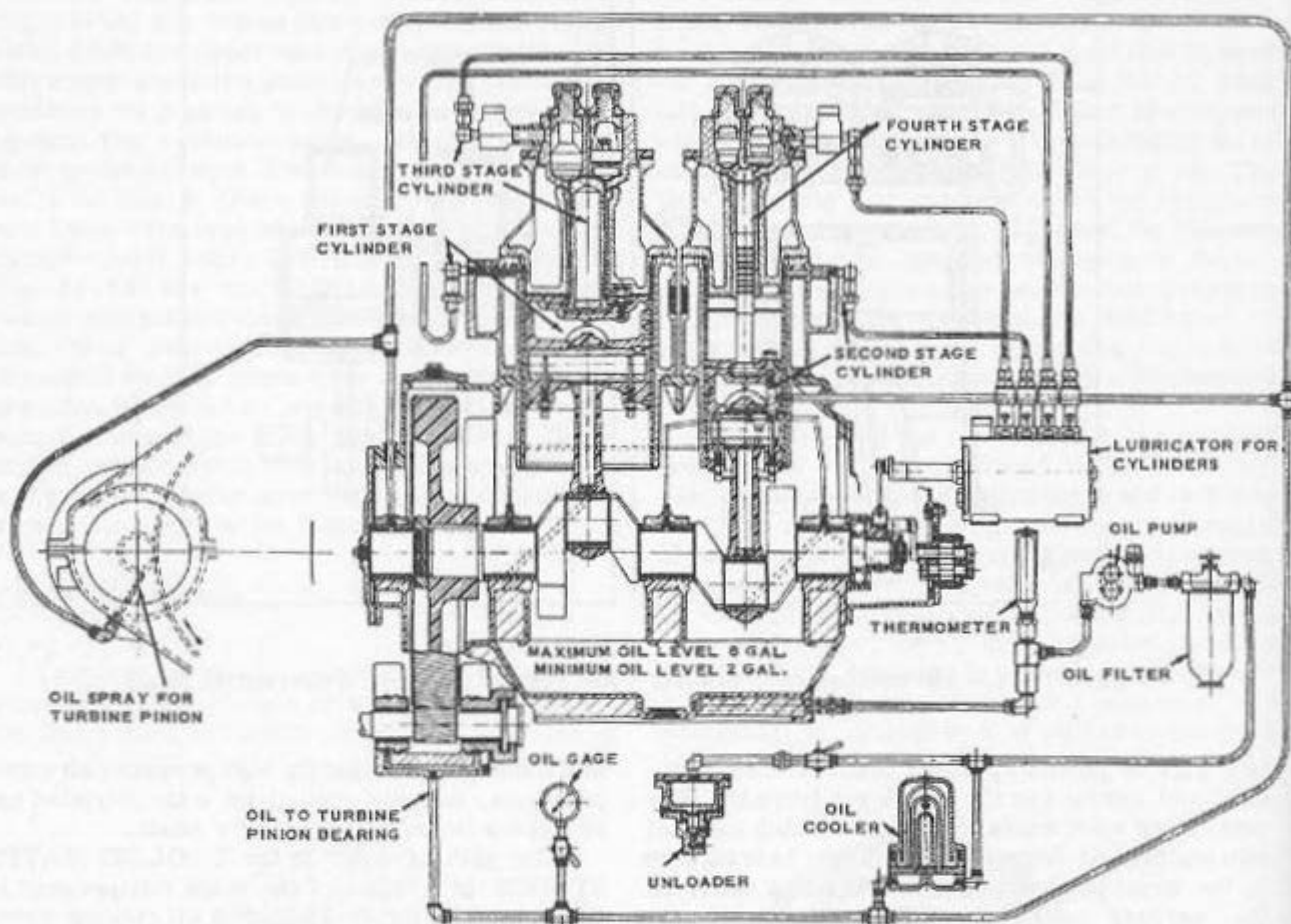
Cooling Systems

Most high pressure and medium pressure compressors are cooled by sea water supplied from the ship's fire, flushing, or water service mains. The cooling water is generally available to each unit through at least two sources. Compressors located outside the larger machinery spaces are generally equipped with an attached circulating water pump as a standby source of cooling water. Small low pressure compressors for ship's service and diesel engine starting,

and some small capacity high pressure air compressors, are air cooled by a fan mounted on, or driven from, a compressor shaft.

The path of water in the COOLING WATER SYSTEM of a typical four-stage compressor is illustrated in figure 14-7. Not all cooling water systems have identical paths of water flow, but in all systems it is important that the coldest water be available for circulation through the oil cooler. Valves are usually provided so that the water to the oil cooler can be controlled independently of the rest of the system. Thus oil temperature may be controlled without harmfully affecting other parts of the compressor. Next in importance are the inter coolers and after coolers, then come the cylinder jackets and heads. The high pressure air compressors require anywhere from 6 to 25 gallons of cooling water per minute, while medium pressure air compressors require from 10 to 20 gallons per minute.

Since sea water is used as the cooling agent, all parts of the circulating system must be of corrosion-resisting materials. The cylinders and heads are therefore composed of gun metal or valve bronze composition, with water jackets cast integral with the cylinders. Each cylinder is fitted with a liner of special cast iron or steel



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Figure 14-6.—Lube oil system of a multistage turbine-driven high pressure air compressor.

to withstand the wear of the piston. The cylinder jackets are fitted with handholes and covers so that the water spaces may be inspected and cleaned. Jumpers are generally used to make water connections between the cylinders and heads, since these prevent any possibility of leakage into the compression spaces. In some compressors, however, the water passes directly through the joint between the cylinder and the head. With this latter type, extreme care must be taken to ensure that the joint is properly gasketed to prevent leakage which, if allowed to continue, would ruin both the cylinder liner and the piston rings.

The INTER COOLERS and AFTER COOLERS remove the heat generated during compression and cause the condensation of any vapor that may be present. This prevents unwanted accumula-

tion at low points, water hammer, freezing or bursting of pipes in exposed locations, faulty operation of pneumatic tools, and possible damage to electrical apparatus where air is used for cleaning. The removal of heat is also required for economical compression. During compression the temperature of the air is increased, thus causing the air to expand to a larger volume which, in turn, requires a corresponding increase of work to compress it. Multistaging, therefore, with cooling of the air between stages, reduces the power requirement for a given capacity. The intercooling reduces the maximum temperature in each cylinder and thereby reduces the amount of heat which must be removed by the water jacket at the cylinder. Also, the resulting lower temperature in the cylinder ensures good lubrication of the piston

and the valves. Both the inter coolers and the after coolers are of the same general construction except that the after coolers are designed to withstand a higher working pressure than the inter coolers.

WATER-COOLED INTER COOLERS may be of the straight tube and shell type or, if size permits, may be of the coil type. In coolers with air pressure below 250 psi, the air flows either through the tubes or over and around them. In coolers with air pressure above 250 psi, the air flows through the tubes. Suitable baffles are provided in tubular coolers to deflect the air or water in its course through the cooler. In coil type coolers the air passes through the coil, with the water flowing around the outside. Suitable provision is made for the expansion of the tube nest.

AIR-COOLED INTER COOLERS and AFTER COOLERS may be of the radiator type or may consist of a bank of finned copper tubes located in the path of blast air supplied by the compressor fan.

Each inter cooler and after cooler is fitted with **RELIEF VALVES** on both the air and water sides. Water relief valves are generally set at 5 psi in excess of the maximum working pressure which may be applied to the system. The air relief valves must be kept set in accordance with directions given in the particular manufacturer's technical manual, or in Bureau of Ships Technical Manual.

All inter coolers and after coolers are also fitted with **MOISTURE SEPARATORS** on the discharge side, to remove the condensed moisture and oil from the air stream. The separators are of a variety of designs. The removal of liquid is accomplished by centrifugal force, impact, or sudden changes in velocity of the air stream. Drains are provided on each separator for removing the water and oil.

Oil coolers are of the coil type, tube and shell type, or a variety of commercial types. External oil coolers are generally used but some naval compressors are fitted with a base type oil cooler in which cooling water is circulated

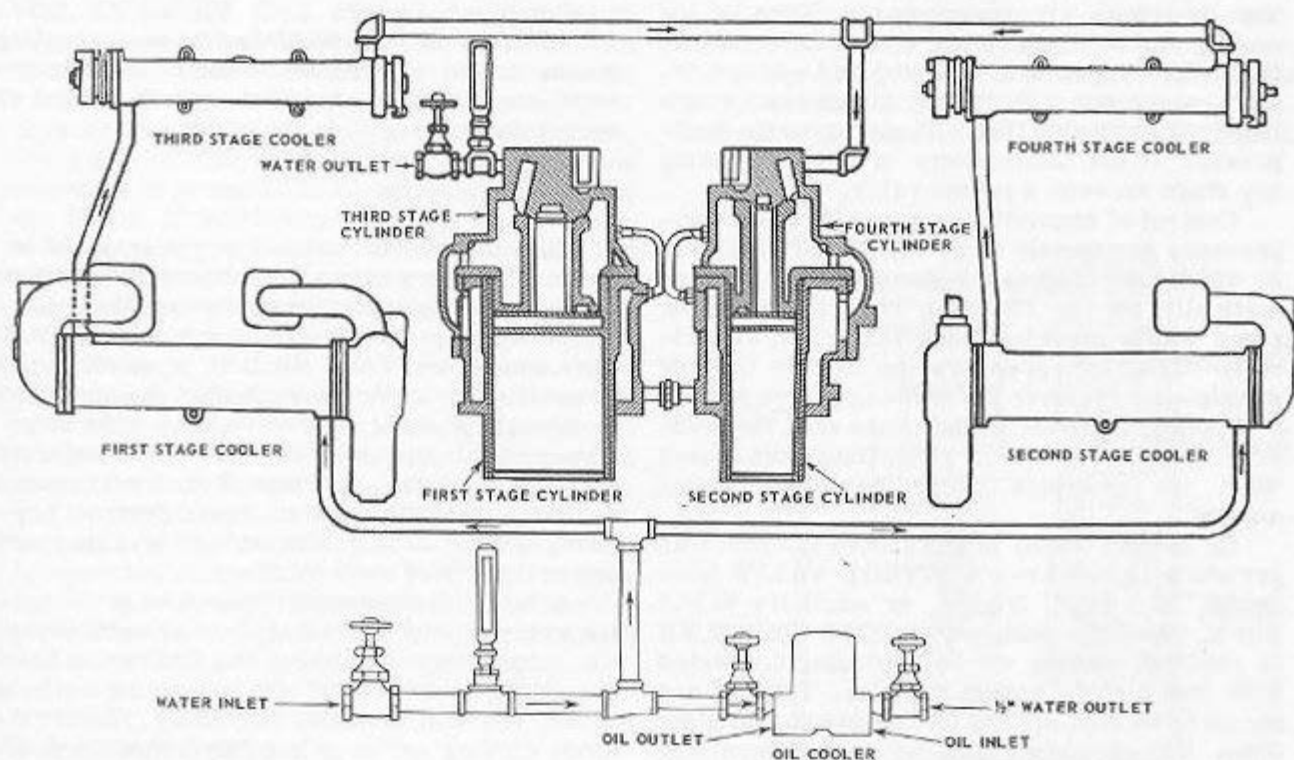


Figure 14-7.—Cooling water system in a multistage air compressor.

through a coil placed in the oil reservoir. As with the inter coolers and after coolers, the materials of the tubes, coils, or cores of these coolers, are of a copper-nickel alloy with shell and tube sheets of bronze composition. On all later model compressors the circulating water system is so arranged that the quantity of cooling water passing through the oil cooler may be regulated without disturbing the quantity of water going to the cylinder jackets, inter coolers, or after coolers. Thermometers or other temperature detecting devices are fitted to the circulating water inlet and outlet connections, the intake and discharge of each stage of compression, the final air discharge, and to the oil reservoir.

Control Systems

The control system of an air compressor may include one or more of such devices as an automatic temperature shutdown device, start-stop control, constant speed control, and speed-pressure governor.

AUTOMATIC TEMPERATURE SHUTDOWN DEVICES are fitted on all recent designs of high pressure air compressors. Thus, if the cooling water temperature rises above a safe limit, the compressor will stop and will not restart automatically. Some compressors are fitted with a device that will shut down the compressor if the temperature of the air leaving any stage exceeds a preset value.

Control of regulating systems for naval compressors are mainly of the **START-STOP TYPE**, in which the compressor starts and stops automatically as the receiver pressure falls or rises within predetermined limits. On electrically driven compressors the system is very simple—the receiver pressure operates against a **PRESSURE SWITCH** that opens when the pressure upon it reaches a given limit, and closes when the pressure drops a predetermined amount.

On steam-driven compressors the receiver pressure is piped to a **CONTROL VALVE** (also known as a pilot, trigger, or auxiliary valve) which, when the designed **CUTOFF PRESSURE** is reached, admits air to a plunger connected with the turbine governor valve. This causes steam to be shut off and the compressor to stop. When the pressure falls to a predetermined level, the control valve closes, and the air acting upon the plunger is released by leakage or bleeding to the atmosphere. The steam is thereby

permitted to flow through the governor valve and restart the turbine.

On motor-driven units this is done by the use of two pressure switches with a three-way valve or cock, so that receiver pressure is admitted to the pressure switch which has the desired range of settings. Another control method is to direct the air from the receiver through a three-way valve to either of two control valves set for the respective range of pressures. To do this a single pipe is run from the control valves to the pressure switch, which is set to function at the desired pressure.

On turbine-driven units the arrangement is similar to that on the motor-driven, except that the combined line from the control valves is piped to the plunger (trigger valve) acting on the turbine governor valves.

The **CONSTANT SPEED CONTROL** is a method of controlling the pressure in the air receiver by controlling the output of the compressor without stopping or changing the speed of the unit. This control is used on compressors that have a fairly constant demand for air, where frequent stopping and starting is inadvisable.

Combined SPEED AND PRESSURE GOVERNORS are usually furnished for reciprocating steam-driven compressors, where neither the start-stop nor the constant speed control is very satisfactory.

Unloading Systems

Air compressor unloading systems are installed for the removal of all but the friction loads on the compressors; that is, they automatically remove the compression load from the compressor while the unit is starting, and automatically apply the load after the unit is up to operating speed. For units having the start-stop control, the unloading system is separate from the control system. For compressors equipped with the constant speed control, however, the unloading and control systems are integral parts of each other.

A detailed explanation cannot be given here for every type of unloading device used to unload air compressor cylinders, but you should know something about several of the unloading methods which you will probably encounter. These include closing or throttling the compressor intake, holding intake valves off their seats, relieving inter coolers to the atmosphere, relieving the final discharge to the atmosphere

(or opening a bypass from the discharge to the intake), opening up cylinder clearance pockets, using miscellaneous constant speed unloading devices, and the employment of various combinations of these methods.

As an example of a typical compressor unloading device, consider the MAGNETIC TYPE UNLOADER. Figure 14-8 illustrates the unloader valve arrangement. This type of unloader consists of a solenoid-operated valve connected with the motor starter. When the compressor is at rest, the solenoid valve is deenergized, admitting air from the receiver to the unloading mechanism. When the compressor approximates normal speed, the solenoid valve is energized, releasing the pressure from the unloading mechanism and loading the compressor again.

For detailed information on the various unloading devices, refer to the pertinent manufacturers' technical manuals for compressors installed on your ship.

COMPRESSED AIR RECEIVERS

An air receiver or accumulator is installed in each space housing air compressors. The receiver acts as a supply tank and a storage tank. If demand is in excess of compression capacity, some of the stored air goes into the system. If demand is less than the compressor capacity, the excess is stored in the receiver or accumulator. Thus, in a compressed air system, the receiver functions to retard increase and decrease of pressure in the system and thereby the length of start-stop-start cycles. The receivers may be horizontal or vertical. The vertically mounted ones have convex bottoms to permit proper draining of accumulated moisture, oil, and foreign matter. All receivers include such fittings as inlet and outlet connections, drain connections and valves, connections for operating a line to compressor regulators, pressure gages, relief valves (set at 10 percent above normal working pressure of receiver), and handhole or manhole plates (depending upon the size of the receiver). The discharge line between the compressors and the receiver is as short and straight as possible to eliminate vibration due to pulsations of the air and to reduce pressure losses due to friction.

TYPICAL LOW PRESSURE AIR COMPRESSORS

Having considered the various parts which comprise an air compressor, follow the course

of air through a typical compressor. Figure 14-9, as an example, illustrates various views of a radial, single-acting, three cylinder, two-stage, motor-driven, low pressure air compressor with a V-belt connected flywheel, air-cooled cylinders, and air-cooled inter coolers and after coolers.

The free atmospheric air is drawn in through the two AIR INLET FILTERS and then through the inlet or SUCTION VALVES of the two FIRST-STAGE CYLINDERS as the two FIRST-STAGE PISTONS are on their downward or suction stroke. As the first-stage pistons are sent on their upward or compression stroke, by action of the CRANKSHAFT, the air is compressed in the two cylinders and forced out of the DISCHARGE VALVES. The FINS on the outside of the cylinders distribute the compression heat over a larger area, and therefore facilitate the removal of heat by the cooler air directed on them by the FLYWHEEL FAN.

The discharged compressed air is directed from the discharge valves on the first-stage cylinders, through the first-stage discharge line, to the air-cooled INTER COOLER. In the inter cooler, the first-stage compressed air loses most of its heat by passing through coils surrounded by cooler air. From the inter cooler, the compressed air is discharged, through the SECOND-STAGE SUCTION LINE, into the suction valve of the SECOND-STAGE CYLINDER.

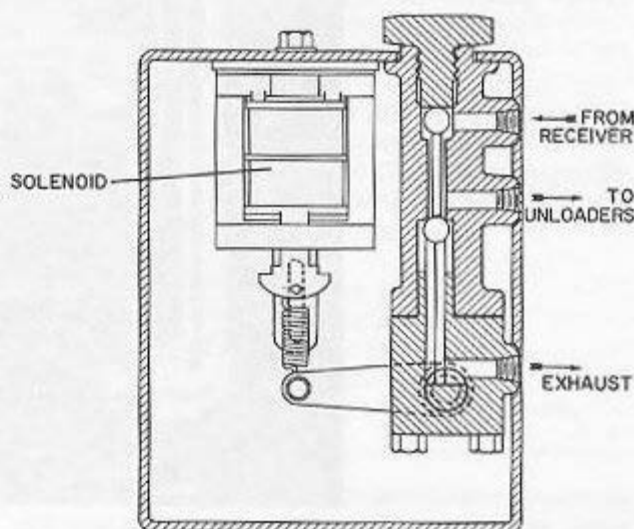


Figure 14-8.—Magnetic type unloader. 47.158

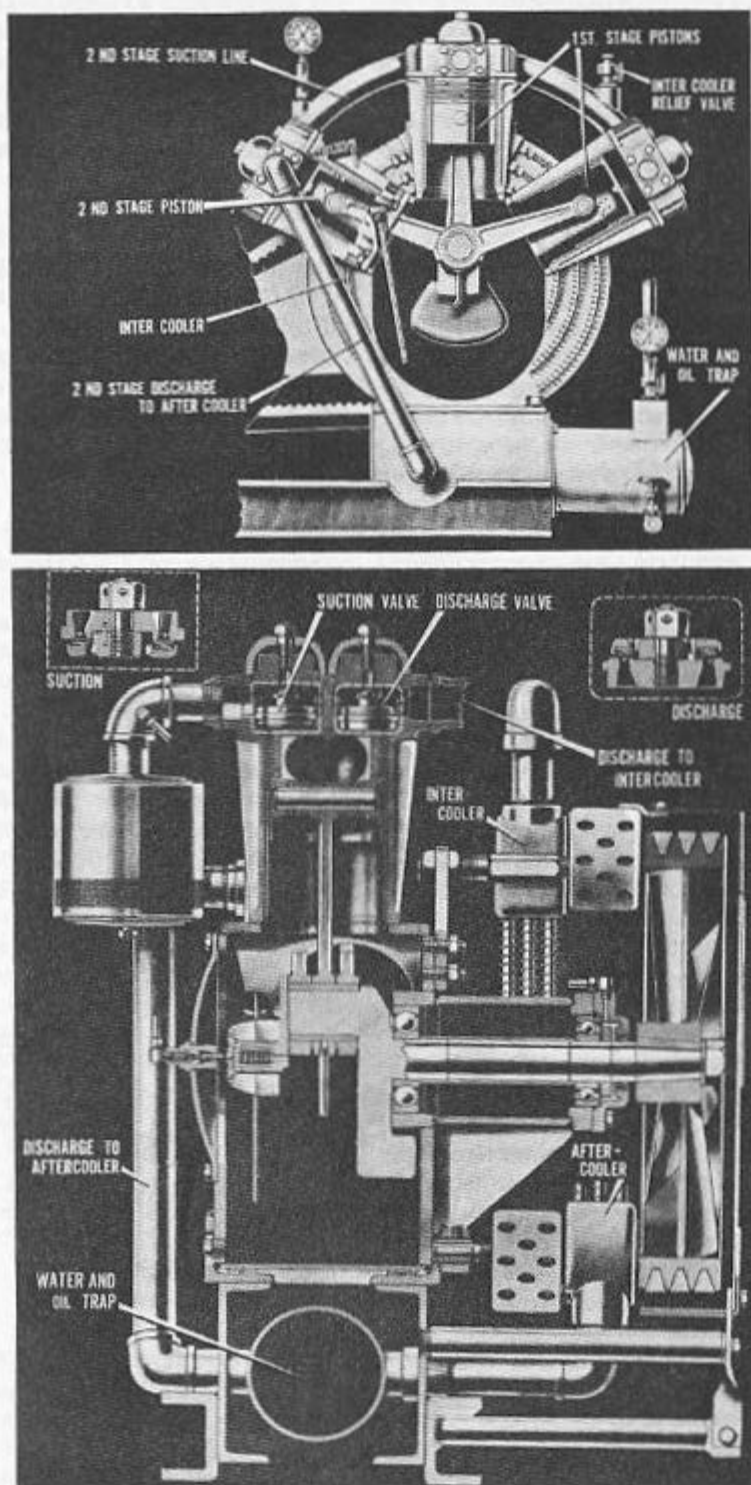


Figure 14-9.—A radial, single-acting, three cylinder, two-stage, motor-driven, air-cooled, low pressure, air compressor.

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Here the air is further compressed to the designed pressure, and then forced through the DISCHARGE VALVE, the SECOND-STAGE DISCHARGE LINE, and the WATER AND OIL TRAP, to the AFTER COOLER, where the second-stage compression heat is removed. From the after cooler, the compressed air is discharged into the AIR RECEIVER.

OPERATION OF AIR COMPRESSOR

Before attempting to operate any air compressor for the first time, be sure that you are THOROUGHLY familiar with the machine. Study the accompanying manufacturer's technical manual. There are numerous varieties of compressors in naval use, so that it would be impossible in the limited space of this training course to present the operating procedures for each type of compressor. The following operating procedure is of a general nature.

STARTING A COMPRESSOR

1. Inspect and clean the compressor exterior. Tighten any loose nuts, including foundation bolts. Remove any loose equipment that may be lying around.
2. Check the oil reservoirs and (if necessary) fill to the proper level with the correct grade of oil. Prime the oil pump and lubricator.
3. Set the overspeed tripping device (if provided).
4. Jack the compressor over by hand. (Be sure the power is off.)
5. Turn on cooling water to the cooling system. Vent the system.
6. Open all air system stop valves.
7. Open all separator drains and remove all accumulations of moisture or oil from the separators. These should remain open until the compressor is running.
8. When the compressor is up to normal speed, gradually put a load on the compressor by closing the separator drains and indicator cocks, taking care to close those connected with the first stage, and then those connected with the second stage. If fitted with additional stages, continue progressively through these stages.

OPERATING A COMPRESSOR

1. After the compressor has been in operation a few minutes, recheck the oil level in the

reservoirs; if it has fallen appreciably, add sufficient oil to bring the level to normal.

2. Drain the receivers and accumulators at least once each watch.

3. Adjust the flow of cooling water so as to cool the air properly between stages. For compressors using salt water for cooling, the temperature of the outlet water must not be allowed to exceed 125°F.

4. Drain the inter cooler and the after cooler separators frequently and regularly.

5. Check the operation of all relief valves regularly—use the hand levers, when provided.

6. Read the pressure gages and thermometers regularly while the compressor is in operation.

Securing is usually the reverse of the starting procedure.

CARE AND MAINTENANCE OF AIR COMPRESSORS

The over-all problem in maintaining compressed air systems is to take the necessary steps to prevent a reduction in compressor capacity. Some of the common troubles which reduce compressor capacity, and the causes of these troubles, are as follows:

Troubles	Causes
Overheating of air cylinders	Insufficient cooling water. Cooling fins dirty. Leaky air valves.
Air Leaks	Worn piston rings. Leaky air valves. Leaky flanges, fittings, (in coolers) tubes and tube sheets.
Reduction in capacity	Leaky valves. Leaks in system. Worn piston rings. Insufficient speed. Clogged intake filters.

To keep a ship's air compressor operating efficiently at all times and to prevent as many troubles as possible, it is necessary to know how to care for air intakes and filters; how to maintain and replace air valves; how to take care of

air cylinders, pistons, and wrist pins, how to adjust bearings and couplings; and how to properly maintain the lubrication, cooling, control, and air systems.

AIR INTAKES AND INTAKE FILTERS

A supply of clean, cool, dry air is essential to the satisfactory operation of compressors. To ensure this, the AIR INTAKE FILTERS must be regularly inspected and cleaned; otherwise, the filter becomes clogged and causes loss of capacity. Clogged air intake screens or filters may also cause compressors to draw oil from own crankcase around rings, or through oil seals, resulting in explosion or "dieselization."

To clean, remove the filter element and subject it to a jet of hot water or steam, or plunge it into a strong solution of sal soda. The filter body should be drained and replaced. If the filter is the oil-wetted type, dip it in clean, medium grade oil and allow it to drain thoroughly before replacing the filter in the intake. Do not use gasoline or kerosene for cleaning filters; fumes may collect and explode in the compressor or receiver.

Care must also be taken to prevent entrance of rain or spray into INTAKE PIPES, and means should be provided for draining the intake pipe of any water which may collect. The lines should be as short and direct as possible.

Care must be taken to prevent intake of exhaust gases from internal combustion engines located near compressors used to supply air for divers. Intake of explosive fumes should also be prevented from nearby fuel tank vents, spilled oil, and gasoline adjacent to compressors used to supply air for divers.

AIR VALVES

Air inlet and discharge valves must be kept clean and in good working order. Leaky valves are generally dirty valves, and cause capacity loss. The valves are removed by first loosening their setscrews or clamps, and then removing their cover plates. Each valve and valve unloader, if fitted, may then be lifted out. Each valve should be marked, to make certain that it is returned to the same port from which it was removed.

Valves removed for inspection should not be taken apart for cleaning unless their condition

makes it necessary. Dirt or carbon in valve ports can usually be removed without taking the valve apart. This is done by soaking the valves in kerosene, and then giving them a stiff brushing or a light scraping. Valve action should be tested by inserting a screwdriver through the seat ports; the valve should lift and close freely.

If it becomes necessary to disassemble the valve, note the arrangement of the various parts so that the proper relationship will be kept when the valve is reassembled. (Periodic shipboard reports indicate damage to pistons and associated valve parts resulting from improperly assembled valves that protrude in the way of the oncoming piston.)

Before replacing air valves in a cylinder, inspect the gaskets and replace any which are damaged. Copper-covered asbestos or plain, thin copper gaskets should be used. If these are not available, 1/16-inch compressed-asbestos sheet gaskets may be used temporarily. Each valve assembly should be inserted in the same hole from which it was removed. Since it may be difficult, in many cases, to distinguish between suction or discharge valves, extreme care must be taken when the valves are being inserted in the cylinder. Make certain that suction valves open TOWARD, and the discharge valves AWAY FROM, the center of the cylinder; otherwise serious damage or loss of capacity will result. Then place the valve cover on the cylinder, making certain that its gasket is squarely in place; draw down on cover nuts evenly, and in turn, so as not to tilt the cover. Tighten down the valve setscrew or clamping bolt, drawing it tight to hold the valve on its seat. If special locknuts are not provided to seal against leakage at the threads of the valve setscrew, a turn of solder or fuse wire should be placed around the screw and set down into a recess by the locking nut.

CYLINDERS AND PISTONS

The cylinders and pistons should be inspected only AFTER the manufacturer's technical manual has been consulted. Care should be taken when removing heads, particularly where metal-to-metal joints are involved, to prevent damage to the joint. Where joints are fitted with a gasket, the gaskets can occasionally be saved by running a knife blade in between the gasket and head, after the head has been lifted not over 1/4 inch.

IF REPLACEMENT OF PISTON RINGS is required because they are worn or broken, accurate measurements of the cylinder liners should be taken. Standard size rings may be used in oversize cylinders if the oversize does not exceed 0.003 inch per inch of cylinder diameter. The **LINER** may also need to be replaced if it is badly worn or out of round. When replacing piston rings, first fit them to the cylinder to check for proper end clearance. File the ends, if necessary, to make them fit. The side clearance of the rings should be such that the rings will fall easily into the piston grooves, which should be deep enough for the ring thickness. Ring splits should be staggered. After assembly of the piston, wire the rings tight with a soft copper wire, so that they will enter the bore easily. This wire can be removed through the valve ports after the ring has started into the cylinder bore.

When **REASSEMBLING** the air cylinders and heads, be sure they are all drawn down evenly, especially on multistage compressors where the heads contain cylinders for third and fourth stages. Otherwise, excess wear on the cylinders and pistons will result.

When a compressor piston has been replaced, the **PISTON END CLEARANCE** must be checked. This is done by inserting a lead wire through a valve port or indicator connection. Jack the compressor over. When the piston has moved to the end of its stroke, the lead will be flattened to the exact amount of clearance. The wire should be long enough to permit a reading near the center of the piston. These readings should also be taken after any adjustment or replacement of these bearings: main, crank pin, wrist pin, or crosshead. Methods of adjusting the clearances vary in accordance with compressor design; consult the manufacturer's instructions for this adjustment.

MISCELLANEOUS ADJUSTMENTS

Other miscellaneous adjustments required from time to time on compressors include those pertaining to wrist pins, crosshead shoes, reduction gears, couplings, and V-belt drives. The manufacturer's technical manual will give you specific information for the care, adjustment, and replacement of all fitted bearings. Refer to the manufacturer's instructions for detailed and specific information regarding when and how to make these adjustments.

WRIST PIN BUSHINGS are **REPLACED WHEN NECESSARY**. This is done when they are worn to the point of becoming noisy. In making a replacement, be sure the oil hole in the bushing is properly lined up with the oil hole in the connecting rod. After being pressed into the rod, the new bushing must be reamed.

CROSSHEAD SHOES are provided with shim or wedge adjustment. Wear should be slight, but adjustment should be made when the travel of the piston rod causes a movement in the stuffing boxes.

Alignments of **REDUCTION GEARS AND PINIONS** should be checked periodically, especially on a new compressor. Misalignment may be caused later by settling, straining, or springing of foundations; pipe strains on turbine-driven compressors; bearing wear; or springing due to heat from a turbine.

FLEXIBLE COUPLINGS require very little maintenance when properly lined up. Some types require occasional lubrication to prevent excessive wear of springs or bushings. A noisy coupling is an indication that the bushing is worn and requires replacement.

V-BELT DRIVES require adjustment for belt tension. Belts generally stretch slightly during the first few months of use. A loose belt will slip on the motor pulley and cause undue heating and wear on the belt. A tight belt will overload the bearings. Belts should be protected against oil, and should not be used at temperatures above 130° F, to prevent rapid deterioration. V-belts are usually installed in sets of two or three. If a single belt is worn or deteriorated, then the complete set should be replaced to ensure that each belt will carry its share of the load.

LUBRICATION SYSTEM

Proper care of a compressor lubrication system includes the following procedures:

1. Keeping the oil at a normal level in the reservoir at all times, to maintain proper oil temperature.
2. Changing crankcase oil periodically, and at the same time cleaning and flushing the crankcase and cleaning the oil filter.
3. Maintaining proper lube oil pressure, by keeping the oil pump in good working order and adjusting the bypass relief valve.
4. Keeping the oil cooler free from leaks (since pressure on water side exceeds that of

the oil), to prevent oil contamination and emulsification.

5. Properly adjusting the lubricator for the specified quantity of oil feed.

COOLING SYSTEM

Proper care of a compressor cooling system includes the following inspections and maintenance procedures:

1. Periodically inspecting the inter coolers and after coolers.

2. Removing collections of gummy oils or tarry substances from the cooler tubes by washing tube nests with a suitable solvent. See that they are thoroughly dry before reassembling.

3. Correcting any leakage in tube nests, to prevent leaks of water into the compressor while secured, or leaks of air into water side during operation.

4. Inspecting and cleaning cylinder water jackets periodically with a cleaning nozzle.

When FILLING THE COOLING WATER SYSTEM after the compressor has been drained, open the water inlet valve slightly to allow the water to rise slowly in the cooler shells and water jackets. Vent valves fitted to the water spaces should be opened to permit entrapped air to escape, and to remove any air pockets.

CONTROL DEVICES

Because of the great variety of REGULATING AND UNLOADING DEVICES employed on compressors, you will have to consult the manufacturer's technical manual for information regarding the adjustment of these devices on particular compressors.

If a CONTROL VALVE fails to work properly, it should be taken apart and cleaned. Some valves are fitted with a filter filled with a sponge or woolen yarn to prevent particles of dust or grit from being carried into the valve chamber, and to remove gummy deposits from oil used in compressor cylinders. When repacking, use only genuine wool. Cotton will pack and stop the air flow. RELIEF VALVES, very important for safe compressor operation, should be set as specified by the manufacturer, test-lifted by hand each time the compressor is placed in operation, and periodically tested by raising the pressure in the spaces to which they are attached (to check the setting).

AIR SYSTEM EQUIPMENT

The air flasks and separators of surface ships must be given a surface inspection every three months. These inspections are made to determine if there is any external corrosion or damage to flasks or piping. High pressure piping must be inspected at each regular overhaul and cleaned if oil is found. Air flasks must be blown down weekly. Moisture separators installed down stream of the compressor must be blown down hourly during operation of the compressor. Filter elements must be changed in accordance with existing instructions.

The drainage of air system equipment must be sufficiently frequent to prevent excessive accumulations of moisture and oil. Such accumulations not only cause internal corrosion and fouling of moving parts, but also create a serious hazard in that excessive oil accumulation may cause an explosion.

In addition to shipboard inspection and maintenance of high-pressure air flasks and separators, there must be an inspection, cleaning, testing, and repainting performed at prescribed intervals by a repair activity. For surface ships the initial and subsequent intervals should not exceed six years. Inspection intervals for separator flasks should be approximately every three years. However, if there is reason to believe that serious corrosion is taking place in either the exteriors or interiors of air flasks, inspection should be made before the elapse of the normal interval.

The periodic examinations should include not only a complete examination of the interior and exterior surfaces of flasks and separators, but a thorough cleaning, ultrasonic inspection, and the performance of hydrostatic tests. Flasks which pass the hydrostatic test are given the prescribed internal protective coating, and the exterior surfaces are painted if necessary. Detailed information on the inspections and maintenance performed by naval shipyards can be found in the Bureau of Ships Technical Manual.

INSPECTION AND TESTS

Minimum requirements for the performance of inspections and tests on compressed air plants are shown in figure 14-10.

It is the responsibility of the engineer officer to determine if the condition of the equipment,

hours of service, or operating conditions necessitate more frequent inspections and tests. Details for outline tests and inspections may be

obtained from the appropriate manufacturer's technical manual or from the Bureau of Ships Technical Manual.

Time	Action	Time	Action
When starting compressor for first time, or starting one which has been idle for some time.	Inspect all intake and compressor control lines for obstructions and foreign matter. Inspect interior and exterior of compressor.		sive, overhaul is necessary. Make general inspection of all compressor parts; pull pistons and remove connecting rods only if cylinder conditions and other conditions indicate necessity.
Before starting any compressor.	Jack over several times by hand.		Test operation and setting of speedlimiting and emergency overspeed tripping devices, if installed.
After starting compressor.	Test relief valves by hand. Test operation of automatic controls.	Annually	Test all parts of the air system under full pressure.
At frequent intervals during compressor operation.	Test for excess lube oil by opening compressor separator and receiver drains. Check instruments for signs of improper operation.	During Naval Shipyard Overhaul Period	Disassemble and inspect compressor. Test all relief valves by pressure. Inspect interior of air receivers.
ROUTINE TESTS (Record results in Engineering Log.)		At Prescribed Intervals	Test hydrostatically, at 1 1/2 times the designed working pressure, all low and medium pressure air accumulators or receivers.
Daily	Jack over all compressors by hand.	At Discretion of Engineer Officer	Test capacity of compressors.
Weekly	Run compressors by power.		
Monthly	Inspect all air inlet and discharge valves.		
Quarterly	Measure starting and operating power of motor-driven compressors; if excess		

Figure 14-10.—Tests and inspections for compressed air plants.

SAFETY PRECAUTIONS

Peak operating performance from a compressed air plant requires that steps be taken to prevent or minimize the occurrence of casualties which may reduce plant capacity or result in serious damage. Explosions are a potential hazard, especially in high-pressure systems, and personnel should take every possible precaution to prevent them. To help prevent explosions and to maintain a compressed air plant in satisfactory operating condition, the following safety precautions should be observed:

1. Minimize the possibility of explosions in an air compressor, discharge line, or receiver by taking appropriate steps to prevent or eliminate:

- a. Dust-laden intake air.
- b. Presence of oil vapor in compressor or receiver.
- c. Leaking or dirty valves which result in abnormally high temperatures.

2. See that the compressor intake receives only cool, clean, dry air.

3. Use only prescribed agents for cleaning compressor intake filters, cylinders, or air passages. DO NOT use benzene, kerosene, or other light oils that vaporize easily and that, under compression, form a highly explosive mixture with air.

4. Use only the minimum amount and the proper grade of oil for cylinder lubrication.

5. Secure compressor immediately if there is an abnormal rise in the temperature of air discharged from any stage.

6. Make sure that a relief valve is installed between a compressor and a stop valve or check valve, if either of the latter valves is installed between a compressor and receiver. Otherwise, if the compressor is started against a closed valve or a deranged check valve, the air cannot escape and a ruptured line will result.

7. Never leave a compression station after starting a compressor—especially one that is new, or one that has been idle for some time—without making certain that control, unloading, and governing devices are functioning properly.

8. Do not disconnect any part of a compressor if the system is under pressure. Serious accidents can be avoided if the following precautions are taken before servicing or removing any part of a compressor:

- a. Leave pressure gages open.
- b. See that the compressor is actually secured and cannot be started automatically or accidentally.
- c. See that the compressor is completely blown down.
- d. See that all valves, including the control or unloading valves, between the compressor and receiver are closed.

9. Prevent damage from excessive temperatures by operating a compressor at recommended speeds and maintaining proper cooling water circulation.

10. Drain the circulating water system of a compressor if it is to remain idle for any length of time, or if it is to be exposed to freezing temperature.

CHAPTER 15

ADDITIONAL AUXILIARY EQUIPMENT

This chapter provides general information on the operation and maintenance of steering and hoisting mechanisms and the care of hydraulic systems.

ELECTROHYDRAULIC SPEED GEAR

Some units of the auxiliary machinery such as the anchor windlasses, are required to operate at variable speeds over a considerable range. In addition, there must be close control of speed between maximum and minimum limits. A common requirement of some auxiliary machinery units is high starting torque and ability to accelerate to maximum speed quickly. To meet these requirements in most Navy ships, the electrohydraulic drive has been adopted. Because some electromechanical and steam-driven auxiliary machinery units are still being used, we will discuss these units in the section dealing with steering gears and their controls.

In an electrohydraulic drive, rotary motion is transmitted by a combination of an electrically driven hydraulic pump (A-end) and a hydraulic motor (B-end). See figure 15-1. For a discussion of the operation of this pump (axial piston variable-stroke pump) refer back to chapter 9 of this publication. Although radial piston variable-stroke pumps may also be utilized, the axial piston pump will be used as the example of a hydraulic pump in this chapter.

The B-end is made to rotate by the hydraulic force of the oil acting on the pistons. Movement of the pistons' A-end is controlled by a tilt box in which the socket ring is mounted.

Moving the tilting box one way or the other will control the direction of flow, and the amount of angle at which the tilting box is placed in either direction controls the length of piston movement. This in turn controls the amount of fluid flow. The socket ring in the A-end is always in motion, but with the tilt box in a

neutral or vertical position no oil is pumped to the B-end. Any movement of the tilt box, regardless of how slight, causes pumping action to start, and therefore causes immediate action in the B-end.

When reciprocating motion is required, such as in a steering gear, the B-end is replaced by a piston or ram. The force of the hydraulic fluid causes movement of the piston or ram. The tilt box in the A-end can be controlled either locally (anchor windlass) or by remote control (steering gear).

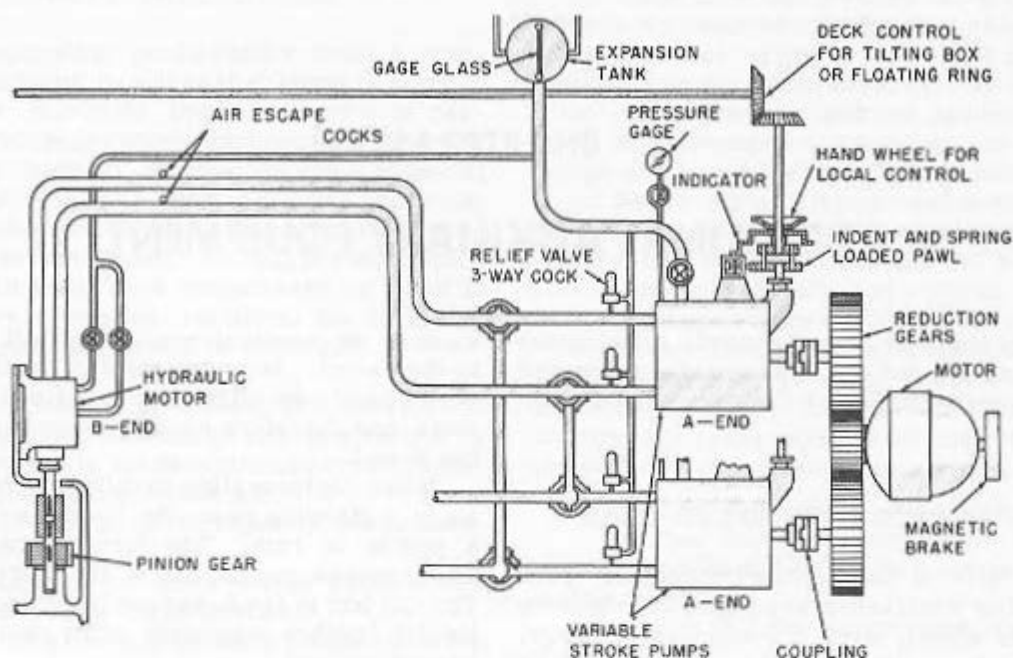
USES OF ELECTROHYDRAULIC SPEED GEAR

Electrohydraulic drives are used for driving or controlling steering gears, windlasses, winches, capstans, airplane cranes, ammunition hoists, airplane elevators, and distant control valves. This chapter contains information on electrohydraulic drives and some machinery with which they are used.

ADVANTAGES OF ELECTROHYDRAULIC MACHINERY

The electrohydraulic type of drive efficiently meets the operating requirements of certain naval machinery. Some of the major advantages of electrohydraulic machinery are that it:

1. Incorporates tubing which requires very little space and readily transmits fluids around corners.
2. Allows flexibility in location of components.
3. Operates at variable speeds, when required.
4. Permits close control of speeds from minimum to maximum limits.
5. Permits rapid shifting from no load to full load rapidly without damage to machinery.



47. 138X

Figure 15-1.—An electrohydraulic power transmission system.

6. Accelerates quickly.
7. Has a high rate of efficiency.
8. Has favorable power to weight ratio.

STEERING GEARS AND THEIR CONTROLS

The three types of steering gear used on naval ships are: electrohydraulic, electro-mechanical, and steam-driven.

ELECTROHYDRAULIC STEERING GEAR

Most steering gear installations on naval ships are of the electrohydraulic type and use only the A-end of the previously described electrohydraulic speed gear. The development of this type was prompted primarily by the large momentary electrical power requirements for electromechanical steering gears—particularly for ships of large displacement and high speed. Also the elimination of d-c power from ships made switching and speed control of electric motors more difficult. Advantages of the electrohydraulic steering gear are:

1. Little friction and inertia of moving parts, such as in heavy differential screw and gears.

2. Low power consumption peaks.
3. Sensitive response, with little lag, to movements of the steering wheel.
4. Small deck space and headroom required.
5. Savings in weight.
6. Flexibility in the arrangement of hydraulic cylinders, pumps, and control mechanisms.
7. Dependability.

Types of Steering Gears

There are various types of electrohydraulic steering gear layouts in use, but their operating principles are about the same. Some ships have double hydraulic rams and cylinders mounted fore and aft; others have double-cylinder single rams mounted athwartship. Some systems use axial piston variable-stroke pumps; others use radial piston pumps.

Information on electrohydraulic steering gear components can be obtained from manufacturers' technical manuals.

How The Steering Gear Operates

Figure 15-2 shows a simple diagrammatic arrangement of a double-ram type electrohydraulic steering gear. The RUDDER YOKE

is connected to two hydraulic PLUNGERS or RAMS, each of which is equipped with CYLINDERS at both ends. The pressure of the hydraulic fluid in the closed system is maintained by one of the two electric motor driven, rotary, positive displacement, VARIABLE-STROKE PUMPS. The rate of fluid delivery is regulated by the angle of the TILTING BOX in the hydraulic pump, which is in turn controlled either electrically or hydraulically from the steering wheel on deck. The CONTROL SHAFT and gearing are indicated in figure 15-2.

Note that the forward port and after starboard cylinders are interconnected (through piping), and that the same is true of the forward starboard and the after port cylinders. A double-acting RELIEF VALVE serves to bypass the fluid from the supply (or the discharge) to the return (or the suction) line, thus relieving the piping from excessive strain—should an unusual resistance to the rudder (caused by wave action or by jamming) result in abnormal oil pressures. The motor runs at constant speed.

Starting with a neutral position of the tilting box and no flow of oil, suppose the STEERING WHEEL is turned to starboard. Turning the wheel on the bridge causes an electric signal to be transmitted to the synchronous receiver in the steering gear room. The SYNCHRONOUS RECEIVER will then turn correspondingly (counterclockwise in fig. 15-2, as viewed from the left). Shaft A is turned clockwise, carrying gear B with it. The gears C, meshing with gear B and internal gear teeth on E, turn counterclockwise. Then E turns counterclockwise and turns the CONTROL SHAFT, which operates the TILTING BOXES on the PUMPS. A quantity of oil now flows to the forward port and after starboard cylinders, the rams move as indicated in figure 15-2, and an equal portion of oil is returned to the pump from the opposite cylinders. The rudder is thereby caused to move to the right.

When the steering wheel and synchronous receiver stop moving, the starboard ram, in moving forward, operates the RACK AND

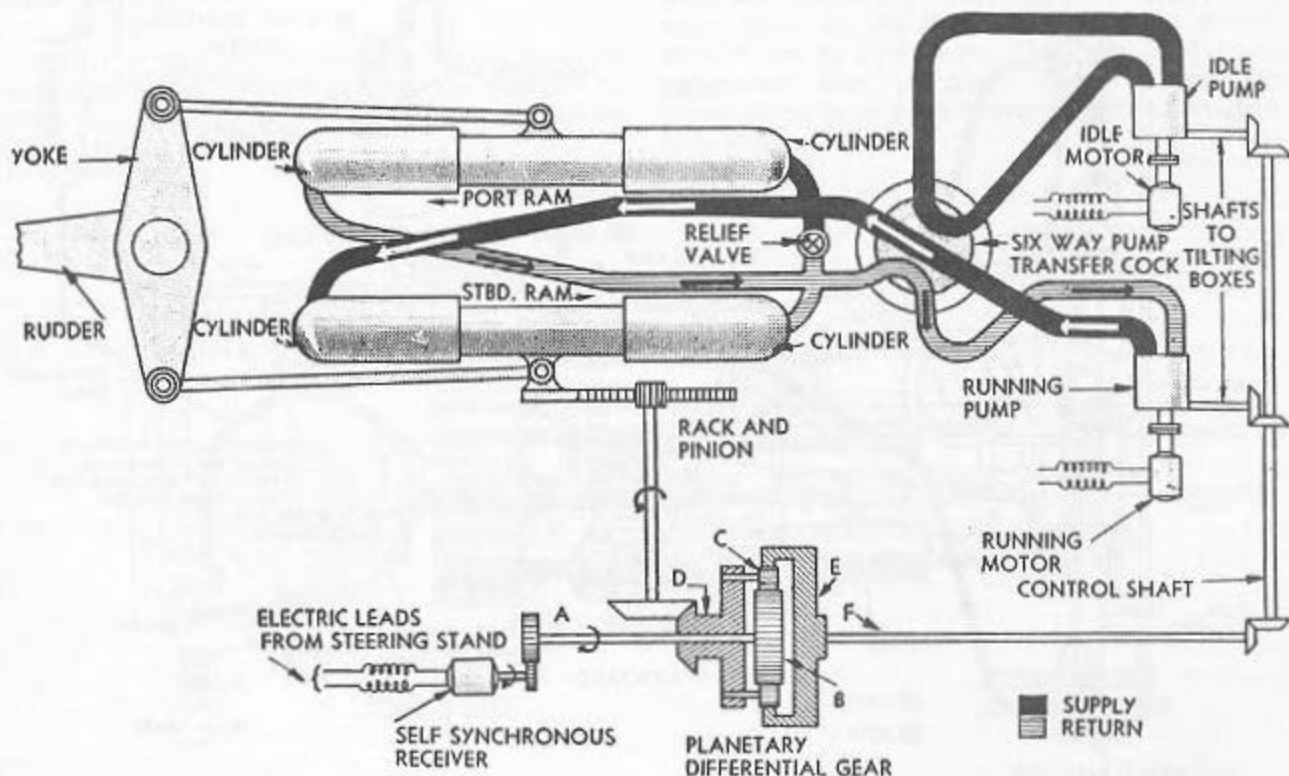


Figure 15-2.—Simple diagrammatic arrangement of a double-ram electrohydraulic steering gear.

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PINION and turns gear D clockwise. Gear B and shaft A are held by the now motionless synchronous receiver, and gears C and casing E turn clockwise, thus returning the tilting boxes to the neutral position and stopping the flow of oil. The PLANETARY DIFFERENTIAL GEAR, thereby, operates as a followup mechanism. If the steering wheel is turned to port, the actions described are the opposite in direction.

In some installations, two sets of synchronous receivers and two sets of electric motors and pumps, are provided for reliability and flexibility. (Destroyers and smaller ships normally have only one receiver in the steering gear room.) The SIX-WAY PLUG COCK makes it possible to transfer quickly from the operating pump to the standby pump.

The single-ram type of electrohydraulic steering gear, illustrated in figure 15-3, operates on the same principle as does the double-

ram type. The only difference is that there is but one ram, with port and starboard cylinders. As the port plunger is forced to move by the pressure of oil against it, the starboard plunger moves correspondingly and forces the same amount of oil out of the starboard cylinder.

STEAM-DRIVEN STEERING GEAR

There are many types of steam-driven steering gears, but all of them operate on the same general principle. You should understand this general principle, as well as what inspections should be made, and how to maintain the mechanism in good working order.

Principles of Operation

Figure 15-4 illustrates a right- and left-screw steering gear. Turning effort is through

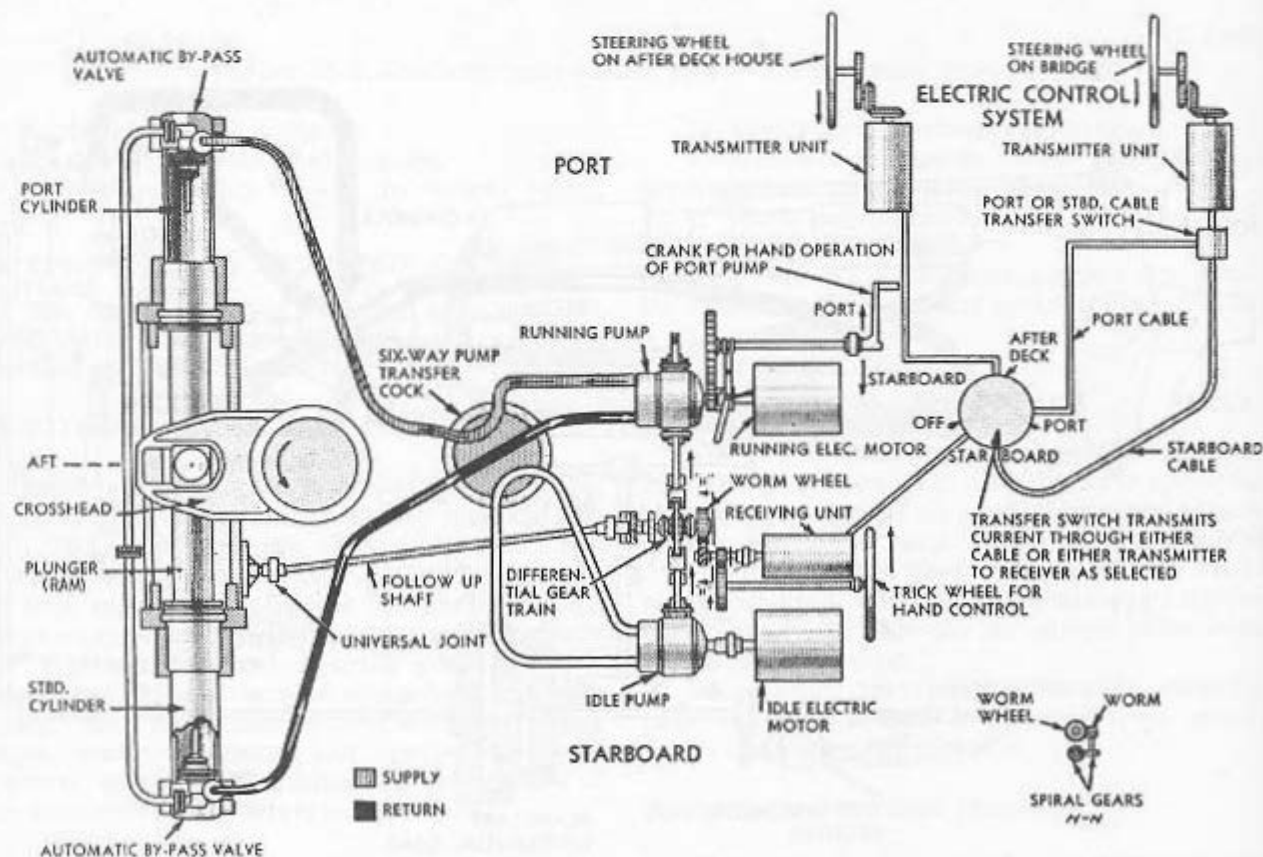


Figure 15-3.—Diagrammatic arrangement of a single-ram electrohydraulic steering gear.

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a gear train comprised of a spur gear on the power input shaft, which drives the right-threaded and left-threaded screw shaft. The drive nuts on the screw shaft move forward and aft as the shaft turns and the links transmit the movement to the rudder yoke which is keyed to the stock of the rudder. Figure 15-5 illustrates a worm gear and quadrant type steam steering gear. Two or more cylinders are used on this steering gear (each acting as a simple reciprocating steam engine), driving a common crankshaft. The cranks are placed at right angles when two cylinders are used, to provide for a continuous even torque, and to keep the engine from ever being at a dead center position. To reduce the height of the installation, the cylinders are sometimes placed in a horizontal or an inclined position.

Except for use on some auxiliary ships, steam-driven steering engines have been abandoned because of vulnerability of the steam piping, lost heat, poor economy, excessive space and height, and lack of flexibility.

Inspection and Care of Steam-Driven Steering Gear

All bearings in the steering engine must be well lubricated. Bearings that are difficult to reach or those located in hot places should be given special attention.

Emery, emery cloth, or any other gritty substance should never be used for cleaning the bright surface of the steering engine or its associated gear. The spaces adjacent to gears must be kept clean, and not used as storage places for clothing or other articles. Such material might become entangled with the transmission gears.

When the ship is not underway, and the steering gear is not in use, the steering engine should be turned over at least twice a week to preserve the pistons, valve stems, and other working parts. During freezing weather, steering engines not in use should be drained of water, and the drain valves left open so that condensate of any leaking exhaust steam may drain. Be sure the drain holes are kept clear; otherwise, the cylinders or jackets may freeze.

ELECTROMECHANICAL STEERING GEAR

Electric motors were first introduced as prime movers of steering gears on combat ships to serve in cases of failure of the steam steering engines. Later on, however, they were used as the primary source of power, with steam as a reserve. This type of steering equipment may be found on naval auxiliary ships which have been converted from maritime type ships.

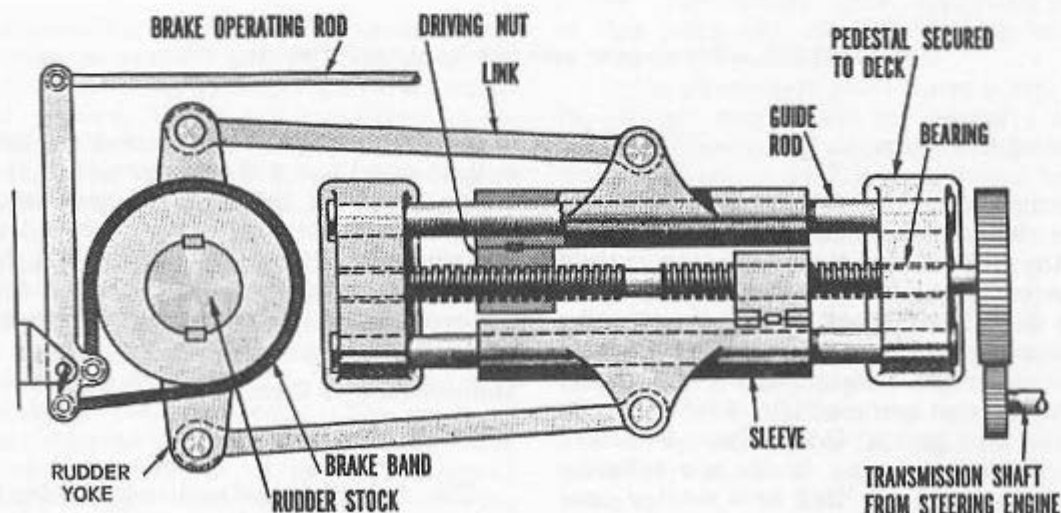


Figure 15-4.—Right-and-left screw steering gear.

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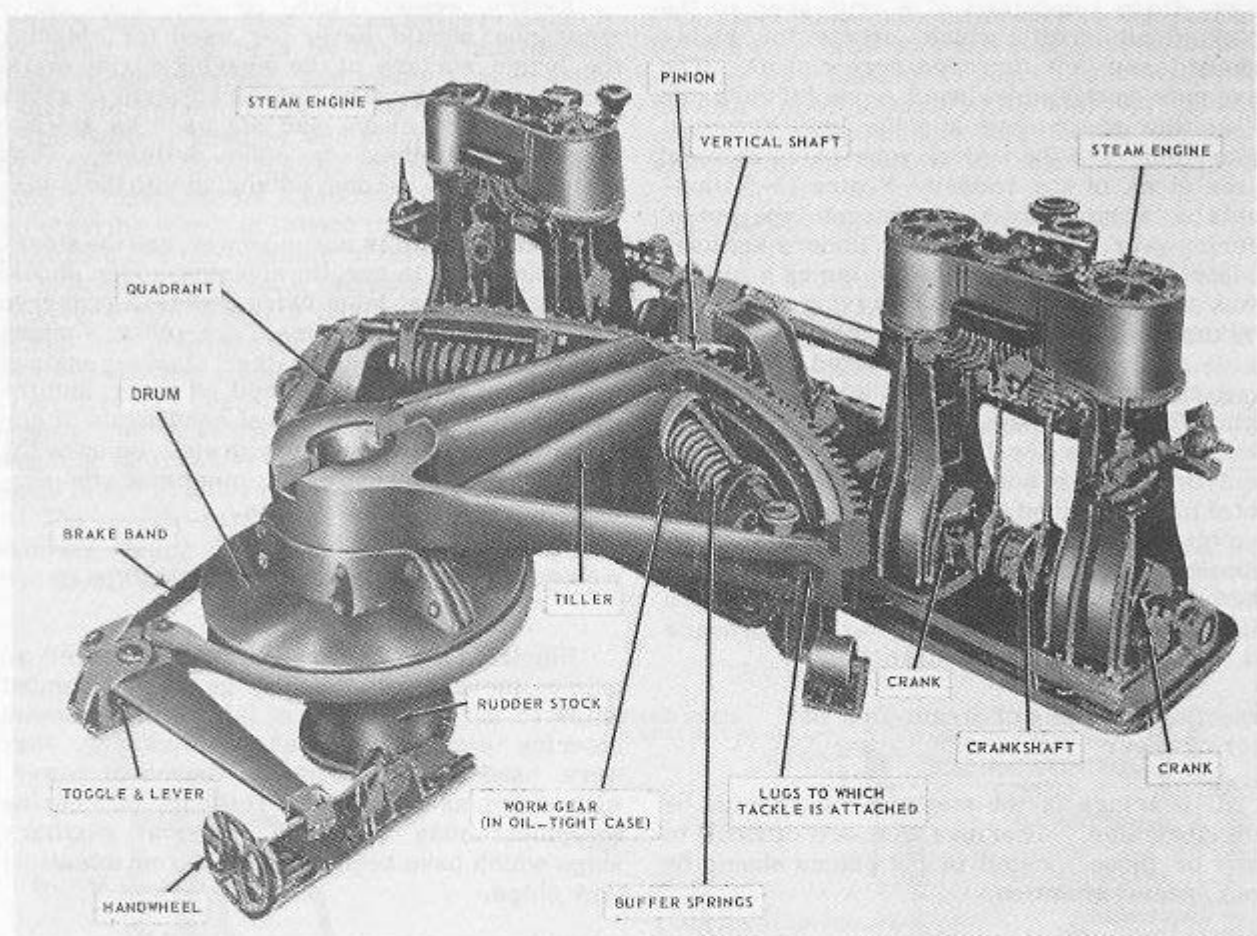


Figure 15-5.—Worm gear and quadrant type steering gear.

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Principles of Operation

The principles of operation are practically the same in all electromechanical steering gears. Any differences that exist are mainly in the manner in which the driving motor is connected to the rudder stock, and the method by which the motor is controlled. The electric motor drives a right-and-left screw (fig. 15-4), or worm gears and quadrant (fig. 15-5), as with the steam-driven gears. Control may be either followup or non-followup. In the non-followup type the motor is controlled by a master controller at the steering station. The followup type of control usually uses a roller and ring type contact in the steering engine stand. The rollers are geared to the helm and rotating the wheel brings a roller in contact with a contact

ring. The ring is connected to the motor control panel and when the circuit is closed, the motor turns in the proper direction. When the ring has rotated to the required position, the electrical circuit is broken and the motor stops. Most wire rope and chain drive steering gears use a followup control system.

Maintenance of Electromechanical Steering Gear

The following instructions are for the care and inspection of electromechanical steering gear. The frequency of inspection usually depends on the amount of operation and operating conditions. Inspections should be conducted at least once a month.

1. Gears and bearings should be lubricated in accordance with the manufacturer's technical manual.

2. Fine sandpaper should be used to clean the inner and outer surfaces of contact rings.

3. The air gaps between ring sections should be cleaned by passing a piece of paper through the gaps.

4. Ensure that brushes slide freely in their holders and bear squarely on their surfaces.

5. Check contact rollers for freedom of movement.

CONTROL OF STEERING GEARS

Control of the steering gear from the steering wheel on the bridge may be accomplished by any of the following remote control systems, although most modern naval ships use the first one:

1. **ELECTRICALLY**, by means of an alternating current synchronous transmission system.

2. **HYDRAULICALLY**, by means of a hydraulic telemotor system.

3. **ELECTRICALLY**, by means of a direct-current pilot motor and its controller.

4. **MECHANICALLY**, by means of shafting or a wire rope from the steering station.

Alternating-Current Synchronous Transmission

The alternating-current synchronous transmission type of remote control consists of receiving and transmitting units which are similar to small motors; these are connected to the same alternating-current supply. When the transmitter rotor is turned, the receiver motor turns at the same speed and in the same direction.

The transmitters are located in steering stands at remote control stations and are mechanically connected through gearing to the steering wheels. A transmitter at one of the remote stations is electrically connected to a receiver in the steering room. The receiver is connected to the control shaft of the variable displacement hydraulic pump through a differential. Where more than one remote steering station is provided, a switch is provided for selecting the desired control station. Indicating lights are provided on the steering stands and at the selector switch to indicate the selected circuit and that power is available.

Hydraulic Telemotor Control

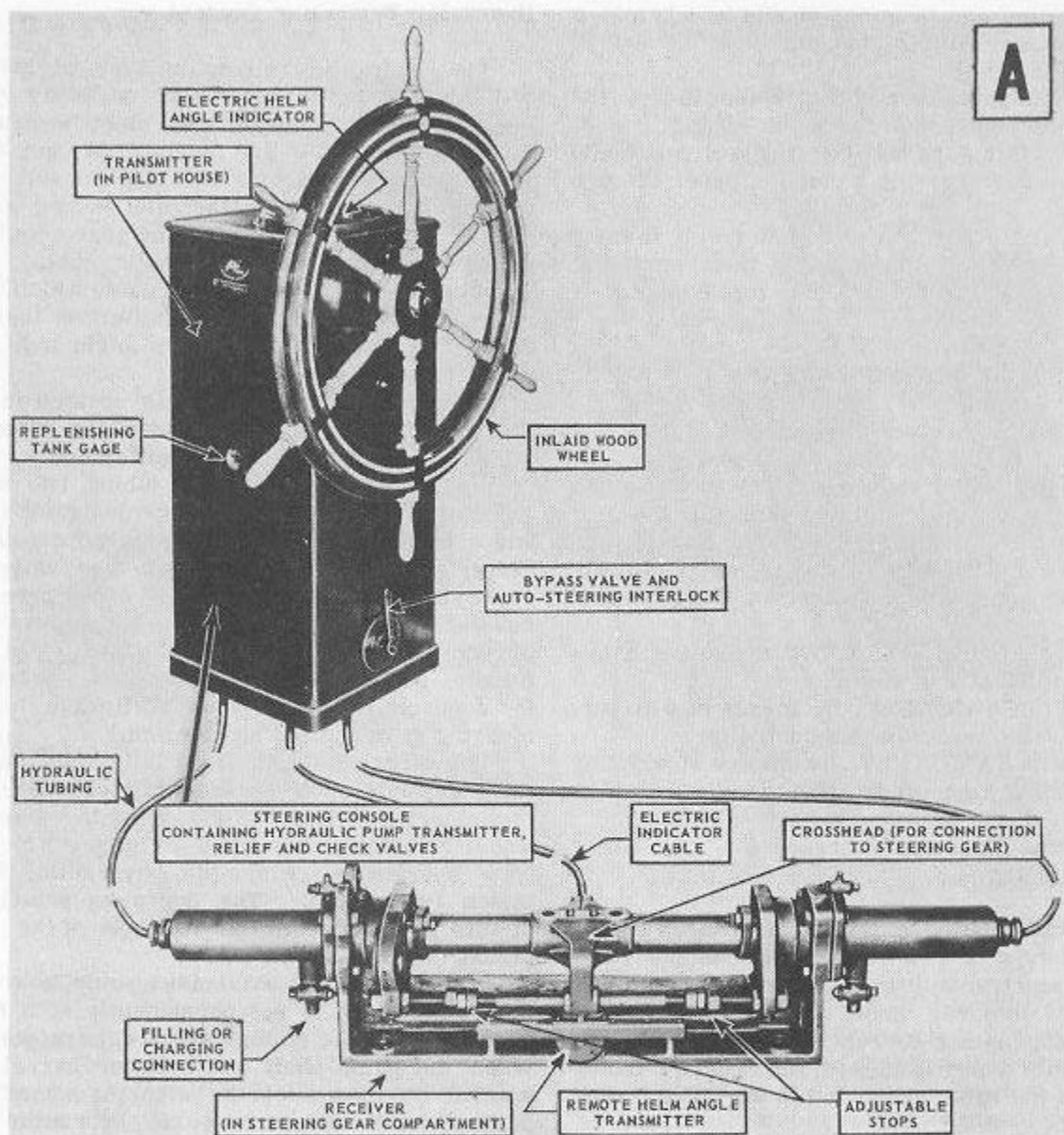
The hydraulic telemotor type of remote control (fig. 15-6) is found on many Navy auxiliary ships equipped with electrohydraulic steering engines. The system (A and C of fig. 15-6) consists of a steering console (hydraulic transmitter) in the pilot house; a hydraulic receiver in the steering gear compartment, and connecting hydraulic tubing. In addition, there is an electric cable which connects the helm angle transmitter on the receiver housing with the helm angle indicator on the steering console.

A hydraulic transmitter is located inside the steering console and under the steering wheel. The hydraulic transmitter components consist of a pump, hydraulic tubing, two relief valves, two check valves, a replenishing tank, and a bypass valve. The remotely located receiver is a hydraulic plunger-type unit with two cylinders—one on each end of the receiver housing—in axial alignment. A double-acting plunger operates in the cylinders. On the middle portion of this plunger a crosshead is connected for mechanical linkage to the steering gear control mechanism.

The direction of the hydraulic fluid movement depends upon the direction of rotation of the steering wheel. Rotation of the steering wheel actuates bevel and spur gears which in turn operate a reversible, hydraulic, axial piston type pump. The operating principles of this pump are similar to those of the axial piston variable-stroke pump.

In the reversible axial piston pump, however, the socket ring is set permanently at a fixed angle so that the pistons are always on stroke. When the pump shaft and cylinder barrel are rotated by means of the steering wheel, the pistons draw fluid in from one hydraulic fluid line and discharge it to the other hydraulic fluid line. Reversing the rotation of the steering wheel reverses the direction of fluid flow through the pump. The pump has external check valves and piping for replenishing the hydraulic system from the tank. Relief valves and a bypass valve (B, fig. 15-6) are also included, as well as vents for purging the system.

When the hydraulic pump shaft is rotated in one direction, the fluid output is discharged from one side of the pump to one of the receiver cylinders. In the other cylinder, hydraulic fluid is displaced to the hydraulic



A. Telemotor components

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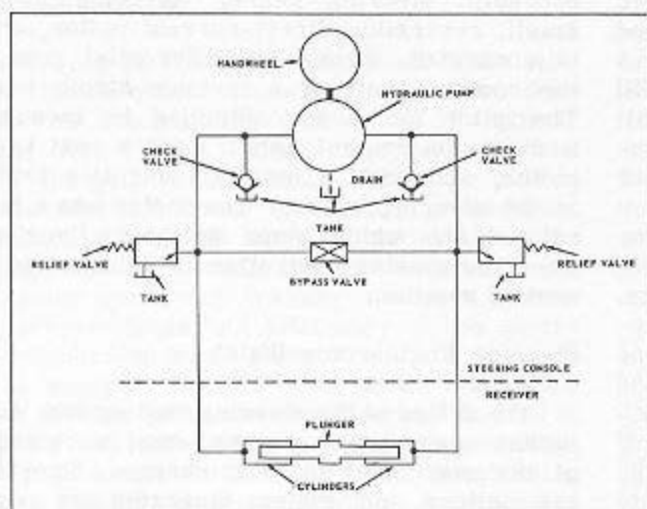
Figure 15-6.—Hydraulic telemotor control.

pump. Thus the hydraulic fluid under pressure moves the receiver plungers and produces a linear movement of the crosshead. This motion is, in turn, transmitted to the connected steering gear control mechanism. Travel of the crosshead and plungers is limited by adjustable stops on the receiver housing. In figure 15-6C, the solid arrows show direction of action for right rudder while the broken arrows

show the flow of hydraulic fluid for right rudder.

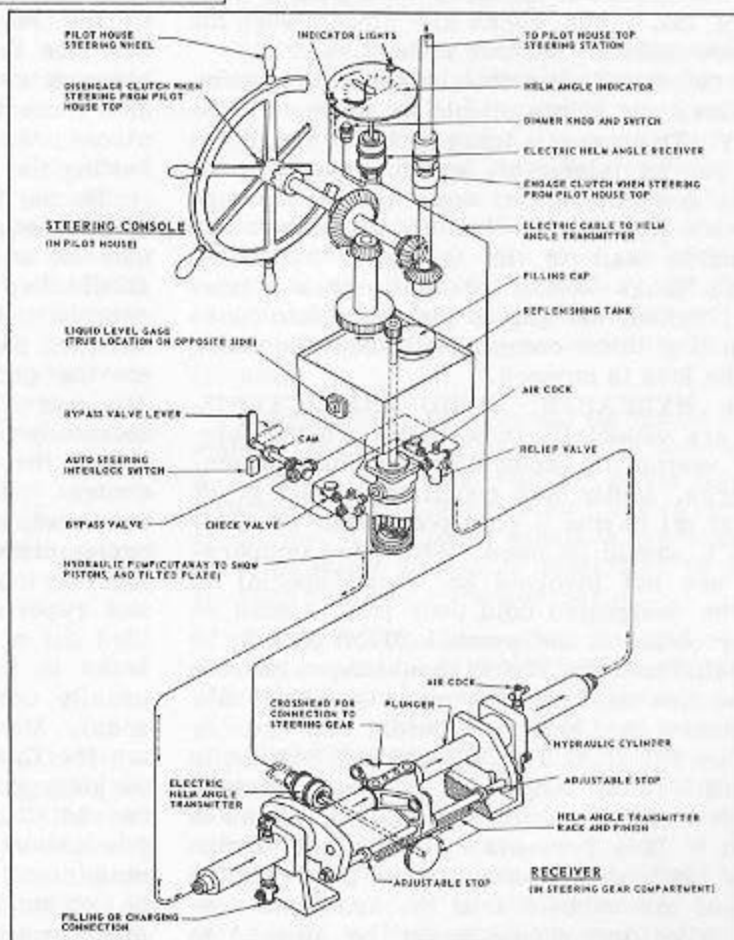
Air cocks and filling or charging connections are provided on the receiver cylinders for venting, filling, or purging the hydraulic system.

FILLING THE TELEMOTOR SYSTEM from the charging tank is done by opening the air cocks at the forward telemotor and starting



B

C



B. Hydraulic circuit diagram

C. Schematic diagram of telemotor components

Figure 15-6.—Hydraulic telemotor control—Continued.

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the charging pump. After the oil has appeared at the air cocks, the pumping is continued until the oil is free of bubbles. The air cocks are then closed and the oil allowed to fill the replenishing tank. While the pump is still operating, the valve leading to the replenishing tank is closed and the system is subjected to a slight pressure.

The effective operation of the telemotor system depends upon the PURGING OF ALL ENTRAINED AIR and the elimination of leaks. Purging the system of air, under normal operating conditions, is done by opening the valve leading from the replenishing tank, and the air cocks at the forward telemotor. Because the replenishing tank is located above the highest point of the telemotor system, the air is forced out of the air cocks by the gravity flow of oil. The cocks are closed when the oil flows smoothly without bubbles.

To detect and eliminate leaks in the system, the valves and joints should be inspected frequently. To correct a leaky piston in the internally packed telemotor, see that the leathers are in good condition, and that the springs (when used) keep the leather in contact with the inside wall of the telemotor cylinders. To stop leaks in the externally packed telemotor, tighten the glands just enough to cause the packing to be compressed about the rams, until the leak is stopped.

The HYDRAULIC FLUID CHARACTERISTICS are especially important when the telemotor system is exposed to low ambient temperatures. Under such conditions, a high grade mineral oil having a cold pour point of -24°F to -40°F should be used. Where low temperatures are not involved or where special oil with the designated cold pour point cannot be readily obtained, the symbol 2075H oil may be used satisfactorily. The oil should have a low rate of expansion and be sufficiently viscous at 150°F to remain a good hydraulic fluid.

When FILLING THE CHARGING TANK with hydraulic fluid, strain the oil into the tank through a funnel which has in it a fine mesh screen. This prevents the entry of foreign matter and at the same time prevents the entry of air bubbles into the hydraulic system. The oil should never be allowed to become contaminated with water.

Direct-Current Pilot Motor Control

The direct-current pilot motor type of remote control is used with some early electro-

hydraulic steering gears. It consists of a small, reversible direct-current motor, which is connected, through a differential gear, to the control shaft of a variable-stroke pump. The pilot motor is controlled by means of a magnetic control panel located next to the motor, and with a master controller located at the steering wheel. The motor has a magnetic brake which stops and holds the motor when the master controller is returned to the neutral position.

Steering Engineroom Watch

The duties of the steering engineroom watch include operation, care, and emergency repair of the machinery in their charge. Operating instructions and system diagrams are posted in the steering gear room. The diagrams describe the various methods of operating the steering gear under normal as well as emergency conditions. The diagrams show the relative position of the valves concerned for setting the gear for each method of operation.

During the steering engineroom watch, the standby equipment should be ready for instant use in an emergency. The steering gear should be inspected thoroughly. The unit in operation should be checked by feeling the various parts. Use extreme caution with moving parts to prevent injury to the hands. Any part that feels HOT to the bare hand should be reported to the OOD on the bridge and to the officer of the watch in main engine control. Investigation for binding, overloading, and lack of lubrication should also be accomplished. New or unusual sounds, which indicate loose parts or wear, should be detected and reported to the OOD. All air should be bled out of the system, and a check made for leaks in the lines and fittings. Piping leaks usually occur following unusual strain (rough seas). Most leaks can be corrected by tightening the flange bolts. Very small leaks at ram packing glands are not objectionable since the small amount of hydraulic fluid provides lubrication. Sufficient fluid should always be maintained in the tanks. All lubrication should be accomplished in accordance with the instructions on the lubrication chart.

All applicable safety precautions should be observed. Keep oil off the deck. Extreme caution should be exercised when working in the confined spaces around the rams and actuating gear.

Steering Casualty

Steering is normally controlled in the pilot house by the helmsman, who receives his orders from the commanding officer via the officer of the deck (OOD). If steering control is lost from the pilot house, control must be shifted to steering aft using emergency procedures. Shifting of control may be necessitated by damage to the remote control system or as a routine underway training measure to test the preparedness and efficiency of the steering engineroom watch party.

In general, this is what would take place when shifting from normal steering control to steering aft in the event of a steering casualty. The pilot house watch would sound the steering alarm located in steering aft. At the same moment "STEERING CASUALTY—STEERING CASUALTY" would be passed over the 1JV circuit. The steering engineroom watch would immediately, and without further orders, take local control with the trick wheel. The steering engineroom watch matches the trick wheel to the actual rudder angle, and if necessary, shifts to the standby unit. They would report to the OOD as soon as steering aft had steering control and would steer as directed by the OOD. The nature and extent of damage or casualty should be determined and reported to the OOD, and to the officer of the watch in the main engineroom. As soon as the casualty has been repaired, the OOD and the officer of the watch in the main engineroom should be informed. When the order is received to shift back to the pilot house, the rudder is brought amidships with the trick wheel, the control shifted to the pilot house, and the OOD informed that the pilot house has control.

ANCHOR WINDLASSES

The term WINDLASS refers to a piece of deck machinery used primarily for paying out and heaving in an anchor chain. A WILDCAT (drum) may be mounted vertically or horizontally at the end of the windlass shaft for handling the anchor chain. The wildcat is fitted with WHEELPS to engage the anchor chain. On the windlass there may also be a CAPSTAN HEAD or WARPING HEAD (concave drum) for handling mooring lines.

General requirements of the anchor windlass are that it must be simple, rugged, reliable, and

capable of reversal; it must have a high mechanical advantage, suitable brakes, and a control for veering the chain. Three general types of power-driven anchor windlasses are used, electrohydraulic, electric, and steam. Hand-operated windlasses are limited to small ships where the weight of the anchor gear is such that it may be handled in a reasonable time and without excessive effort on the part of operating personnel.

Even though used intermittently and only for relatively short periods of time, a windlass must be capable of handling the required load under extremely severe conditions. To prevent deterioration and to provide dependable operation whenever required, maintenance and adjustment must be continued during the periods when the machinery is not in use.

Windlass brakes must be maintained in satisfactory condition if they are to perform their function properly. Because of wear and compression of brake linings, the clearance between the brake drum and band will increase after a windlass has been in operation. Means of adjustment are provided on all windlass brakes. Since maladjustment of a windlass brake could result in the loss of the anchor and chain, it is advisable that you become familiar with maintenance procedures recommended by the manufacturer.

Lubrication instructions furnished by the manufacturer should be carefully followed. If a windlass has been idle for some time, the equipment should be lubricated before operation is attempted. After a windlass has been used, the equipment should be lubricated to protect finished surfaces from corrosion.

The hydraulic transmissions of electrohydraulic windlasses and other auxiliaries are manufactured with close tolerances between moving and stationary parts. If these tolerances are to be maintained and unnecessary wear prevented, every precaution possible must be taken to prevent the entry of dirt and other abrasive material. When the system is replenished or refilled, only clean oil should be used and the oil should be strained as it is poured into the tank. If a hydraulic transmission control system has been disassembled, all parts should be thoroughly cleaned before reassembly. Before piping or valves are installed, their interiors should be cleaned to remove any scale, sand, or other foreign matter.

ELECTROHYDRAULIC ANCHOR
WINDLASSES

An electric motor drives the hydraulic pump (A-end of the variable-speed gear). This pump is a rotary, variable-displacement pump. Oil under pressure transmits the power to the hydraulic motor (B-end of the gear) which through reduction gearing, rotates the windlass. The rate of hydraulic power delivery may be regulated by varying the displacement of the A-end of the pump.

Figure 15-7 illustrates an electrohydraulic windlass arrangement. This particular mechanism has but one constant speed electric motor, which drives the two variable-stroke pumps through a coupling and reduction gears. Band brakes are provided at the wildcats on the upper deck, and clutches are provided at the lower end of the vertical shaft. Figure 15-8 illustrates an electric spur-gear type windlass of a destroyer.

permits disconnecting of the wildcat shaft, thus permitting free operation of the wildcat as when dropping anchor.

ELECTRIC AND STEAM WINDLASSES

Some ships are equipped with geared windlasses driven by reciprocating steam engines; other ships, such as destroyers and destroyer escorts, are equipped with the electric motor variety. The electric motor or steam engine drives the wildcat through a coupling and reduction gears. Band brakes are provided at the wildcats on the upper deck, and clutches are provided at the lower end of the vertical shaft. Figure 15-8 illustrates an electric spur-gear type windlass of a destroyer.

WINCHES AND CAPSTANS

A winch is a piece of deck machinery that has a large winding drum on a horizontal shaft for handling heavy loads with wire rope. In

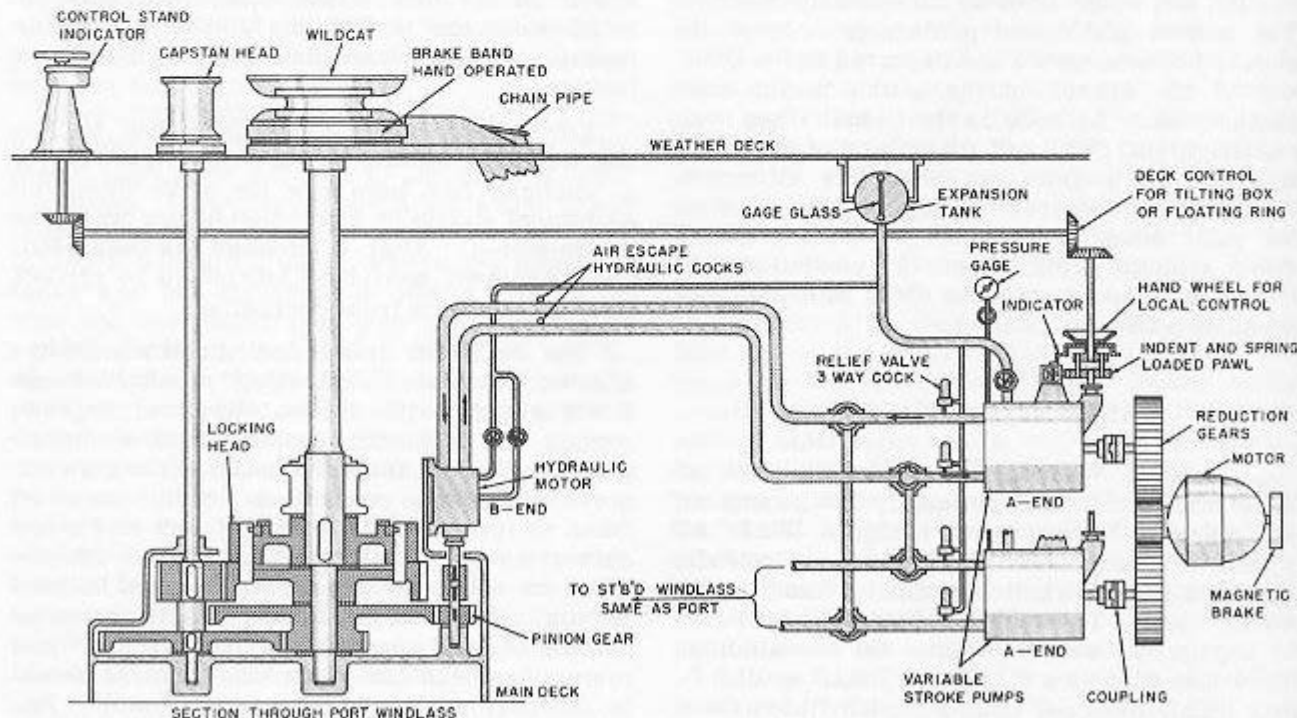


Figure 15-7.—An electrohydraulic anchor windlass arrangement.

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addition, cargo winches may be equipped with one or two gypsy heads fitted for handling manila lines. Winches are used for heaving in on mooring lines, hoisting boats, topping lifts on jumbo booms of large auxiliary ships, and for handling cargo. Power for operating shipboard winches is usually furnished by steam or electricity. Where delicate control and high acceleration without jerking are required, such as for handling aircraft, electrohydraulic winches are usually installed. Most modern auxiliary ships are equipped with either electrohydraulic or electric winches, while the older auxiliary ships are equipped with either steam or electric winches.

CARGO WINCHES

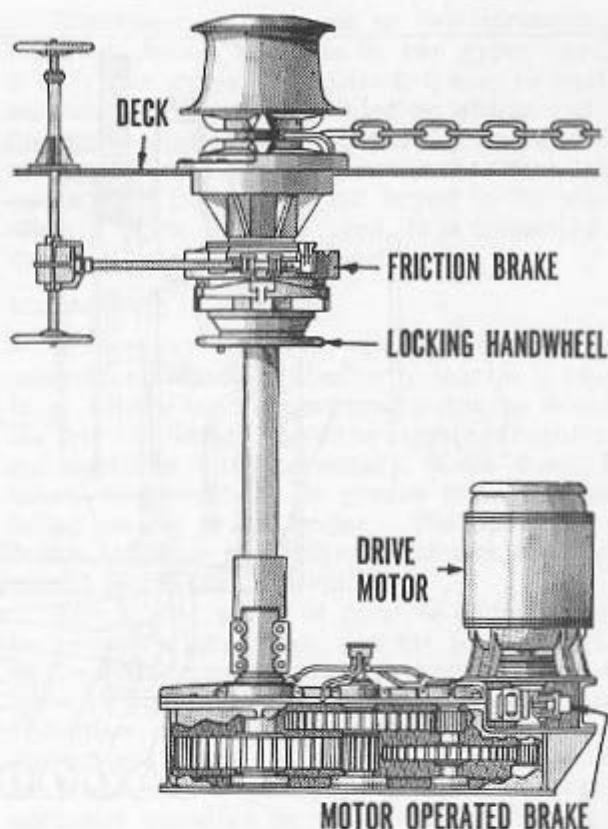
Among the various types of winches for general cargo handling are: double-drum double-gypsy, and single-drum single-gypsy units. Four-drum two-gypsy machines are generally used for mine sweeping.

Steam Winches

The steam-operated deck winch (fig. 15-9) is driven by a two-cylinder, single expansion, double-acting reciprocating engine. The drive is by means of a train of spur gears in which a gear shift is provided to give two drive speeds.

Part A of figure 15-9 is a plan view of a winch with two gypsy heads (1), one mounted at each end of the main drive shaft. The speed and direction of rotation of the engine is controlled by a hand lever (14). Steam is admitted through the steam line connections (6) and (8).

With the winch in "compound gear," the drum turns to lift a load when the hand lever (14) is raised. With the lever in this position, a spool-type valve passes steam from the reverse valve (9) through the two top horizontal pipelines (5) to the cylinders where it drives the engine. (Also see parts B and C, fig. 15-9.) The two lower pipes (4) are exhaust lines. When the lever is lowered below the horizontal position, the direction of steam flow is reversed in these pipes and the engine turns in the opposite direction, thus lowering the load. Some levers are provided with an automatic latch for holding them in the horizontal, or neutral position. For all other positions, the controls must be in the hands of the winch operator who must hold the lever in position for the desired speed.



3.224X
Figure 15-8.—An electromechanical anchor windlass.

A spool-type steam valve slides back and forth, opening and closing the ports for the flow of steam to or from the cylinders. The reciprocating motion of the steam valve is imparted to it by a rod moving through a stuffing box and connected to the eccentric on the main shaft.

With the winch in "single gear" the direction of rotation is reversed and a load is raised by lowering the lever. The clutch mechanism consists of a sleeve (11) which is keyed to the crankshaft (12) and provided with a shifter yoke which is operated by a lever (7) located near the reverse valve (9). (See C, fig. 15-9.) When this lever is thrown to the left, the position shown in figure 15-9A, the pinion which is integral with it, is engaged with the gear (2) on the intermediate shaft. This is the "compound gear" position and gives a slower drum speed with an increase in available line pull. When

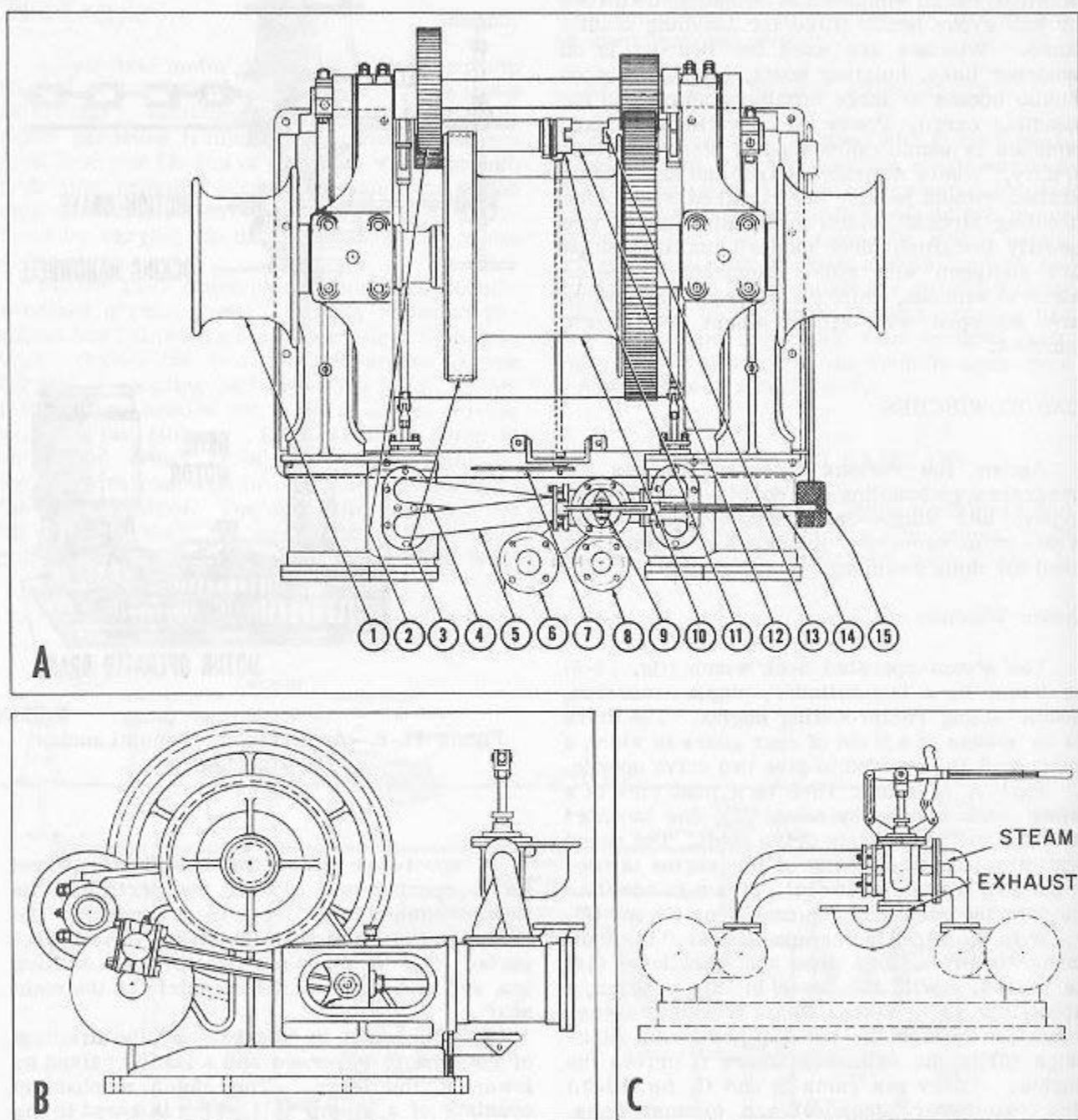


Figure 15-9.—Steam-operated winch.

- A. Plan view.
- B. Side view.
- C. Reversing throttle valve.

the shifter lever (7) is thrown to the right, the driving sleeve is shifted to the right. This disengages the pinion from the intermediate shaft gear (2) and engages the square jaw clutch

(13) and pinion which is always in mesh with the main drive gear. This gives a direct drive from the crankshaft to the main shaft, and is called the single gear position. The single gear position gives a higher drum speed for a given engine speed, but with a decrease in the available line pull.

The "neutral" position is obtained by placing the shifter lever (7) in the vertical position, leaving no connection between the driving sleeve (11) and either pinion. The shifter lever can be latched in any of the three described positions. Care should be taken to latch the lever in the desired position before the winch is operated.

When the winch is under heavy load, there is a high pressure between clutch faces, or gear teeth. This makes it impossible to shift the sleeve and change the gear ratio. To make a change, it is necessary to remove the load from the winch and then turn the engine over very slowly while making the shift.

With the engine running in a given direction, the shifting from compound gear to single gear, or vice versa, reverses the direction of drum rotation. The design of the winch is such that lowering the load by lowering the hand lever (14), applies for heavy loads (compound gear), while the reverse, lowering the load by raising the lever (single gear) applies for higher speeds where heavy loads are not encountered.

The winch is provided with a gypsy head (1) at each end of the main drive shaft. Being keyed to the shaft, the gypsies are turned with the hoisting drum. The drum (10) is provided with a standard type of band brake (3) with a foot-operated control and ratchet lock. The locking device is controlled by springing the foot pedal (15) laterally. The brake band is secured to the winch bed plate in such a manner that the brakes may be conveniently taken up to compensate for wear.

Electrohydraulic Winches

Electrohydraulic winches (fig. 15-10) are always drum type. They are usually installed on ships having alternating current and where a wide range of speed, close control, and smooth acceleration are required, as in cargo handling. The drive equipment is like most hydraulic systems; a constant speed electric motor drives the (A-end) variable-stroke hydraulic pump which is connected to the (B-end) hydraulic motor, by suitable piping. The drum shaft is driven by the hydraulic motor through reduction gearing.

Winches may have one or two horizontally mounted drums and one or two gypsy heads. If only one gypsy is required, it may be easily removed from or assembled on either end of the drum shaft. Gypsy heads are keyed to the drum shaft and rotate whenever the winch is in operation. Drums are not keyed to the shaft. When a drum is to be used, it is connected to the shaft by a clutch.

Maintenance of Winches

In several respects, the maintenance required for a winch is similar to that for a windlass. Where band brakes are used on the drums, the friction linings should be inspected regularly and replaced when necessary. Steps should be taken to prevent oil or grease from accumulating on the brake drums. The operation of brake-actuating mechanisms, latches, and pawls should be checked periodically.

The sliding parts of positive clutches must be properly lubricated, and the locking device on the shifting gear should be checked to determine if it will hold under load. The oil of gear reduction units should be checked for proper amount and purity. Periodic inspections should be made of the pressure lubrication fittings normally installed on slow-moving parts. On installations which use hydraulic transmission, the pumps and lines are maintained in the same way as those of any other hydraulic system.

CAPSTANS

A capstan is a spool shaped, vertical, revolving drum for hauling in on heavy mooring lines. Figure 15-11 shows an anchor windlass capstan head.

The type of capstan installed aboard ship depends on the load requirements and type of power available. In general, a capstan consists of a single head mounted on a VERTICAL shaft, reduction gearing, and a power source. The types, classified according to power source, are electric and steam.

Electric Capstans

Electric capstans are usually of the reversible type and develop the same speed and power in either direction. Capstans driven by alternating-current motors have two speeds, full speed and one-half speed. Capstans driven by direct-current motors usually have from three to five speeds in either direction of rotation.

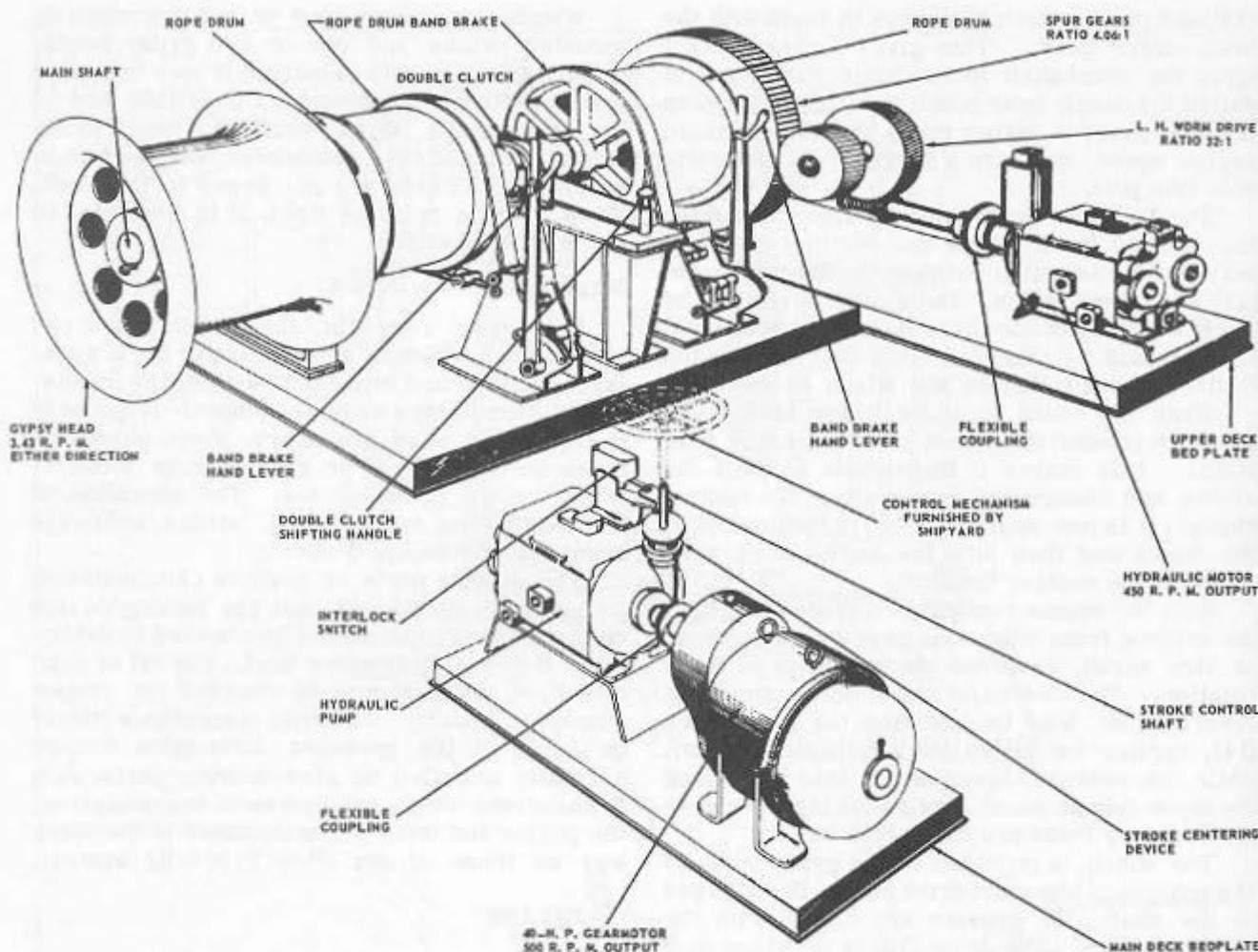


Figure 15-10.—Electrohydraulic winch units.

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Steam Capstans

Steam capstans were formerly used extensively on Navy ships, but they are now used only occasionally where the electric power is insufficient.

Steam cylinders are driven by twin cylinder, reciprocating, reversible steam engines. A hand-operated control valve reverses and controls the speed of the capstan. Steam-driven capstans generally do not operate on full boiler pressure, usually a reducing valve is used to reduce the steam supply to 100 psi.

Cranes

The hoisting whips and topping lifts of cranes are usually driven by hydraulic variable-speed gears, through gearing of various types. This provides the wide range of speed and delicate control required for load handling. The cranes are usually rotated by an electric motor connected to worm and spur gearing, or by an electric motor and hydraulic variable-speed gear connected to appropriate reduction gearing.

Some of the electrohydraulic cranes are also provided with automatic slack line takeup equipment, consisting of an electric torque motor

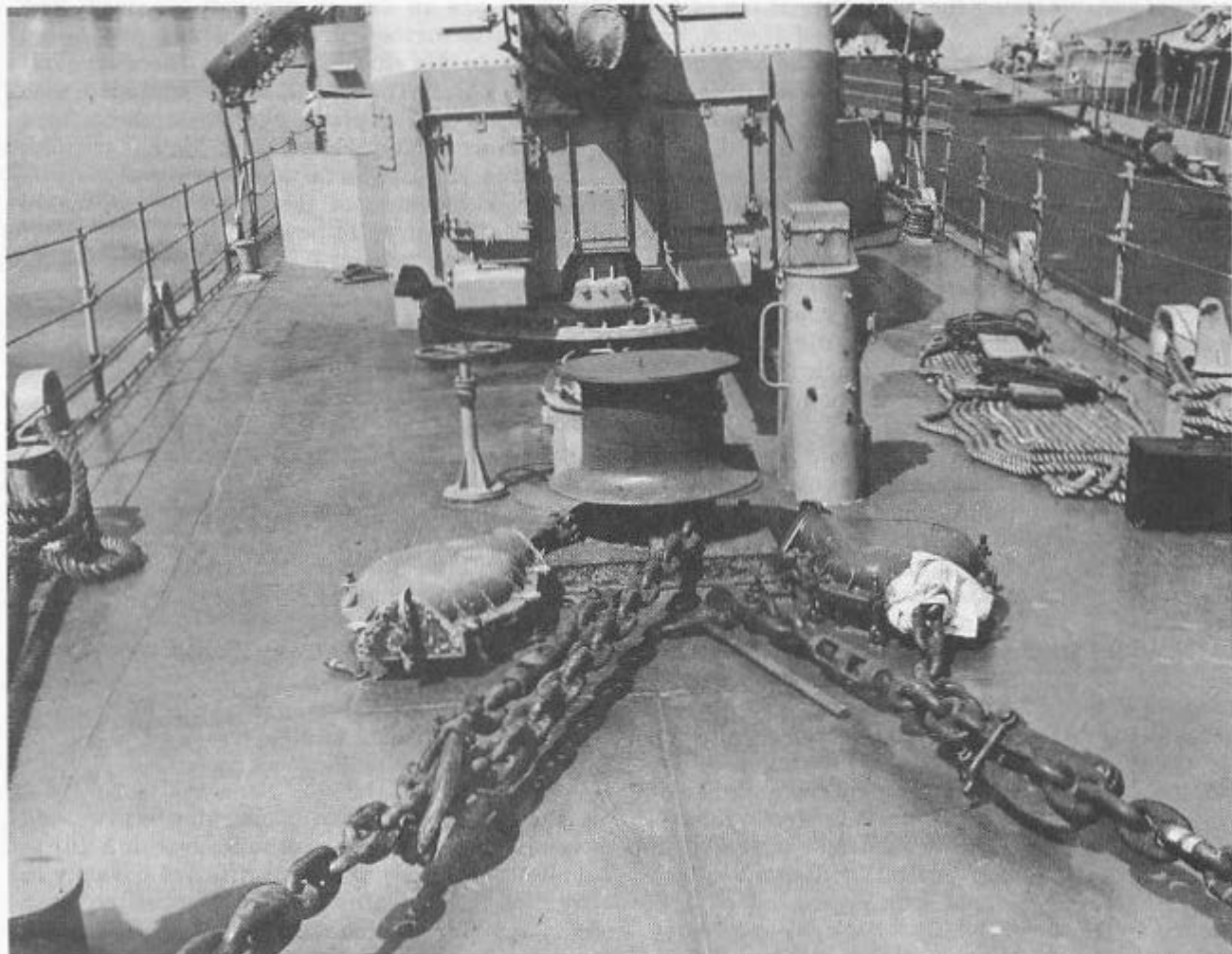


Figure 15-11.—Vertical-shaft anchor windlass capstan head.

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geared to the drum. When these cranes are used for lifting boats, aircraft or other loads from the water, the torque motor assists the hydraulic motor drive to reel in the cable in case the load is lifted faster by the water than it is being hoisted by the crane.

Electrohydraulic equipment for the crane consists of one or more electric motors, running at constant speed. Each motor drives one or more A-end variable displacement hydraulic pumps whose strokes are controlled through operating handwheels. START, STOP, and EMERGENCY RUN pushbuttons are located at the operator's station for the control of the electric motors. Interlocks are provided to prevent

starting the electric motors when the hydraulic pumps are on stroke. B-end hydraulic motors are connected to the A-end pumps by piping, and drive the drums of the hoisting and topping units or the rotating machinery.

Reduction gears are provided between the electric motor and the A-end pump and between the B-end hydraulic motor and the rotating pinion. Each hoisting, topping, and rotating drive is provided with an electric brake on the hydraulic motor output shaft. The electric brake is so interlocked with the hydraulic pump control that the brake will set when the hydraulic control is on neutral or when electric power is lost. A centering device is provided for accurately

finding and retaining the neutral position of the hydraulic pump.

Relief valves are installed for the protection of the hydraulic system. These relief valves are normally set at 150 percent of the normal working pressure.

A rapid slack-takeup device consisting of an electric torque motor, which is connected to the hoist drum through reduction gearing, is usually provided on cranes. This device works in conjunction with the pressure stroke control on the hydraulic pump, and provides for fast acceleration of the hook in the hoisting direction under light hook conditions. Thus, slack is prevented from forming in the cable when hoisting is started.

Some cranes are provided with a light-hook paying-out device. This device is mounted on the end of the boom to pay out the hoisting cables when the weight of the hook and cable beyond the boom head sheave is insufficient to overhaul the cable as fast as it is unreeled from the hoisting drum.

When the mechanical hoist control is in neutral, the torque motor is not energized and the cable is gripped lightly by the action of a spring. Moving the hoist control to LOWER energizes the torque motor, and the sheaves clamp and pay out the cable as it is unreeled from the hoist drum. When the hoist control is moved to HOIST, the torque motor is reversed and operates to unclamp the sheaves. A limit switch opens and automatically deenergizes the paying-out device. Figure 15-12 shows the light-hook pay-out device with the torque motor paying out the cable.

Maintenance of cranes should be accomplished in accordance with manufacturers' instructions. In general, the maintenance of electrohydraulic cranes requires that the oil in the replenishing tanks be kept at the prescribed levels, and that the system be kept clean and free of air. The limit stop and other mechanical safety devices must be checked regularly for proper operation. When cranes are not in use, they should be secured in their stowed positions and all electric power to the crane controllers disconnected at the power distribution panel.

ELEVATORS

Some of the hydraulic equipment with which you may be concerned will be found in electrohydraulic elevator installations. Elevators of

this type are in use on aircraft carriers. The elevators described in this chapter are of the type now in service on ships of the Forrestal class (CVA). These ships are equipped with four deck-edge airplane elevators which have a maximum lifting capacity of 79,000 pounds. The cable lift platform of each elevator projects over the side of the ship and is operated by an electrohydraulic power plant.

POWER PLANT

The electrohydraulic power plant consists of the following:

1. A horizontal plunger type hydraulic engine.
2. Five variable delivery parallel piston type pumps.
3. Two high pressure tanks.
4. One low pressure tank.
5. Sump tank system.
6. Two constant delivery Denison vane type pumps (sump pumps).
7. Oil storage tank.
8. Piping system and valves.
9. Nitrogen supply.

The hydraulic engine is operated by pressure developed in a closed hydraulic system. Oil is supplied to the system in sufficient quantity to cover the baffle plates in the high pressure tanks and allow for piston displacement. Nitrogen makes up the rest of the volume. Nitrogen is used because air and oil in contact under high pressure form an explosive mixture. Air should not be used except in an emergency. Nitrogen should be maintained at 97 percent purity in the system.

PRINCIPLES OF OPERATION

The hydraulic engine is fitted with a balanced piston type valve with control orifices and a differential control unit. This control assembly is actuated by an electric motor and can be operated by hand. To raise the elevator, the valve is moved off center, allowing high pressure oil to enter the cylinder. High pressure oil entering the cylinder, moves the ram, which, through a system of cables and sheaves, moves the platform upward. Cable speed of the elevator is controlled by the amount of pressure in the high pressure tank and the control valve.

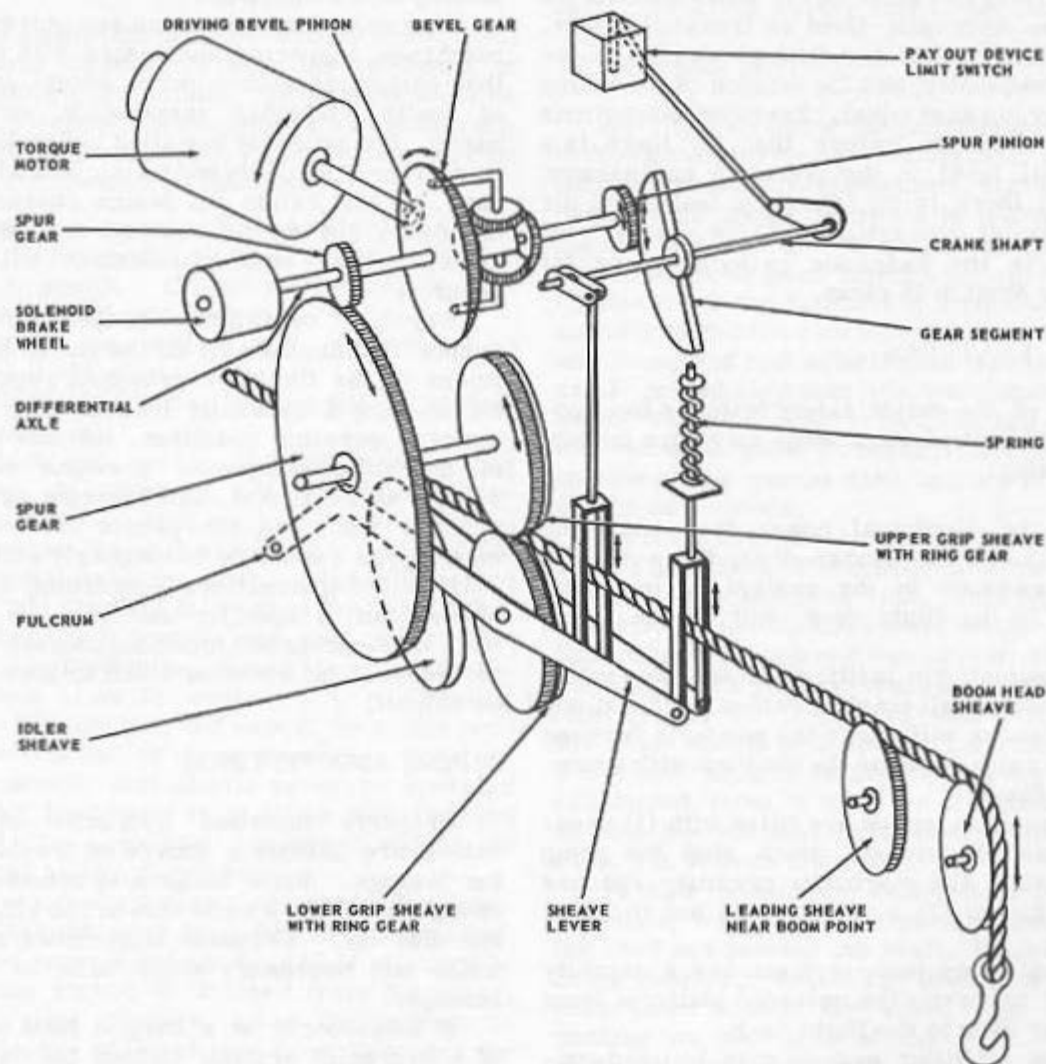


Figure 15-12.—Light-hook pay-out device.

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When the elevator starts upward, the pressure in the high pressure tank drops. This pressure drop automatically starts the main pumps which transfer oil from the low pressure tank to the high pressure system until the pressure is restored. An electrical stopping device automatically limits the stroke of the ram and stops the platform at the proper position at the flight deck level.

To lower the elevator, the control valve is moved in the opposite direction, which permits the oil in the cylinder to flow into the exhaust

tank. As the platform descends, oil is discharged to the low pressure tank and the original oil levels and pressures, except for leakages, are reestablished. The speed of lowering is controlled by the control valve and the cushioning effect of the pressure in the exhaust tank. Leakage is drained to the sump tanks and is automatically transferred to the pressure system by the sump pumps. An electrically operated stopping device automatically slows down the ram and stops the platform at its lowest level.

The maintenance procedures for elevators are relatively the same as for other auxiliaries which use hydraulic fluid to transmit power.

Elevator cables and fittings should be inspected frequently, and the tension of the cables in each group kept equal. Frequent inspections must be made to ensure that (1) there is a proper oil level in the pressure and exhaust tanks, (2) there is no excessive leakage in the sump leak-off connections, (3) the pistons seal properly in the hydraulic cylinders, and (4) the entire system is clean.

SAFETY FEATURES

Some of the major safety features incorporated into modern deck edge elevators include the following:

1. If the electrical power fails while the platform is at the hangar deck, there will be enough pressure in the system to move the platform to the flight deck, without the pumps running.

2. The platform is fitted with serrated safety shoes. Should all hoisting cables break on one side, the shoes will wedge the platform between the guide rails and stop the platform with a minimum of damage.

3. The main pumps are fitted with (1) pressure actuated switches which stop the pump motors when the discharge pressure reaches 1140 psig, and (2) a relief valve set to lift at 1270 psig.

4. The sump pump system has a capacity sufficient to return the unloaded platform from the hangar deck to the flight deck.

5. The oil filter system may be used continuously while the engine is running, thus part of the oil may be cleaned with each operation of the elevator.

MAINTENANCE OF HYDRAULIC SYSTEMS

The overall efficiency of hydraulic installations used to control or drive auxiliary machinery is basically dependent upon size of installation, oil pressure, speed, and condition of the equipment. The care given the hydraulic components of the system is an important factor. Major repair of hydraulic gear, except for piping and fittings, is generally performed at a naval shipyard or by the manufacturer. Routine maintenance, keeping the oil clean,

and maintaining proper fluid levels is the responsibility of the operator.

Hydraulic transmissions are sturdy, proven machines, inspected and tested with such care that casualties seldom occur except as a result of faulty assembly, installation, or maintenance. If a properly installed hydraulic system is operated regularly and maintained with proper care, it will retain its design characteristics of power, speed, and control, and the need for costly repair and replacement will seldom occur.

Regular operation, proper lubrication, proper maintenance of all the units, and cleanliness of the fluid are principal requirements for keeping a hydraulic transmission in satisfactory operating condition. Regular operation of hydraulic equipment prevents corrosion, sludge accumulation, and freezing of adjacent parts. The need for proper lubrication and cleanliness cannot be too strongly emphasized.

Detailed instructions concerning the maintenance of a specific unit may be obtained from the appropriate technical manual; however, the general information which follows will also be helpful.

PIPING AND FITTINGS

Properly installed hydraulic piping and valves are seldom a source of trouble, except for leakage. Some leaks may become serious enough to cause a reduction in the efficiency of the unit (s). Frequent inspections should be made and necessary steps taken to eliminate leakage.

If leaks occur at a flanged joint in the line of a hydraulic system, tighten the flange bolts evenly, but not excessively. If the leaks persist, use the standby unit, if available, or shut down the equipment while the gasket of the leaking flange is being replaced. Make certain that the flange surfaces are cleaned carefully before the new gasket is applied.

Relief valves or shuttle valves of a hydraulic system may be sources of trouble. The seats of leaking relief valves should be reground. Loss of power may indicate a leaking relief valve. Shuttle valves may stick and fail to cut off. Existence of this condition is indicated when oil escapes from the high pressure side of the line into the expansion tank, or when the pressure control fails. When a shuttle valve fails to operate, the stop valves should be closed and the defective valve removed for repair.

FLUID SYSTEM

When inspection of an oil sample drawn from a hydraulic system reveals the presence of water, sludge, or acidity, the system must be drained, cleaned with the prescribed flushing oil, and filled with clean oil. The system may be drained and cleaned as follows:

1. Remove permanent type filters and wash them in flushing oil. Use low pressure air for drying purposes. If filters have replaceable elements, install new elements.
2. Drain the system, as completely as possible, of old oil.
3. Close all connections and fill the system with flushing oil.
4. Start and operate the unit under idling conditions, in order to fill the system thoroughly with the flushing oil.
5. Secure the unit and allow it to stand idle for approximately one hour. This idle period permits the flushing oil to dissolve any sludge.
6. Start and operate the unit under light load for 3 to 5 minutes, unless otherwise specified. Then allow the equipment to remain idle for about 15 minutes, and repeat the entire process. Do this two or three times.

A hydraulic unit should never be operated under full load when it is filled with flushing oil, and the operating pressure should be maintained as low as possible.

After each short operating period, the cleaning handles of edge type filters (if installed) should be turned and an amount of oil equal to its volume should be drained from the filter.

7. If time permits, allow the system to stand idle for an additional hour following the series of short operating periods.

8. Drain the system of flushing oil, close the system, and fill it with the proper hydraulic oil.

As the system is being filled, the oil should be strained through a fine wire screen of 200 mesh. If the oil is not clean, it should be run through a centrifuge. Adequate protection should be provided against dust and moisture. Moisture should be expelled from oil before it is poured into a system; this can be done by heating the oil to 250°F.

When a hydraulic system is being filled, sufficient fluid should be used to completely fill the active parts of the mechanism, leaving no air pockets. During the filling procedure, air valves should be opened so that air can escape

to the oil expansion box. After the system has been filled, the valves should be closed tight.

PUMPS AND MOTORS

An electric motor is provided to rotate the hydraulic A-end (pump end) variable speedgear (rotary, positive displacement, variable stroke pump). Oil under pressure is delivered from the A end to the hydraulic motor (B-end) variable speed gear through piping. The B-end rotates the individual unit or equipment through suitable reduction gearing. Whether the A-ends and B-ends of hydraulic transmissions are of the axial- or radial-piston type, maintenance procedures and operating principles are relatively the same. In general, maintenance information on other type pumps also applies to hydraulic pumps and motors.

On some hydraulic transmissions, the SHAFT STUFFING BOX PACKING is of the square-braided pure asbestos type. This type packing is easily removed. Care must be taken to ensure that it is not replaced too tightly; if properly installed, this packing makes a tight joint with light pressure. If packing wears out quickly, the shaft should be inspected for roughness. If a machine shop is available, roughness may be eliminated from a shaft by a finishing cut to smooth the surface; otherwise, it may be necessary to replace the shaft.

Packing should be renewed at prescribed intervals, to prevent the packing from becoming hard and scoring the shaft. When packing is being replaced, a uniform thickness should be maintained around the shaft. An excess of packing on one side of the shaft will cause shaft deflection and may even result in breakage. Stuffing boxes should be packed loosely and the packing gland set up lightly, allowing adequate leakage for cooling and lubrication.

There is less likelihood of POOR ALIGNMENT BETWEEN THE DRIVING AND DRIVEN MEMBERS of a hydraulic transmission if the wedges, shims, jacking screws, or adjusting setscrews are properly set and secured when connected units are installed. However, because of a casualty, misalignment may occur that will cause severe stress and strain on the coupling and connected parts. Excessive misalignment should be eliminated as soon as possible by replacing any defective parts and readjusting the installed aligning devices. If this is not done, pins, bushings, and bearings will have to be replaced frequently.

Since there is no end play to either the A-end or the B-end shaft, flexible couplings are generally used in hydraulic transmissions. Such couplings permit satisfactory operation with a slight misalignment, without requiring frequent renewal of parts.

Complete maintenance of all types of hydraulic systems cannot be given in this publication. Maintenance instructions concerning any specific unit can be found in the appropriate manufacturer's technical manual. Although the information which follows applies specifically to electrohydraulic elevators, it is generally applicable to most shipboard electrohydraulic systems.

REPLACING HYDRAULIC ENGINE CYLINDER PACKING

As the plunger moves in and out of the cylinder, the cylinder packing confines the pressure in the cylinder and prevents leakage of oil. The packing is made up of several split rings. To prevent leakage, the cylinder gland nuts must be tightened periodically. If the gland nuts have been tightened and the packing continues to leak excessively, the packing is worn or damaged and must be renewed.

Packing is renewed as follows:

1. Lock the platform at the flight deck.
2. Set the stroke of the main pumps at zero and close all pressure tank, exhaust tank, and strainer valves.
3. Drain the oil from the cylinder, through the engine drain line. When oil stops draining, close the drain line.
4. Remove the gland nuts and the gland.
5. Remove the old packing rings.
6. Insert new packing rings in the packing gland. Stagger the splits in the rings at 90° intervals. It may be necessary to support the ram in order to insert new packing on the underside of the ram.
7. Replace the gland and nuts. Care must be taken to pull the nuts up evenly and only to the point where they are snug.
8. Open all valves to the exhaust and pressure tank and open the engine air cocks.
9. Check to be certain that the main pump handwheels are set at zero stroke. Start the main pump motors and set the pumps on automatic control.
10. Open the control valve slightly, by rotating the hand control valve counterclockwise, until the oil flows from the engine air cocks.

11. Close the control valves.

12. Tighten the packing gland nuts one turn at a time until oil leakage, through the packing gland, is a few drops per second. (Nuts should be tightened so that the gland is drawn up evenly.) Some oil leakage is necessary for proper lubrication of the packing.

13. Loosen each nut one-half turn and lock with jam nut.

CAUTION: If the packing is too tight the plunger will not operate at proper speed and may also damage the packing.

14. Bleed all air from the cylinder and pressure line.

15. Check the oil levels and pressures before placing the elevator in service. An oil seal is provided for wiping the plunger of foreign material on the in-stroke. It is split and can be removed after the plate is slid off.

REPLACING MAIN SHAFT OIL SEALS

When the main shaft oil seals become worn or damaged and cause excessive oil leakage, the seals should be replaced as follows:

1. Disconnect the universal joint from the main shaft by removing the bolt.
2. Shove the main shaft toward the motors.
3. Remove the fork and the plate (fig. 15-13A).
4. Remove the old seal and replace it with a new seal (fig. 15-13B).
5. Reassemble the seals with plate, fork, and universal joint (fig. 15-13C).

REPLACING MOTOR SHAFT OIL SEALS

To determine the condition of the motor pinion assembly and associated oil seals, periodic inspections for excessive leakage should be performed. If it becomes necessary to replace the motor shaft oil seals, the following procedure should be used:

1. Remove the bolts, while supporting the motor, that fasten the motor blocking to the mounting bracket.
2. Pull the motors horizontally away from the gear box until the pinion on the motor shaft is clear of the gear box (fig. 15-14A).
3. Remove the old seals and replace them with new seals (fig. 15-14B).
4. Return the motor pinion into the gear box, and bolt the motor blocking, or frames, into place (fig. 15-14C).

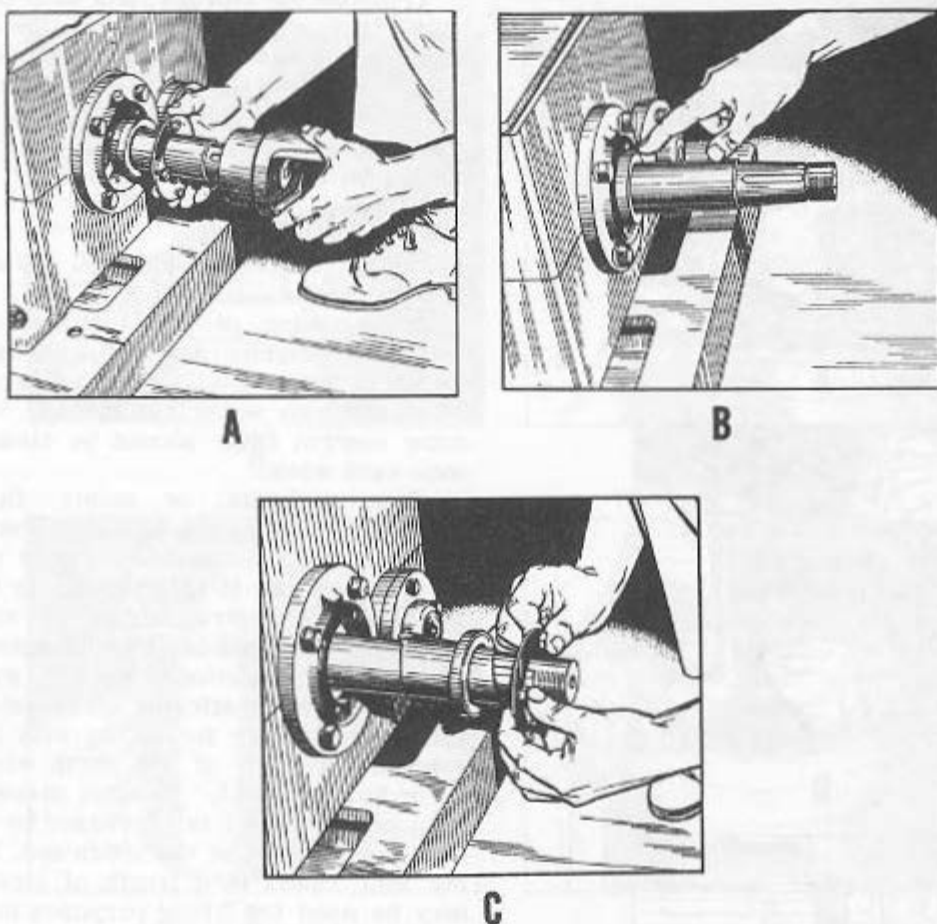


Figure 15-13.—A. Removing fork and plate.
 B. Removing oil seal.
 C. Reassembling oil seal and plate.

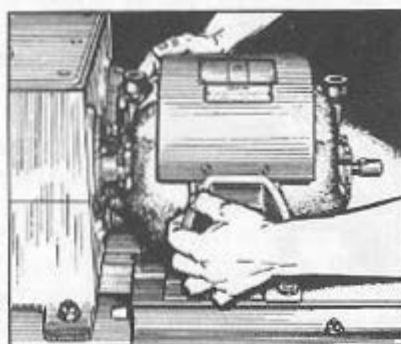
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CLEANING MAIN AND SUMP PUMP OIL STRAINERS

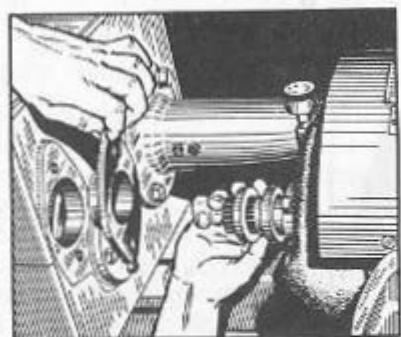
The main pump oil strainers should be cleaned shortly after the hydraulic system has been filled with oil, or after repair work has been completed. (It is possible that foreign matter, such as dirt, metal chips, and filings may have entered the system.) A main pump oil strainer should be cleaned as follows:

1. Close the strainer intake (inlet) valve and the main pump suction valve.
2. Open the air cock, at the top of the strainer, and the drain valve, at the bottom of the strainer. This will drain the oil from the strainer into the sump tank.

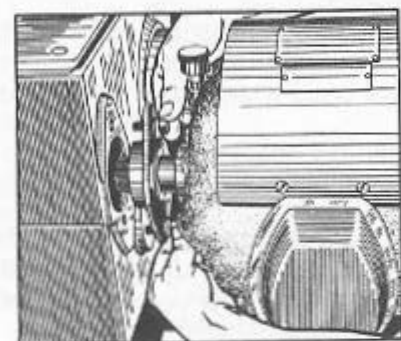
3. Close the drain valve.
4. Loosen the bolts and remove the cover from the strainer (fig. 15-15A).
5. Lift the basket out of the strainer (fig. 15-15B).
6. Blow out all dirt and foreign matter from the strainer basket. Then clean the strainer basket thoroughly (fig. 15-15C).
7. Insert the basket into the strainer, place the cover on the strainer (using a new gasket), replace and tighten the bolts.
8. Open the strainer intake valve and refill the strainer with oil from the system while bleeding off the air.
9. Close the air cock and open the main pump suction valves.



A



B



C

Figure 15-14.—A. Pulling motors.
B. Replacing oil seals.
C. Returning motor pinion
into gear box.

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The sump pump oil strainers should be cleaned at the same time as the main pump oil strainers. They should be cleaned as follows:

1. Close the storage tank stop valve, the exhaust tank stop check valve, the engine stop check valve, and the sump pump stop check valve.

2. Open the air cock and the drain valve. Then continue the procedure as outlined under main pump strainers. (NOTE: The check valves should be open before the strainer is refilled with oil.)

CARE OF MAIN HYDRAULIC PUMPS

Maintenance of the main pump consists mainly of draining and refilling with oil, when the oil in the hydraulic system has become dirty or mixed with water. In addition, the compensator control filter should be cleaned at least once each week.

Fire resistant, or safety, fluid MIL-H-19457 should be used in the hydraulic system. All oil must be strained through a fine mesh wire screen as it is poured into the system. The use of cloth strainers is not recommended, since the continued use of such material tends to cause an accumulation of lint in the system. This may result in the sticking of the pistons. A convenient accessory for filling may be made by soldering a piece of fine mesh wire screen to an ordinary funnel. In some cases the usefulness of the funnel is increased by the addition of a pipe thread at the lower end. By connecting this funnel to a length of pipe, the funnel may be used for filling purposes in places that are not otherwise accessible.

All containers used for filling the system, or for storing oil, should be clean. They must not have been used previously for acids, lyes, or other chemicals. When the pump is drained after having been in service, all dirt and sludge must be cleaned out, and the pump flushed with acid-free cleaning fluid. Before the pump is refilled with oil, all cleaning fluid must be removed from the pump, and the pump blown out with air until dry. Unless this is done, either the chemical or the physical properties of the oil may be impaired by small quantities of cleaning fluids.

In elevator hydraulic systems, water seeping into the pump will usually settle in low points. If the drain plugs are removed, the water will drain out.

Hydraulic equipment which has been standing idle at extremely low temperatures should be started with care. (Before operating the equipment the entrapped air should be bled from the cylinders, control valves, strainer, and piping.)

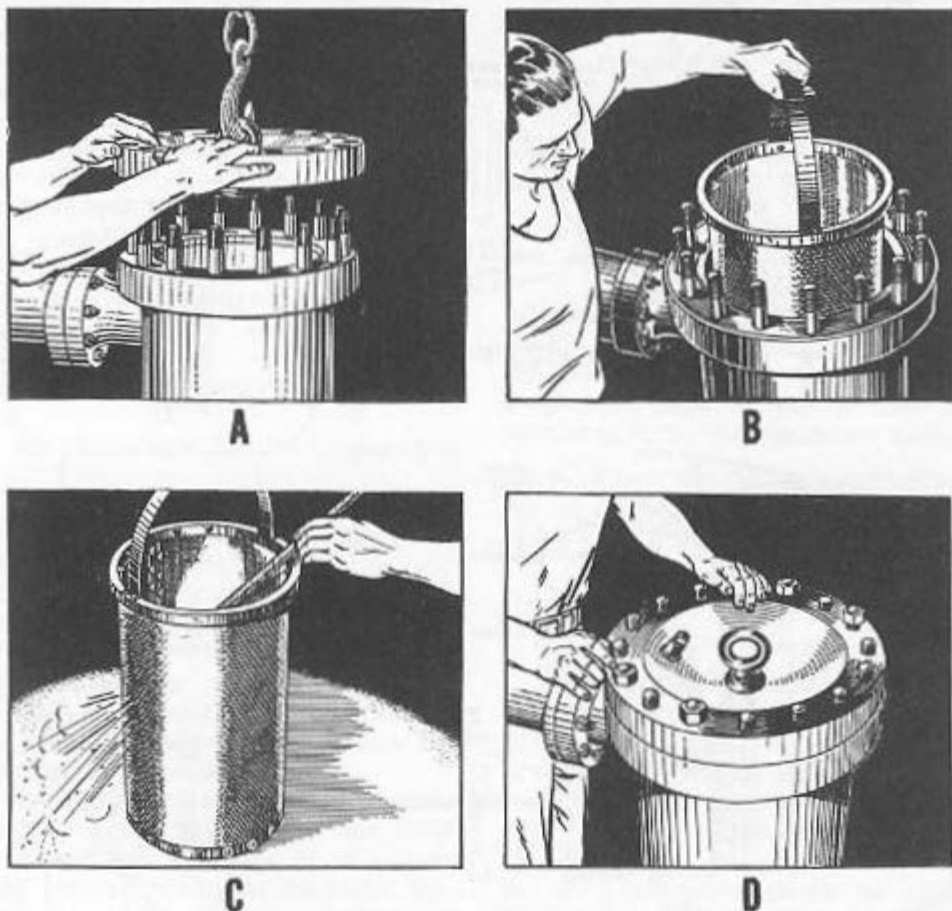


Figure 15-15.—A. Removing strainer cover.
 B. Lifting strainer basket.
 C. Cleaning strainer basket.
 D. Replacing strainer cover.

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While the oil is pumpable at low temperatures, it does not lubricate properly. A short time is required to force the oil between closely fitted parts so as to provide lubrication. Two or three minutes of operation at low pressures will provide ample time for penetration. During this time the oil will warm up and the viscosity will be greatly reduced.

Grit and abrasive particles in the oil will cause wear which destroys the seal between the pistons and the cylinder. This results in the leakage which reduces the efficiency beyond allowable limits. If the wear becomes excessive, the worn part should be replaced.

CLEANING AND REPLACING FILTER ELEMENTS

Each elevator has a micron oil filter (fig. 15-16) installed in its power system. The filter is generally designed to handle approximately 140 gpm of hydraulic oil, at a working pressure of 350 psi, with a pressure drop of approximately 5 psi. The quantity of oil passing through the unit is controlled by an orifice installed between the flanges located on the discharge side of the filter. The quantity of oil will be indicated on the Flo-Gage and the pressure drop on the differential pressure gage. An internal bypass

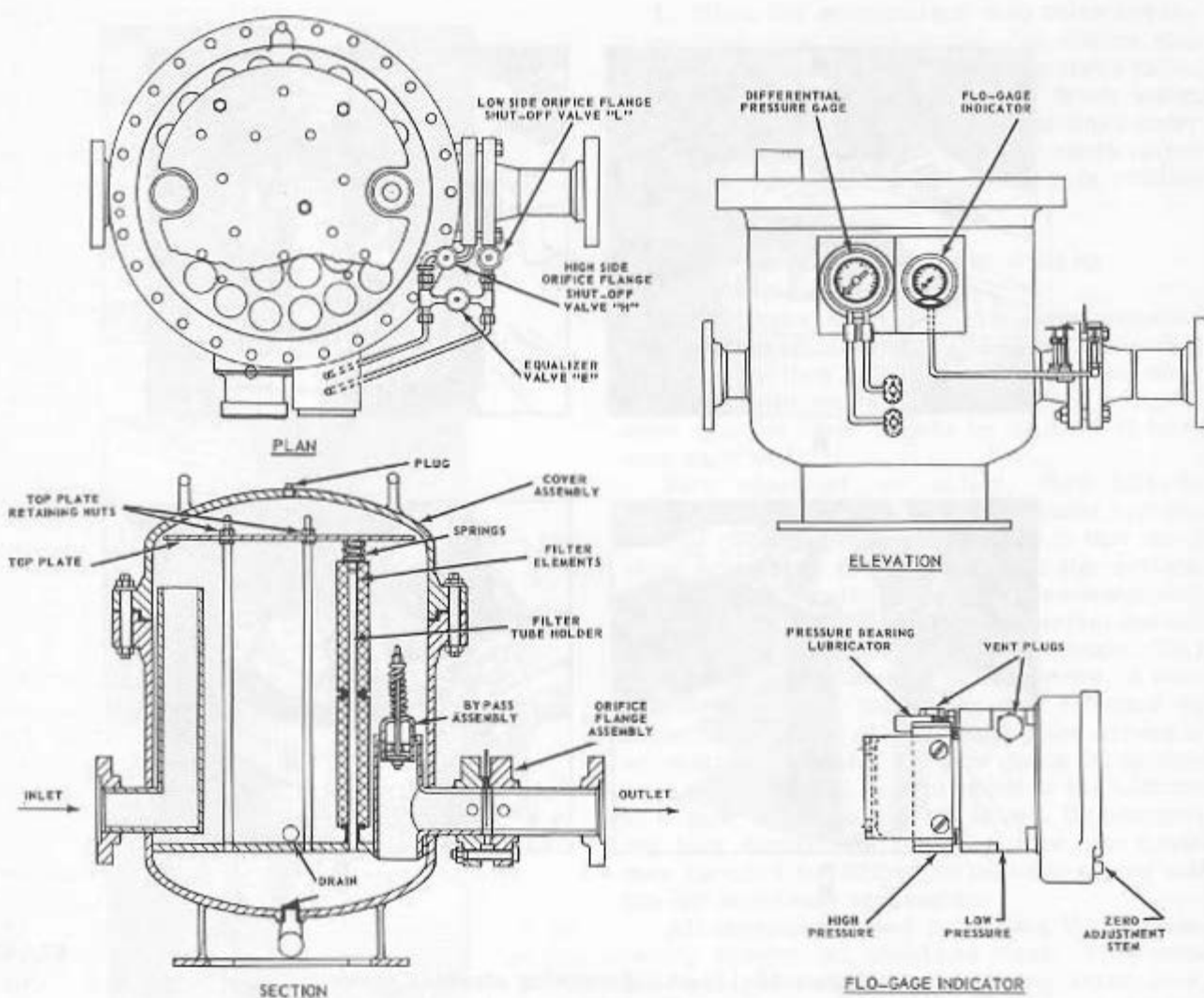


Figure 15-16.—Micronic oil filter.

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valve is installed and set to open at 20 psi above the working pressure. Stop valves are installed on the inlet and outlet sides of the filter to facilitate cleaning and/or replacement of the filter elements. The piping to the filter is arranged to take oil from the exhaust tank and discharge to the suction sides of the main pumps.

To clean all the oil in the enclosed pressure system, the following procedure should be used:

1. Operate the elevator on a cycle once "up" and "down"; this takes approximately 3 1/2 minutes.

2. Use at least one of the main pumps to circulate the oil. Shorten the strokes of the pumps to reduce delivery so that the pumps are not automatically shut down between runs of the elevator.

3. Close the inlet and the outlet valves of the main strainers; this will cause all the oil being pumped to pass through the filter.

4. Watch the Flo-Gage and adjust the strokes of the pumps so that the flow does not exceed 140 gpm.

5. Operate the elevator as frequently as necessary to keep the pumps operating; i.e., run the elevator up and down before the oil level and

pressure are completely restored in the high pressure tank which would shut off the pumps.

6. Maintain this operation for about 30 minutes—in which time, all of the oil should have passes through the filter.

7. Observe the differential pressure gage and if the indication is above 5 psi, stop filtering and clean the filter.

After the complete cleaning of the oil, the filter can be used in parallel with the main strainer. This condition will allow about 10 percent of the oil to flow through for continuous filtering during the normal operation of the elevator.

The filter should be cleaned as follows:

1. Place the Flo-Gage in the inoperative position.

2. Close the inlet and the outlet gate valves.

3. Slowly open the globe valve in the drain line from the bottom of the filter.

4. Open the gate valve in the drain line from the side of the filter body.

5. Close the globe valve in the bottom drain.

6. Attach the air hose (25 psi) to the 1/4-inch size needle valve and allow air to blow back through the filter elements, through the open gate valve to the blow-down tank.

7. Close the drain and air valve, and allow the oil to settle in the blow-down tank after which a check for the cleavage point can be made by using the try cocks on the tank. Impurities in the oil can be disposed of through the 1/2-inch valve installed below the blow-down tank.

8. When refilling with oil, or fluid, open the plug on top of the filter to bleed the air.

9. Open the outlet valve, and the inlet valve. Close the plug when all the air is out.

10. Place the Flo-Gage in operation.

If the filter cannot satisfactorily be cleaned, it should be replaced as follows:

1. Proceed as for cleaning the filter elements; steps 1-4.

2. Remove the filter cover assembly, the top plate retaining nuts, the top plate, and the filter elements.

3. Before replacing the elements, wipe out any sediment on the bottom of the chamber.

4. Replace the filter elements on the filter tube holder and springs.

5. Before replacing the top plate, see that the element holders and springs are all evenly in place. Replace the top plate, the top plate retaining nuts, and the cover assembly.

6. Place the filter in operation by proceeding as in steps 8, 9, and 10 of the cleaning procedure.

CLEANLINESS OF HYDRAULIC SYSTEMS

Dirt or foreign matter in hydraulic systems can disable pumps, cause valves to stick, ruin packing, and damage the control systems. Hydraulic systems should never be opened except for good cause and then only by qualified personnel. When it is necessary to open a hydraulic system, extreme care should be taken to keep out dirt; all parts should be carefully cleaned before being reinstalled. Oil filters should be cleaned or changed at regular intervals. Oil should be filtered once each 6 months. Any oil added to the system should be filtered. Only clean oil of an approved type should be added to a hydraulic system. Use only approved packing and gasket materials and never allow water to enter a hydraulic system.

CHAPTER 16

INTERNAL COMBUSTION ENGINES

Internal combustion engines are used extensively in the Navy as ship propulsion units and as prime movers for auxiliary machinery. Engines in use are of the reciprocating type and the gas turbine type.

In most shipboard installations, internal combustion engines are of the reciprocating (diesel and gasoline) type. Diesel engines are generally used, except where special conditions favor the use of gasoline. Standardization of diesel fuel oils, fuel economy, reliability during starting and in getting underway, and the lesser fire hazard associated with the diesel engine have been the chief factors in favor of this engine's use. However, the low weight-power ratio of the gasoline engine has caused it to be widely used in applications where both speed and light weight are required of the power plant.

Although the gas turbine engine is not new, its application to marine use in the Navy is relatively recent. Experiments have proven that gas turbine engines can be used advantageously to power short-range ships, landing craft, air-sea rescue boats, and also to drive generators and portable pumps.

Since the internal combustion engines in Navy service differ widely, not only in type but also in size and design, detailed information on each type and model of engine is beyond the scope of this chapter. The information given in this chapter is applicable, in general, to all internal combustion engine installations aboard Navy ships. Detailed information on engine operation and maintenance should be obtained from the manufacturer's technical manual(s) for each specific engine installation.

RECIPROCATING ENGINES

Since the pistons in diesel and gasoline engines employ a back-and-forth motion, they are classified as reciprocating engines. The gasoline

and diesel engines differ principally in that the former has a carburetor and a spark ignition system. The fuel and air for the SPARK IGNITION (GASOLINE) ENGINE is mixed in the carburetor. This mixture is drawn into the cylinders where it is compressed and ignited by an electric spark.

The COMPRESSION IGNITION type engine is commonly known as a DIESEL ENGINE. This engine takes in atmospheric air, compresses it, and then injects the fuel into the combustion space. The heat generated by compression ignites the fuel, hence the term "compression ignition" is used for diesel engines.

DIESEL ENGINES

Each type of engine installation presents a special operational problem and requires a special routine for successful operation. The engineer officer will have established a systematic procedure applicable to the engines being operated. It is of the utmost importance that this established procedure be followed.

Operating Conditions

A complete log of all operating conditions must be kept. The operating pressures and temperatures should be observed and recorded in the log, at specified intervals. Deviations from normal pressures or temperatures, and unusual engine noises should be noted. This information is helpful in locating causes of trouble. When unusual operating conditions occur, they are usually indications of conditions for which load, lubrication, cooling, engine speed, or fuel supply are responsible, either directly or indirectly.

LOAD—The manner of applying a load to an engine, and the regulation of the load will vary,

depending on the installation. Load an engine according to applicable instructions.

Whenever a cold engine is started, ample time should be allowed so that the load can be built up gradually. Whenever the situation permits, the engine manufacturer's instructions regarding the application of load should be followed. Gradual application of the load is necessary to prevent damage to the equipment from such conditions as uneven rates of expansion and inadequate lubrication at low temperatures.

An engine should not be operated for any great length of time with less than one-third normal load. Combustion at low load is incomplete; under these conditions, partially burned fuel oil and lubricating oil may cause heavy carbon deposits, which will foul the valve stems, the piston rings, and the exhaust system.

The operation of a diesel engine at 30 percent power or less for long periods of time will lead to a number of troubles. In addition to the formation of carbon on the intake and exhaust ports, on the combustion-chamber surfaces, on the piston head, and in the piston-ring grooves and lands, low-load operation may be responsible for sticking and burning of exhaust valves; dilution of the lubricating oil; scuffing of cylinder liners; increased fuel consumption; and excessive smoke when the load is increased. If operation requirements necessitate engine operation for periods in excess of thirty minutes at 30 percent power or less, the load should be increased to above 50 percent power at the first opportunity.

An engine should never be operated at an overload, except in an emergency. When conditions indicate that the engine is overloaded, the load should be reduced immediately. Overload may be indicated by excessive temperatures, smoky exhaust, or excessive firing pressures.

LUBRICATION.—During engine operation, mechanical oilers, when provided, should be watched to see that they are feeding properly and are not becoming air-bound. The oil level in the sump should be checked frequently; oil should be replenished, as necessary. All make-up oil should be purified, if feasible. Lubricating-oil purifiers, when provided, should be kept operating whenever the engines are in use; they should be operated periodically, during idle periods. The cleaning handle on all metal-edge type lubricating-oil strainers should be

rotated through at least two complete revolutions during each watch. The pressure drop across the filters and strainers should be checked frequently. The viscosity of the lubricating oil should be checked at least once each day to determine the percent of fuel dilution.

PRESSURES AND TEMPERATURES.—All pressures and temperatures must be maintained within the normal operating ranges; if this is not possible, the engine must be secured. All instruments must be checked frequently. The manufacturer's instructions give detailed information concerning the proper operating pressures and temperatures. When this information is not available, the temperature of the lubricating oil as it leaves the engines should be maintained between 140°F and 180°F; and the temperature of fresh water should be not less than 140°F or more than 170°F when the water leaves the engine. The temperatures in the salt-water cooling system should not be allowed to go above 130°F; higher temperatures will cause deposits of salt and other solids in the coolers and piping, and will aggravate corrosion. In order to ensure efficient operating in engines which are cooled by salt water, the temperature of the salt-water coolant should never be allowed to drop below 100°F at the engine discharge.

Frequent checks of the cooling system should be made to detect any leaks. Coolers and heat exchangers should be vented at least once each watch. The level of the fresh water in the expansion tank should be checked frequently; fresh water should be added, as necessary. If the level gets very low in the fresh-water system, cold water should never be added until the engine has cooled.

CRITICAL SPEEDS.—Do not operate an engine at or near any destructive critical speed; the vibrations resulting from operation at such speeds will cause serious damage.

All moving members of machinery have critical speeds. The term applies to certain ranges of speed, during which excessive vibration in the engine is created. Every part of the engine has a NATURAL PERIOD OF VIBRATION, or FREQUENCY. When impulses set up a vibration which coincides with the natural frequency of the body, each impulse adds to the magnitude of the previous vibration; finally, the vibration becomes great enough to damage the engine structure.

Vibration may be set up by lineal impulses from reciprocating parts or by torsional impulses from rotating members. The crankshaft is the member which causes torsional vibrations. The pressure impulse on the piston puts a twist in the crankshaft; when the pressure on the piston is somewhat relieved, the shaft untwists. If pressure impulses which are timed to the natural period of the shaft are permitted to continue, the vibration amplitude will become so great that the shaft may be fractured. If the speed of such an engine is changed, however, the pressure impulses will no longer coincide with the natural period of the shaft; the vibration will then cease.

Since each engine has a natural period of vibration, which cannot be changed by the operator, the only control available to the operator is to avoid operating the engine at critical speeds. If critical speeds exist below the normal speed of the engine, the critical ranges must be passed through as quickly as possible when engine speed is being changed. Detailed information concerning critical speed ranges are issued with each installation. Tachometers must be marked to show any critical speed ranges; this will make it easier to keep the engine out of the critical ranges. Tachometers sometimes get out of adjustment; they must, therefore, be frequently checked with mechanical counters.

FUEL.—An adequate supply of proper fuel must be maintained. The fuel system should be frequently checked for leaks. All fuel oil strainers should be cleaned, at periodic intervals. Fuel oil filter elements should also be replaced, whenever necessary. When diesel fuel oil purifiers are provided, all fuel should be purified before it is transferred to the service tank. The service tank should be frequently checked for water and other settled impurities by sampling through the drain valve at the bottom of the tank. Water and impurities should be drained off.

Safety Precautions

The specific safety precautions for a given engine must be obtained from the applicable manufacturer's operating instructions. In addition to the manufacturer's specific precautions, the following precautions also apply to the operation and maintenance of a diesel engine.

RELIEF VALVES.—If a relief valve on an engine cylinder lifts (pops) several times, the engine must be stopped immediately; the cause of the trouble must then be determined and remedied. Relief valves must never be locked in a closed position, except in an emergency. Pressure-relief mechanisms are fitted on all enclosures in which excessive pressures may develop. Strict compliance with designated adjustments on these mechanisms is essential.

FUEL.—Precautions should be taken to see that fuel is not pumped into a cylinder while valves are being tested or while the engine is being motored, since an excessive pressure may be created in the cylinders when combustion of the fuel takes place. When it reaches the injection system, the fuel should be absolutely free from water and foreign matter. The fuel must be centrifuged thoroughly before use; the filters must be kept clean and intact. Leaks of fuel into the lubricating oil system must be avoided; otherwise, dilution of the lubricating oil will occur, with consequent reduction in viscosity and lubricating properties.

WATER.—Do not allow a large amount of cold water, under any circumstances to enter a hot engine suddenly. Rapid cooling may crack the cylinder liner and head or seize the piston. When the volume of circulating water cannot be increased and the temperatures are too high, stop the engine. In freezing weather, all spaces which contain fresh water and which are subject to freezing must be carefully drained, unless an antifreeze solution is added to the water.

AIR.—When engines are stopped, all starting-air lines must be vented; serious accidents may result if pressure is left on. Intake air must be kept as clean as possible; accordingly, all air ducts and passages must be kept clean.

CLEANLINESS.—Cleanliness is one of the basic essentials in the efficient operation and maintenance of diesel engines. Clean fuel, clean air, clean coolants, clean lubricants, and clean combustion must be maintained.

Engines must be kept clean at all times, and steps must be taken to prevent the accumulation of oil in the bilges or in other pockets.

GASOLINE ENGINES

Today's automobile is powered with a 4-stroke-cycle engine designed to burn a commercial grade of gasoline. The same general type of

engine also powers some small Navy Ships. Two-stroke-cycle gasoline engines, however, are used principally to drive outboard motor-boats, and some portable fire pumps.

The main parts of the gasoline engine are similar to those of the diesel engine. The gasoline engine has a lower compression ratio than the diesel engine. A typical marine gasoline engine has a compression ratio of about 8 to 1, compared to an approximate ratio of as high as 16 to 1 in some diesel engines.

Information concerning the engine parts and systems can be obtained from the manufacturer's technical manual for the specific engine.

Operating Procedures

To operate a gasoline engine, the engine must have sufficient fuel, spark, oil, and a cooling medium. To ensure this, checks are made by responsible personnel who should observe pre-starting, starting, and underway procedures in accordance with manufacturer's instructions.

Fuel and Fueling Precautions

The following information applies, in general, to all gasoline engine installations; it applies more specifically, however, to boat engine installations.

1. Do not permit gasoline to accumulate in carburetor drip-pans or in bilges.
2. Keep the bilges dry and well ventilated. In motor boats where an exhaust blower is provided for the engineroom space, this blower must be operated for at least five minutes before the engine is started.
3. Do not permit rags soaked with gasoline or oil to remain in the boat.
4. Smoking, lighting matches, and carrying openflame lights (e.g., lighted oil lanterns) are strictly prohibited in power boats; they should not be permitted within one hundred feet of a boat which is engaged in fueling.
5. Carburetor intakes and crankcase breather pipes must be fitted with back-fire screens of an approved type.
6. The electrical system of the engine must be inspected frequently to guard against grounds and sparking to commutator brushes.
7. Extreme care must be exercised not to spill gasoline into the bilges when fueling the boat.

8. During the fueling of motor launches and motor whale boats, the engine hood or casing must be open to permit a free circulation of air around the engine and thus prevent the formation of an explosive mixture inside the casing. Do not close the cover until the engine has been started and is operating in a satisfactory manner.

9. Only personnel engaged in the actual fueling operation should remain aboard the boat.

10. The controls of the built-in fire-extinguisher system must be ready for instant use.

11. Portable, CO₂ fire-extinguishers must be held in readiness alongside each fuel hose.

12. The main-battery switches must be in the OFF position.

13. A ground wire must be attached to the nozzle of the fuel-supply hose and to the fuel-tank filler-neck; all component parts of the filtering system must be grounded.

14. Boats should not be fueled at night or while close to one another, except in emergencies.

15. Never start an engine when there is a strong odor of gasoline in the engine compartment.

Safety Precautions—General

In addition to following the specific safety precautions listed in the operating instructions for an engine, good judgment must be exercised continuously and the proper steps taken to prevent damage to material and injury to personnel.

In general, damage to machinery can be prevented by operating engines according to prescribed instructions; by observing all rules of cleanliness when handling the parts of an engine during maintenance or overhaul; and by having a complete familiarity with the parts and functions of the machinery being operated and maintained. Damage to a ship or boat may be prevented by maintaining machinery so that the engines will be ready for service at full power in the event of an emergency; and by taking steps to prevent conditions which are likely to constitute fire or explosion hazards.

A great deal can be accomplished to avoid personal injury by personnel having a thorough knowledge of their duties; by the proper handling of tools, machines, and parts; by taking normal precautions around moving parts; and by using safeguards at danger points.

GAS TURBINE ENGINES

The gas turbine engine resembles internal combustion engines of the reciprocating type in that air is compressed, a fuel-air mixture is burned, and the gases of combustion are expanded to produce useful power. In engines of the reciprocating type, compression, combustion, and expansion take place in one component, the cylinder. Since all three phases take place within one component, the power impulse must occur intermittently or periodically as the cycle is repeated. This is not true in gas turbine engines; instead, compression, combustion, and expansion take place in three separate components. Air is compressed in the compressor, combustion takes place in an adjacent burner, and a turbine (or turbines) receives the force created by combustion. The turbine (like the piston in a reciprocating engine) transmits the force of the gases to a shaft which drives a useful load. The three basic components of the gas turbine engine are arranged and connected so that the power output from the turbine is steady and continuous. In brief, the gas turbine engine can be defined as an internal combustion engine that produces power by a continuous and self-sustaining process. An air mass is compressed and then combined with atomized fuel. The resulting mixture then burns, and the combustion gases expand through one or more turbines which change some of the energy into useful power.

Before proceeding with a discussion of the principal systems and components of gas turbine engines, you should be familiar with the advantages and disadvantages of gas turbine engines.

ADVANTAGES AND DISADVANTAGES OF GAS TURBINE ENGINES

In addition to the development of a uniform flow of power output, gas turbine engines have several advantages over reciprocating engines. However, there are certain undesirable features of presently available gas turbine engines which will also be mentioned in the section which follows.

The advantages and disadvantages of the gas turbine engine cannot be listed in order of importance, because the requirements of the engine as a source of power differ in various applications. Note: Not all of the desirable or undesirable features of gas turbine engines are discussed here; however, some of the more important ones are pointed out.

Compared with other types of internal combustion engines, the gas turbine engine weighs less, takes up less space, and has the simpler design with a far smaller number of moving parts. The gas turbine engine develops more power per unit of weight and unit of volume than other engines.

Gas turbine engines start quickly and accelerate rapidly. Some models can develop full power from a cold start in less than one-tenth of the time required for a gasoline engine in a comparable application. The gas turbine adjusts to varying loads more rapidly than other type engines.

The number of personnel required to operate and maintain a gas turbine engine, and the time required for the training of such personnel are much less than in the case of engines of other types. In some cases, only one man is needed for starting and operating a gas turbine engine. The simplicity of the operating controls and the automatic safety devices used reduce the time required for training operators. The time required for training maintenance personnel is much less than that required in the case of other engines because of the simplicity of design and the smaller number of moving parts in the gas turbine.

Compared to a diesel engine, the gas turbine has far fewer components, produces much less vibration at full power, and uses practically no lubricating oil. (The diesel engine uses approximately 40 times as much lube oil as the gas turbine engine.)

The gas turbine engine has a significant advantage over the gasoline engine in the fuel used. The fuel used in gas turbines presents much less of a fire hazard than the highly volatile fuel used in gasoline engines.

Even though the gas turbine engine has some advantages over other types of internal combustion engines, it also has some disadvantages such as a higher rate of fuel consumption and larger components required for air inlet and exhaust.

PRINCIPAL SYSTEMS AND COMPONENTS OF A TWO-STAGE GAS TURBINE ENGINE

The principal systems and components of gas turbine engines discussed in this chapter are applicable to the engines (Boeing 502) of the unit shown in figure 16-1. Regardless of the particular manufacturer or of variations in design of gas turbine engines, most of the discussion in

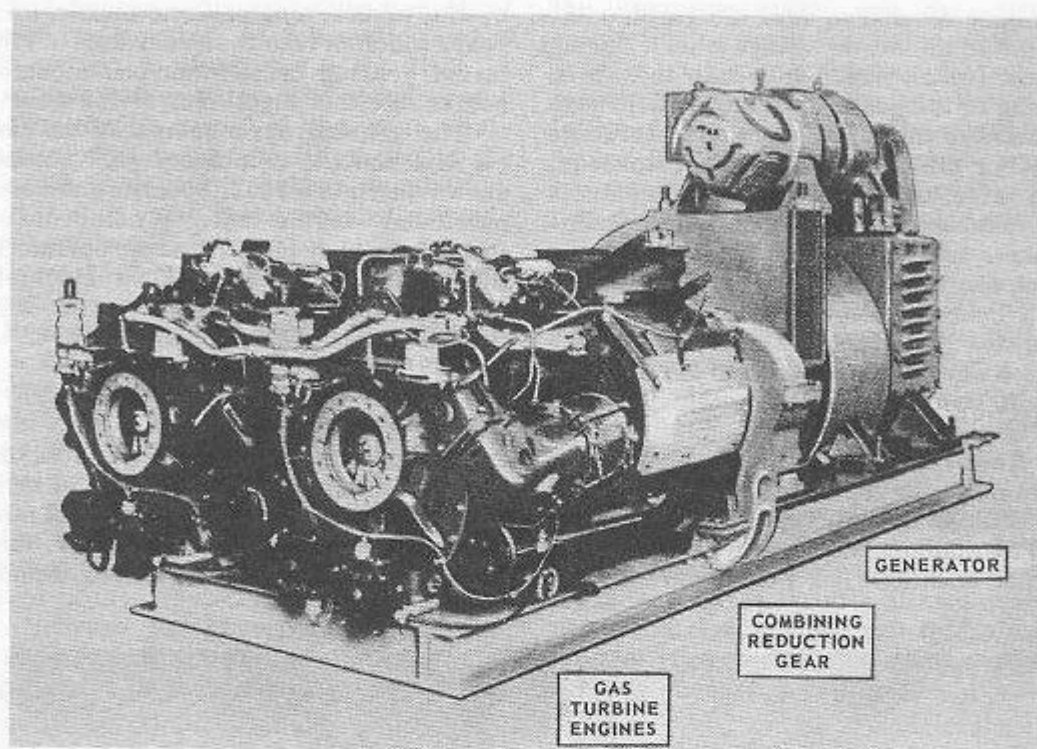


Figure 16-1.—Gas turbine-generator unit.

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this chapter will still be applicable to gas turbine engines in general.

Gas turbine installations, aboard the MSB-5 class minesweepers, supply motive power for the generators in minesweeping operations. The engine generator unit (turbine-generator power package) used for this purpose is shown in figure 16-1. The gas turbine installation consists of two gas-turbine generator units; and each unit consists of two gas turbine engines, a combining reduction gear, and a d-c generator—all mounted on a rigid rectangular frame. Each engine is coupled to a separate input shaft of the combining gear. The overrunning clutch permits single engine operation of the power package.

The engines of the unit shown (fig. 16-1) are divided into two sections or stages; a gas producing section (first stage) which is basically a simple jet engine, and a power output section (second stage) which converts some of the energy of the combustion as gases into useful power as required by the electrical load. Although both engine sections are attached to a casting that forms the engine base, each is mechanically separate, and they are coupled together only by

an interconnecting duct that confines the gas flow between the two sections.

The gas producing section consists of a centrifugal air compressor, two cross-connected through-flow type burners, a nozzle box, an axial flow turbine, and an accessory drive unit. The compressor consists of a rotating impeller enclosed in a case which has diffusing vanes on its inner surface. The impeller is secured to the extended shaft of the turbine wheel to form the rotor assembly of the engine. This turbine wheel is driven by the flow of expanding gases created by burning fuel continuously in the combustion chambers. Pressurized air for supporting combustion is produced by the compressor and conducted, through separate elbows, to the chambers. The essential engine accessories are driven from the rotor shaft through a gear system.

In the power output section, the wheel of a second axial flow turbine drives the splined output shaft through double reduction gearing. This turbine wheel is driven by the flow of combustion gases from the first stage of the engine. These

gases normally discharge into the turbine exhaust duct aft of the second-stage wheel. During reduced load (which would increase the speed output), some of the gases are released, through an outlet ahead of the turbine, into an interstage bleed duct. For all variations in generator load, a gate type valve, in each of two ducts, controls the flow of combustion gases through the second-stage turbine, as required, to maintain a constant output shaft speed. These gate valves are linked to a hydraulically actuated piston by a speed-sensitive governor. The speed of the second-stage wheel and output shaft is limited by a centrifugal switch which automatically stops the engine in the event of overspeeding.

Power from the two gas turbine engines is combined to drive the generator at reduced speed through a combining reduction gear. The latter consists of two pinions and a main gear enclosed within a cast housing. The pinions are driven

by the turbine engines and mesh with the main gear, which drives the generator. Additional internal gearing drives four pad-mounted accessories on the input end of the gear housing.

The general arrangement of the gas turbine engines and the combining gear components is shown in figure 16-2. Specific information on a particular engine unit, or component, may be found by referring to the appropriate manufacturer's technical manual. The principal systems of a gas turbine engine, however, will be discussed in this section of the chapter.

Fuel Oil System

The principal system of a gas turbine engine which supplies fuel for combustion is the fuel oil system. This system consists of an engine-driven pump, high pressure filter, fuel control governor, nozzle, shutoff valve, pressure gage,

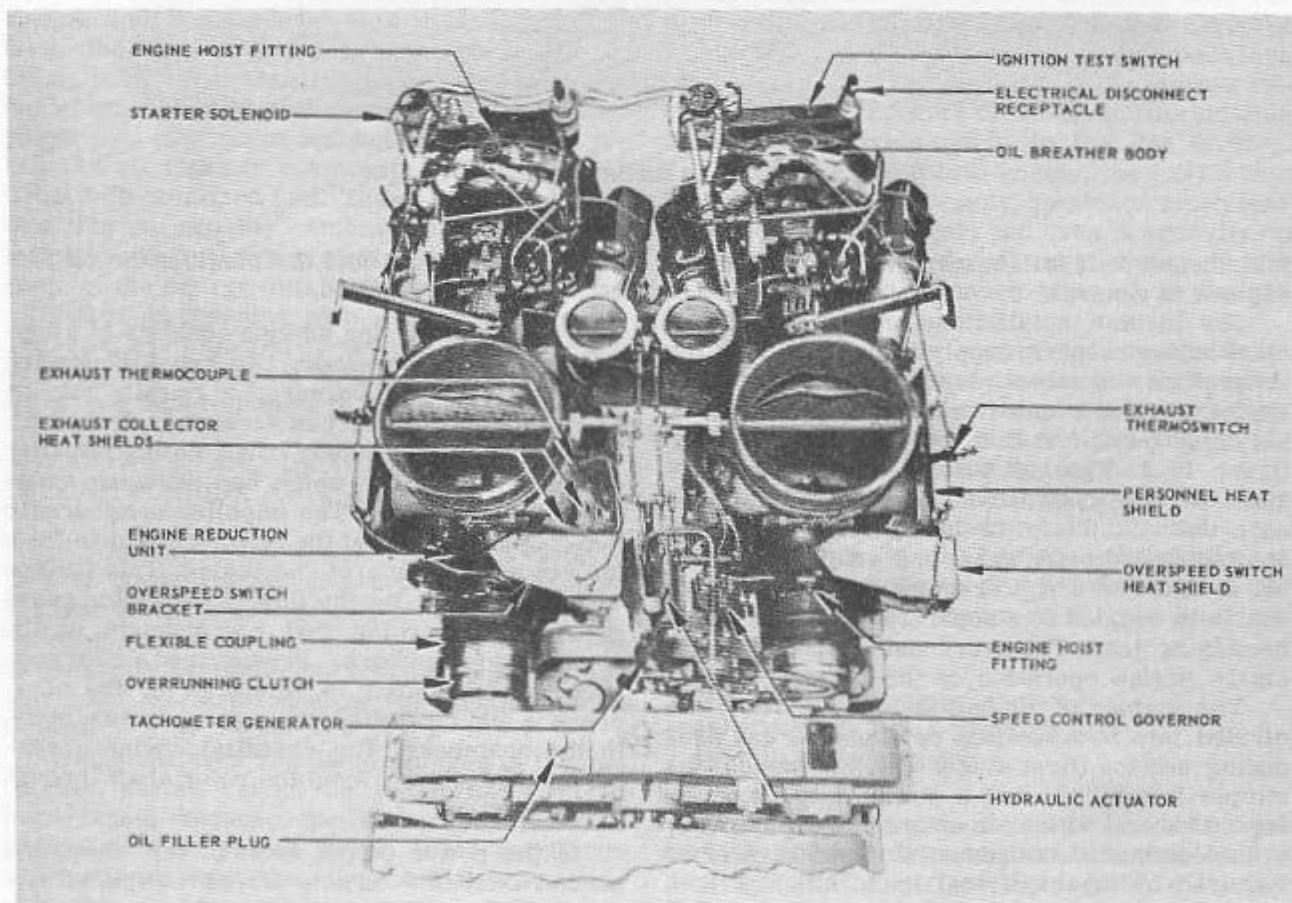


Figure 16-2.—Engines and combining gear.

starting fuel-bypass valve, starting fuel-bleed orifice, and two nozzles. (A schematic view of a fuel oil system is illustrated in fig. 16-3.) A manual shutoff valve, filter, and supply pump are in the fuel supply manifold line, and a similar manual shutoff valve and filter are in the supply line to each power package. In addition, a separate shutoff valve is provided in the supply line to each engine.

See figure 16-3; the fuel flows through the system as follows: The engine-driven pump receives filtered fuel from the motor-driven supply pump at a constant pressure of approximately 15 psi. The engine-driven fuel pump increases the pressure and forces the fuel through the high-pressure filter to the governor. The governor meters the fuel to the nozzles, as necessary, to maintain combustion at the required rate, and returns the excess fuel to the inlet port of the engine-driven pump.

The fuel nozzle shutoff valve is installed in the line between the governor and the fuel nozzles. The fuel-pressure gage, on the engine control panel, is connected to the line between

the governor outlet and the nozzle shutoff valve. During engine cranking, fuel nozzle pressure is maintained (between 50 and 150 psi) by bleeding excess pressure from the governor outlet line to the inlet port of the engine-driven fuel pump. The starting fuel-bypass valve opens the governor outlet line, which contains an orifice that determines the amount of bleed.

VALVES.—A disk type shutoff valve, installed in the line between the governor outlet port and the fuel nozzles, is mounted on a bracket attached to the left side of the accessory drive unit. (The direction of fuel flow is indicated by an arrow on the housing.) When the valve is closed, it shuts off the flow of fuel to the nozzles.

A solenoid, screwed into the top of the valve body, encloses a spring-loaded plunger, which forces the valve disk against the shutoff port. By unlocking the throttle after a cranking speed of approximately 5,000 rpm is attained, the solenoid is energized and the plunger raised. This action causes the disk to lift from the shutoff

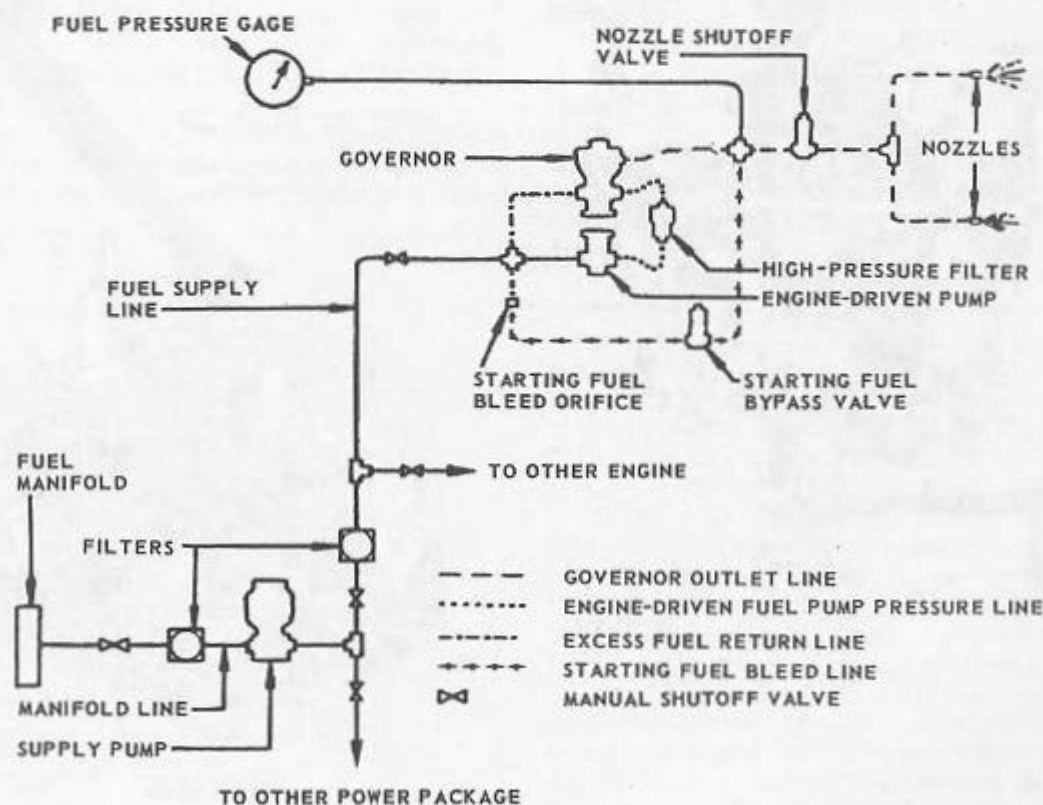


Figure 16-3.—Schematic fuel flow diagram.

port and allows metered fuel flow from the governor to the nozzles.

The starting fuel-bypass valve, identical to the fuel nozzle shutoff valve, is attached to a bracket on the right side of the accessory drive unit (fig. 16-4). This valve is a disk type, solenoid-actuated valve installed in the fuel-bypass line, between the governor outlet and the inlet port of the engine-driven fuel pump. The starting fuel-bypass valve is open only while the starter switch is closed, preventing excessive pressure from building up (during engine starting) in the governor outlet line.

FILTERS.—A high pressure filter is located between the outlet port of the engine-driven fuel pump and the inlet port of the governor. The filter consists of a two-piece housing, a replaceable micronic cartridge, and an internal pressure relief valve. The two sections of the

filter housing are screwed together and sealed by an O-ring. The pressure relief valve is generally set to open at a differential pressure ranging from 26 to 31 psi.

PUMPS.—A motor-driven vane type pump (the fuel supply pump) transfers the fuel from the supply tank to the fuel inlet of each engine. As viewed from the pump end of the assembly, the pump rotation is counterclockwise; and at 2,000 rpm, capacity is 100 to 200 gallons per hour. The pressure range of the pump is adjustable from 2 to 20 psi; however, the desired operating pressure is 15 psi. Seal leakage drain ports are located directly behind the pump body. When viewed from the pump end of the assembly, the fuel inlet port is on the left and the fuel outlet is on the right.

A gear type fuel pump, mounted on the center pad of the accessory drive unit (fig. 16-4), is

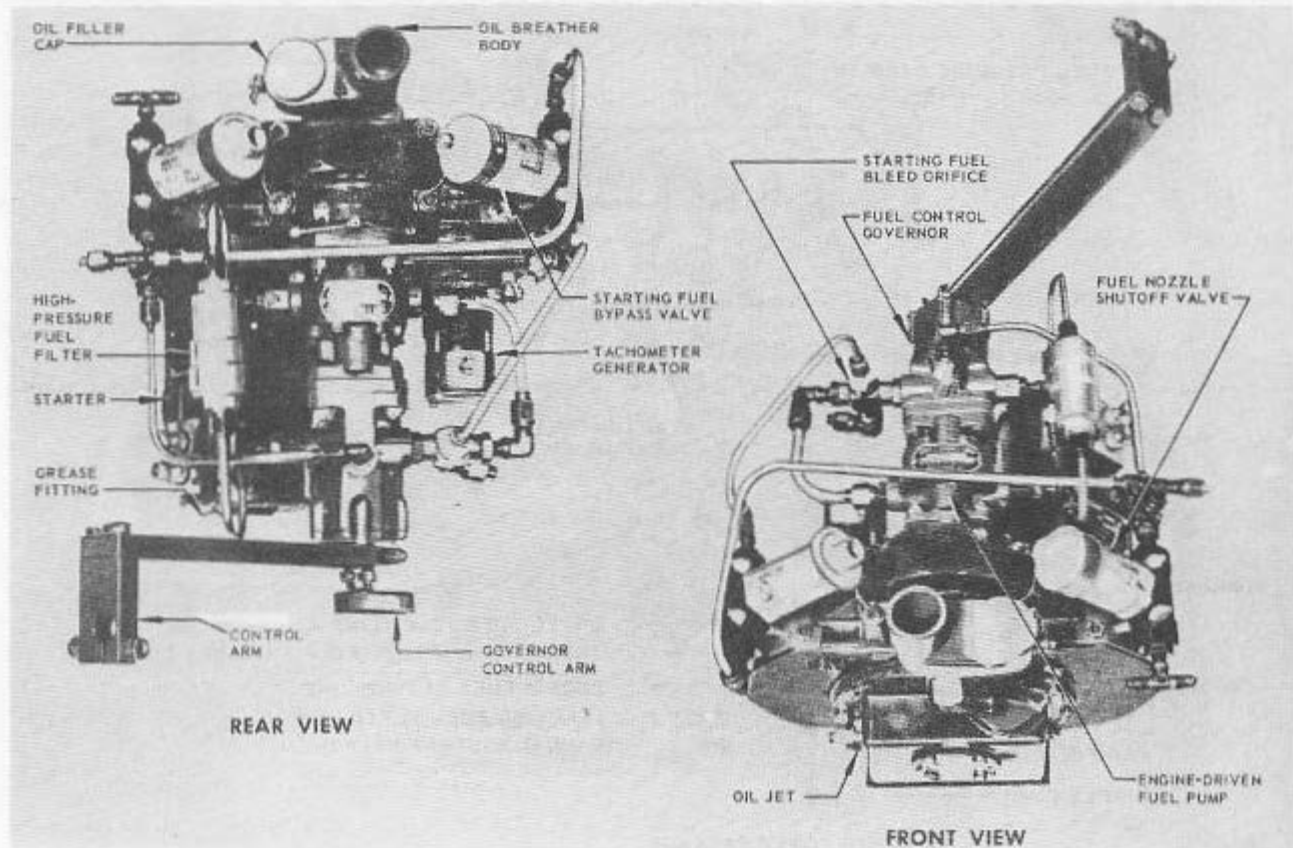


Figure 16-4.—Accessory drive unit and accessories.

driven at a speed ratio of 1 to 12 of the rotor. The fuel governor is attached to the end of the pump body, with the pump and governor shafts connected together for common drive. The engine-driven pump receives fuel from the supply pump, and forces it through the high pressure filter to the governor.

NOZZLES.—Each nozzle assembly, consisting of a 115-mesh screen, an insert, and a head, is screwed into an adapter. The adapter is threaded into a supporting horn cast in the center rear of the burner elbow. A drilled passage in the elbow conducts the fuel from the nozzle shutoff valve line to the nozzle. Fuel enters the nozzle through the strainer screen and passes through grooves in the insert to the head, where it is discharged through the orifice in the nozzle tip. Each nozzle is flow-rated at 9.5 gallons per hour at 100 psi, for use with diesel oil.

GOVERNOR.—The fuel governor, shown in figure 16-5, is a centrifugal flyweight type governor that controls the engine speed by metering the flow of fuel to the nozzles. The governor is mounted on the end of the engine-driven fuel pump, and its drive sleeve (shaft) is directly connected to the pump shaft and rotates at the same speed.

The drive sleeve, to which the flyweights are attached (fig. 16-5), serves as a rotating bushing around the pilot valve plunger. As the flyweights

rotate, their centrifugal force is opposed and balanced by the speeder spring. The compression of a speeder spring can be adjusted by moving the control arm. (The range of movement of the control arm is limited by a stop ring with high-speed and low-speed adjusting screws.)

By referring to figure 16-5, you will notice that the governor has three ports: (1) an inlet port connected to the high pressure side of the engine-driven pump, (2) an outlet (metered flow) port connected to the line supplying the fuel nozzles, and (3) a return (low pressure) port through which excess fuel is returned to the low pressure side of the pump.

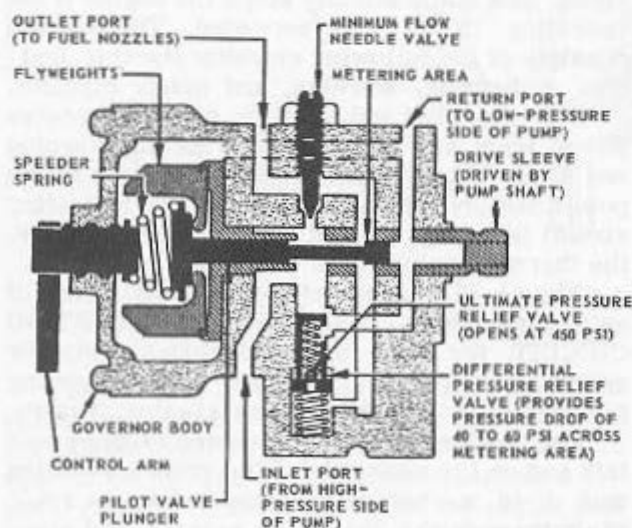
The differential pressure relief valve provides a pressure drop of 40 to 60 psi across the metering port. In addition to the force exerted by the valve spring, this valve is backed up by the governor discharge pressure. The ultimate pressure relief valve, in the differential valve plunger, opens when the governor discharge pressure exceeds approximately 450 psi. When the metering port is closed, the minimum flow needle is preadjusted to provide sufficient fuel flow to the nozzles in order to maintain combustion.

The governor is in equilibrium when (1) the engine is operating at a constant speed, (2) the centrifugal force of the flyweights is balanced by the force of the speeder spring, and (3) the pilot valve is positioned to pass the amount of fuel required to maintain engine speed. Excess fuel is returned to the input side of the engine-driven pump by the differential relief valve.

Any increase in engine speed above the governor speed setting will cause the centrifugal force of the flyweights to overcome the speeder spring tension. This, in turn, causes the control arm to move the pilot valve plunger so as to decrease the flow through the metering ports. Thus, the fuel flow to the nozzles is decreased, returning the engine speed to its former rate.

If the engine speed decreases, the flyweight force diminishes and the speeder spring moves the pilot valve plunger to increase the flow through the metering ports. This results not only in an increase in nozzle pressure but also in a corresponding increase in engine speed.

As the throttle is advanced or retarded, the governor control arm is repositioned to change the compression of the speeder spring accordingly. When governor equilibrium is again established, fuel is metered to the nozzles, as required, to produce an engine speed which corresponds with the throttle position.



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Figure 16-5.—Fuel control governor.

Engine Oil System

Lubrication within gas turbine engines is provided by a circulative type engine oil system. In addition to the lines and strainers, the major components of the engine oil system are an oil thermoswitch, a combination pressure-scavenge pump, a manifold, and a pressure switch. An external oil cooler and filter are incorporated in the system between the pressure outlet port of the pump and the inlet port of the oil manifold.

Oil from the supply reservoir (one gallon capacity), located in the forward end of the engine base, flows to the pressure section of the oil pump. At normal operating speeds, the pump circulates the oil (at 35 to 70 psi) through the cooler and filter to the manifold. From the manifold, the oil is distributed to the accessory drive unit, rotor housing, and engine reduction gear. The line to the accessory drive unit is connected to an oil jet which provides spray lubrication for all accessory-driven gears and bearings. Oil is supplied to the rotor bearings through internal passages in their respective housings. Lubrication of the rotor and the engine reduction is shown in figure 16-6. Oil supplied to the rotor bearings and the accessory drive unit returns to the supply reservoir by gravity. Oil supplied to the reduction unit drains into a separate sump. The scavenge section of the pump returns oil from the sump to the rotor housing. From there it drains into the supply reservoir.

Combining Reduction Gear Oil System

The major components of the combining gear oil system are a pressure pump, filter, oil galleries and spray nozzles in the gear case, scavenge pump, breather, and associated tubing. The oil is cooled by being circulated through an external cooler. An oil pressure gage and high oil-temperature warning light are on the engine control panel.

The rotating elements and bearings of the combining gear, and the single bearing of the generator are lubricated by a separate oil system which also provides fluid for hydraulically actuating the generator speed control system.

Oil identical to that used for the engines is supplied from a sump which forms the bottom of the gear case. (The sump has a capacity of

8 gallons and can be drained by removing the cap on the outlet tee.)

Oil drawn from the sump flows through a tee fitting and tubing to the oil pump. At normal operating speed, the pump circulates oil at 12 to 15 psi, through the oil cooler and oil filter, to an inlet fitting directly below the tachometer drive. Inside the gear case, galleries and riser passages drilled in the housing conduct the oil to the bearings on the pinion, main, and accessory gear shafts, and to the spray nozzles. Figures 16-7 and 16-8 illustrate sectional views of the combining reduction gear.

The combining gear oil-pressure indicator is connected to a fitting on the output end of the gear housing, and registers the gallery oil pressure. A thermoswitch threaded into the input end of the gear sump actuates the combining gear oil temperature warning (amber) light when the oil temperature exceeds 180°F.

Oil which lubricates the combining gears and bearings returns to the supply sump by gravity. A separate pump scavenges the oil which lubricates the generator bearing and discharges it, through an open tube, into the gear sump. Oil removed from the galleries and used in the generator speed control system is returned to the galleries, as permitted, by a separate relief valve.

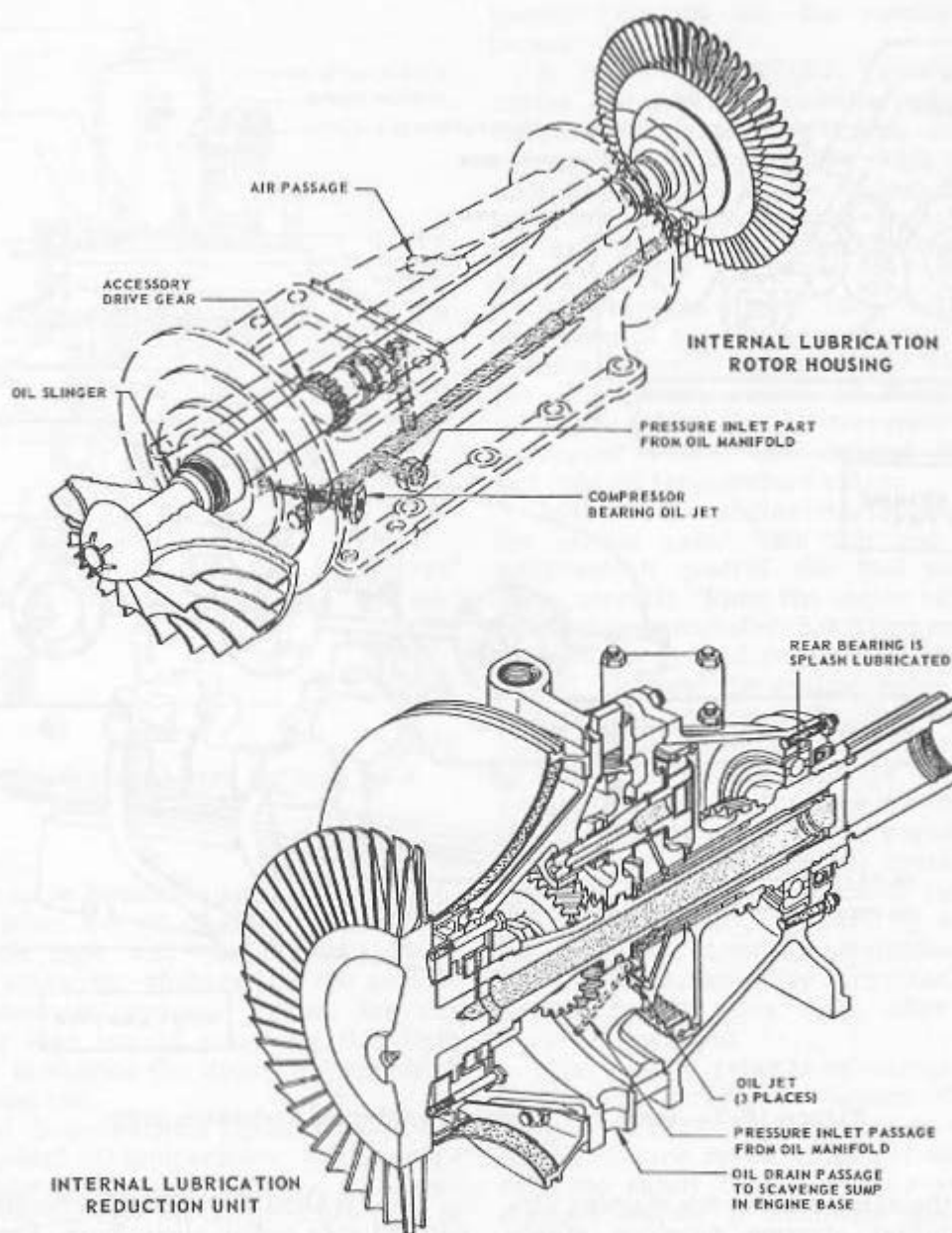
Electrical Systems and Equipment

The electrical system starts the engines, operates certain instruments and warning devices, and automatically stops the engine if the operating limits are exceeded. The system consists of the following circuits: starting, ignition, indicating, warning, and safety circuits.

The starting and ignition circuits receive power from storage batteries, and the warning and safety circuits receive power from the ship's power supply panel. Power for the indicating circuit is self-generated by parts (for example, the thermocouple) in the circuits.

Figure 16-9 illustrates a schematic view of an engine electrical system. The STARTING CIRCUIT for each engine includes a starter switch, power relay, starter motor, starting fuel-bypass valve, and a fuel nozzle shutoff valve.

The engine starter is mounted on the lower left pad on the rear side of the accessory drive unit. It is mechanically connected to the rotor shaft through the accessory gearing, and electrically connected, through the starter relay, to the batteries.



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Figure 16-6.—Internal lubrication of rotor housing and engine reduction unit.

The starting fuel-bypass valve, mounted on a bracket attached to the right side of the accessory drive unit, is identical to the fuel nozzle shutoff valve. The spring-loaded, enclosed bypass valve is installed between the engine fuel inlet and the fuel nozzle shutoff valve. Electrically, the bypass valve is connected in parallel with the engine starter; both units are energized

simultaneously by battery power. In conjunction with the starting fuel-bleed orifice, the bypass valve limits the pressure in the fuel lines to prevent flooding of the combustion chambers, during engine starting.

The **IGNITION CIRCUIT** for each engine, consisting of an ignition test switch, two ignition boost coils, and two glow type igniter plugs, is

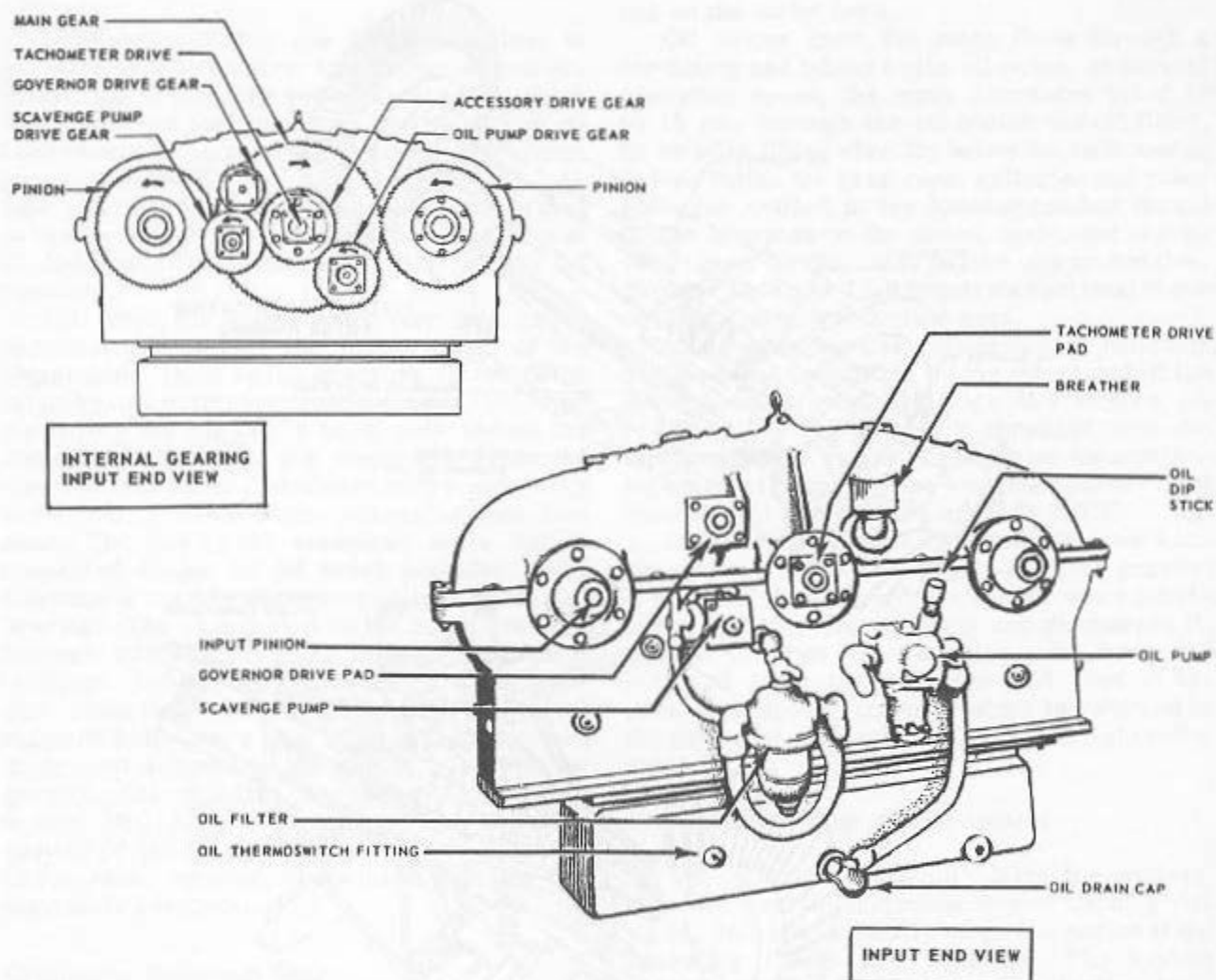


Figure 16-7.—Input end views of combining reduction gear.

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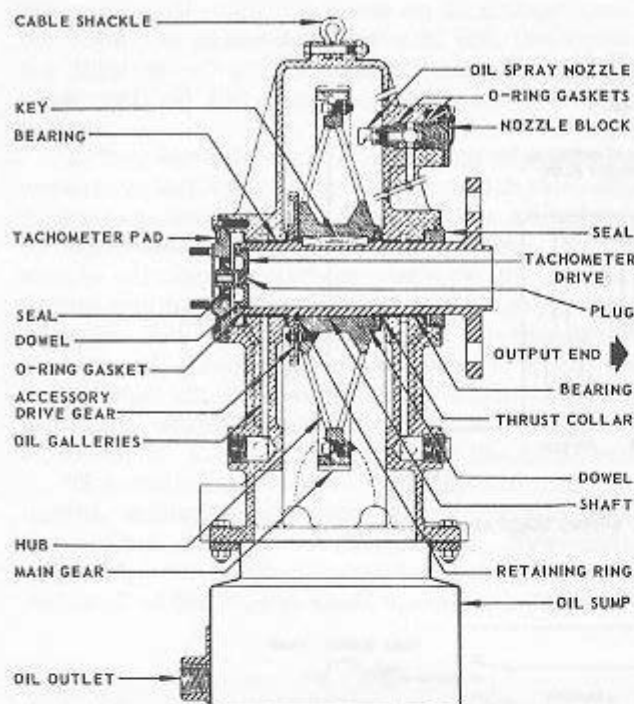
energized at the same time as the starting circuit. After initial starting develops steady combustion, engine operation is self-sustaining.

A TACHOMETER GENERATOR, for each engine, is connected to dual gages on the control panel to indicate engine (rotor) speed. The rotor (first-stage turbine) speed is registered electrically from the proportional voltage developed by a two-pole a-c tachometer generator driven by the accessory gearing. The tachometer generator is bolted to an adapter plate secured to the lower right pad of the accessory drive unit. A short coupling adapts the square drive of the tachometer generator to the drive gear splines.

The WARNING CIRCUIT consists of indicating lights and an alarm horn. Except for one, all the indicating lights are actuated by engine safety circuit components, and the alarm horn can be actuated by the safety circuit whenever the throttle is unlocked.

A white light on the engine control panel indicates the operation of the fuel supply pump. Four amber warning lights are provided for each engine, in order to indicate the cause of automatic shutdown.

The low oil-pressure warning light, operated by the pressure switch at the engine oil



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Figure 16-8.—Sectional view through main gear and shaft.

manifold, turns on simultaneously with the master switch. When the oil pressure rises above minimum, the light will turn off until either normal or automatic shutdown of the engine. Thus, if automatic shutdown occurs for any reason other than low oil pressure, this light and the one indicating the cause for shutdown will be burning (on).

The other three warning lights for each engine indicate high oil temperature, engine overspeed, and high exhaust temperature. As shown in figure 16-9, the high oil temperature light is operated by the oil thermostatic switch in the oil supply strainer, the overspeed light by the overspeed switch on the engine reduction unit, and the high exhaust temperature light by the exhaust thermostatic switch in the exhaust collector. These lights can be turned off by the master switch, which will reset the actuated safety circuit relay for future actuation.

If a throttle is unlocked prior to engine cranking, or automatic shutdown occurs at any time the engine is started, the alarm horn behind the engine control panel will sound until the throttle is returned to its locked position

(pushed inward) or the master switch is turned off.

A SAFETY CIRCUIT, provided for each engine, consists of a pressure switch, speed and temperature actuated switches, and associated relays. If low oil pressure, high oil temperature, overspeed of engine, or high exhaust temperature results after the engine is started, the safety circuit will automatically stop the engine.

Referring to figure 16-9, notice that the activation of the following units will result in opening a series circuit to the sealing relay: the oil pressure switch, oil thermostatic switch and oil temperature relay, overspeed switch and overspeed relay, and exhaust thermostatic switch and exhaust temperature relay.

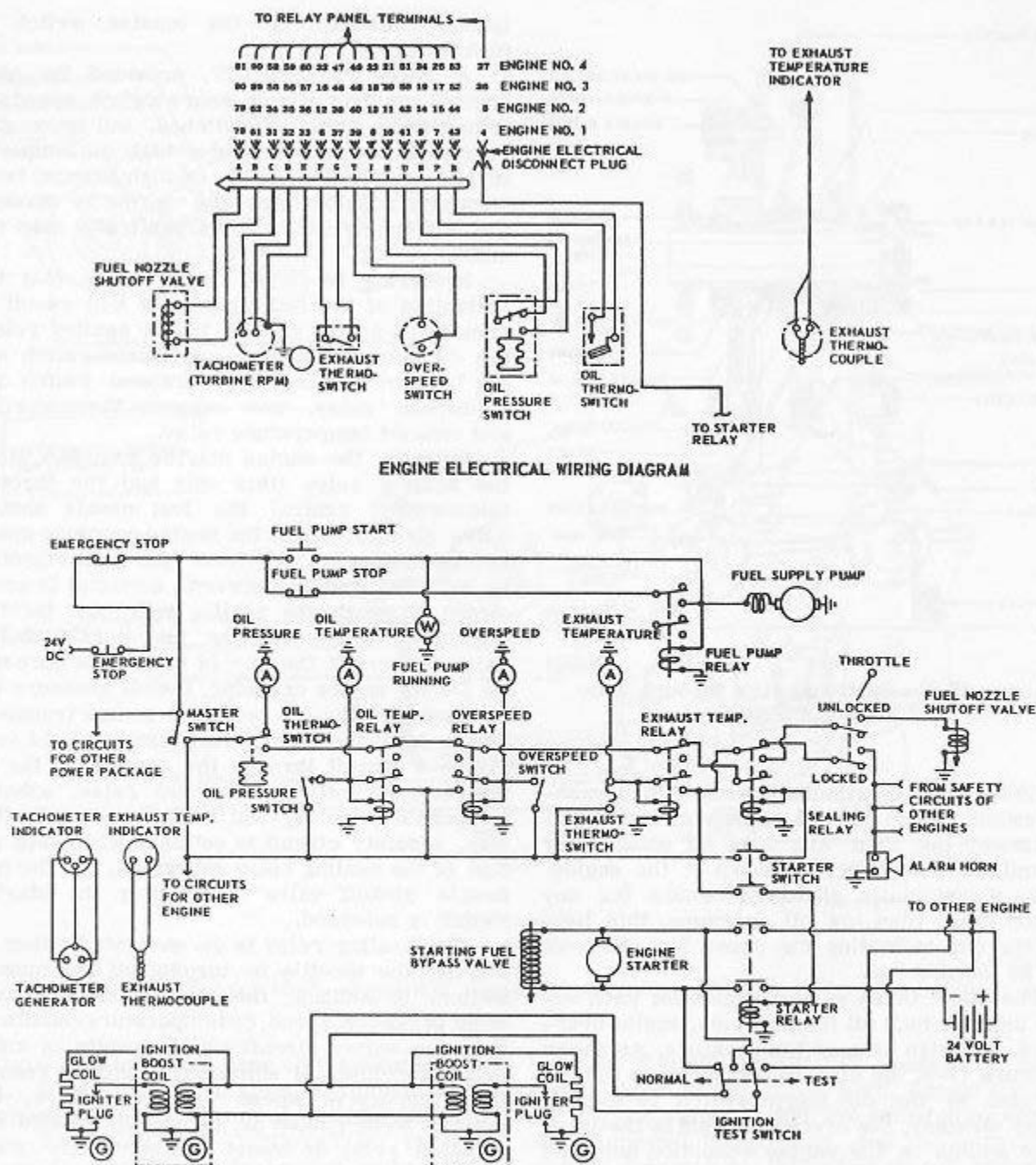
Initially, the engine starter switches close the sealing relay (this unit and the throttle microswitch control the fuel nozzle shutoff valve circuit). When the engine cranking speed reaches approximately 5,000 rpm and the throttle is unlocked (pulled outward), a circuit is completed, through the sealing relay and throttle microswitch, to open the fuel nozzle shutoff valve to permit the flow of fuel to the burners.

During engine cranking, the oil pressure increases and the oil pressure switch transfers power from the oil pressure warning light supply to a circuit through the contacts of the oil temperature relay, overspeed relay, exhaust temperature relay, and sealing relay. In this way, a safety circuit is established to keep the coil of the sealing relay energized, and the fuel nozzle shutoff valve open, after the starter switch is released.

The sealing relay is de-energized either by locking the throttle or turning off the master switch. In addition, the relay is de-energized when pressure, speed, or temperature conditions open the safety circuit which results in automatic shutdown. If automatic shutdown results from excessive speed or temperature, the master switch must be turned off so that the actuated relay is reset and continuity of the circuit restored. (The actuated relay is self-holding after initial closure.) If low oil pressure causes automatic shutdown of the engine and you want to restart the engine, it will not be necessary to turn the master switch off.

The functions of the ENGINE SWITCHES are explained in the following paragraphs.

When the master switch is ON and the engine oil pressure is below minimum (18 to 20 psi), a diaphragm type pressure switch connected to



NOTES

GROUND SYMBOLS INDICATE A COMMON RETURN WIRE EXCEPT POINTS © WHICH ARE ACTUALLY GROUNDED TO TURBINE. CIRCUITS SHOWN WITH ENGINE NOT RUNNING.

Figure 16-9.—Schematic view of engine electrical system.

the engine oil manifold turns on an amber warning light. At pressures above 20 psi, the warning light is off and the switch completes (with other relays) the safety circuit to the sealing relay.

A thermostatic unit, consisting of a tubular capillary and bellows assembly which operates a snap-action switch through an adjustable spring-loaded arm, is threaded into the oil supply strainer mounting plate on the left side of the engine. When the engine oil temperature exceeds 265°F, the engine oil thermostatic switch closes and energizes a relay which opens the safety circuit. As a result, the engine is automatically stopped and an amber warning light turns on to indicate the cause of the shutdown.

The engine overspeed switch shuts down the engine automatically and warns personnel if the engine overspeeds. Centrifugal flyweights, driven by the engine reduction gear at a speed one-half of the output shaft speed, trip the over-

speed switch at a preset limit. At approximately 2,300 generator shaft rpm, the flyweights deflect sufficiently to close the switch, turning on an amber warning light, and energizing a relay which opens the safety circuit to stop the engine automatically. After any overspeed trip, the switch must be manually reset by depressing the button at the center of the switch housing.

The engine exhaust thermostatic switch, threaded into a fitting in the outboard side of the exhaust collector, closes when the gas temperature (at the exhaust collector) exceeds 1,300°F. When the switch contacts close, the relay is energized and opens the safety circuit to stop the engine automatically. In addition, an amber light turns on to indicate the cause of the shutdown.

Switches, instruments, and warning lights for remote operation of the gas turbine engines of two power packages are on a control panel, as shown in figure 16-10. For simple identification purposes, these units are arranged in

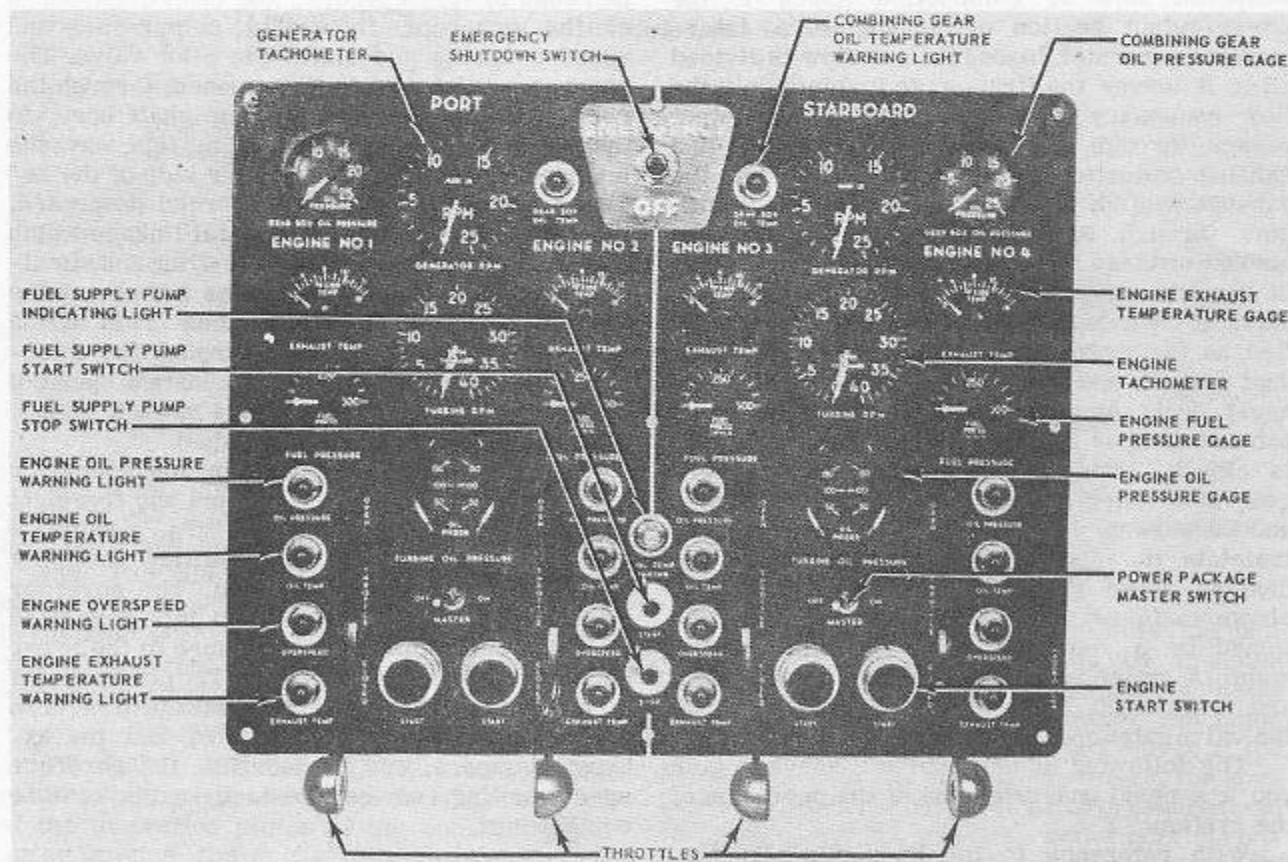


Figure 16-10.—Engine control panel.

vertical groups for each engine, with each half of the panel containing the necessary equipment for operational control of one power package (port or starboard).

The wires between the switches and the warning lights on the control panel and the relays on the relay panel are routed through disconnect plugs at the rear of the control panel. All other wiring, except thermocouple leads, for the power package electrical circuits is connected to the relay panel terminal strips. Each of the tachometers on the control panel (two single gages indicating generator speed and two dual gages indicating engine turbine speeds) have individual disconnect plugs.

Generator Speed Control System

During generator operation, the gas producing section of each engine is operated at approximately maximum speed, to provide a sufficient flow of combustion gases to the power-output section of the engine. At intermediate generator loads, the gas flow is divided after it leaves the first-stage turbine; only the flow necessary for the required power output passes through the second-stage turbine and exhaust collector. Excess gas is bled into the exhaust system ahead of the second-stage turbine through an interstage bleed duct. The amount of bleed is regulated by gate type valves in the interstage bleed and the turbine exhaust ducts of each engine. The valve gates are identified as the waste gate in the interstage bleed duct and the exhaust damper in the turbine exhaust duct. At maximum generator load, the exhaust damper is wide open and the waste gate is closed. Under no-load conditions, or zero generator output, the waste gate is wide open and the exhaust damper is closed sufficiently to maintain the rpm of the generator within the desired speed range. These valve gates, as shown in figure 16-11, are hydraulically positioned by a separate system consisting of a pump, a relief valve, a governor, an actuator, and mechanical linkage (from the piston rod to the valve gates and governor spring control arm).

The following information will serve to give you a general understanding of the operation of the system.

With reference to the hydraulic actuator, shown in figure 16-12, the speed control system pump supplies the upper end (chamber A) of the actuator cylinder with oil, through an inlet port

near the top of the cylinder, at an approximate pressure of 450 psi. Oil is supplied to the lower end (chamber B) of the cylinder at governor-controlled pressure, through an O-ring sealed reducer bushing threaded into the bottom of the cylinder. With the area of the lower surface (C) of the piston twice that of the upper surface (D), piston equilibrium is established when the governor-controlled pressure is one-half that of the pump pressure.

When the centrifugal force of the governor flyweights is balanced by the tension of the speeder spring (fig. 16-13), the pilot valve of the speed control governor blocks the outlet port, thus equalizing the hydraulic forces acting on each end of the actuator piston. Under this condition, the waste gates and the exhaust dampers are positioned to pass sufficient gas flow, through the second-stage turbine of each engine, to maintain a constant output speed, and the speed control system is in equilibrium.

When the generator load is decreased, an increase in speed occurs. The centrifugal force of the governor flyweights compresses the speeder spring and shifts the pilot valve. The governor outlet port is thus opened, through the return passage in the governor shaft bore, to the inlet side of the pump. In this way, the metered pressure on the lower side of the actuator piston is decreased. Forced downward, the piston moves the mechanical linkage which increases the governor speed setting and simultaneously opens the waste gates and closes the exhaust dampers of both engines. This action permits sufficient gas flow through the interstage bleed ducts to maintain constant speed of the second-stage turbine wheel of each engine. Thus, equilibrium is reestablished.

Conversely, an increase in the generator load results in a decrease in rpm and flyweight centrifugal force. This, in turn, results in speeder spring expansion, shifting the pilot valve in the opposite direction. The governor inlet and outlet ports are then interconnected to apply pump discharge pressure to the lower surface of the actuator piston. The piston reacts by moving upward, causing the linkage to reverse the position of the waste gates and the exhaust dampers, and to decrease the governor speed setting, as required, to again restore equilibrium.

SPEED CONTROL SYSTEM PUMP.—A gear type pressure pump, mounted on a drive pad on

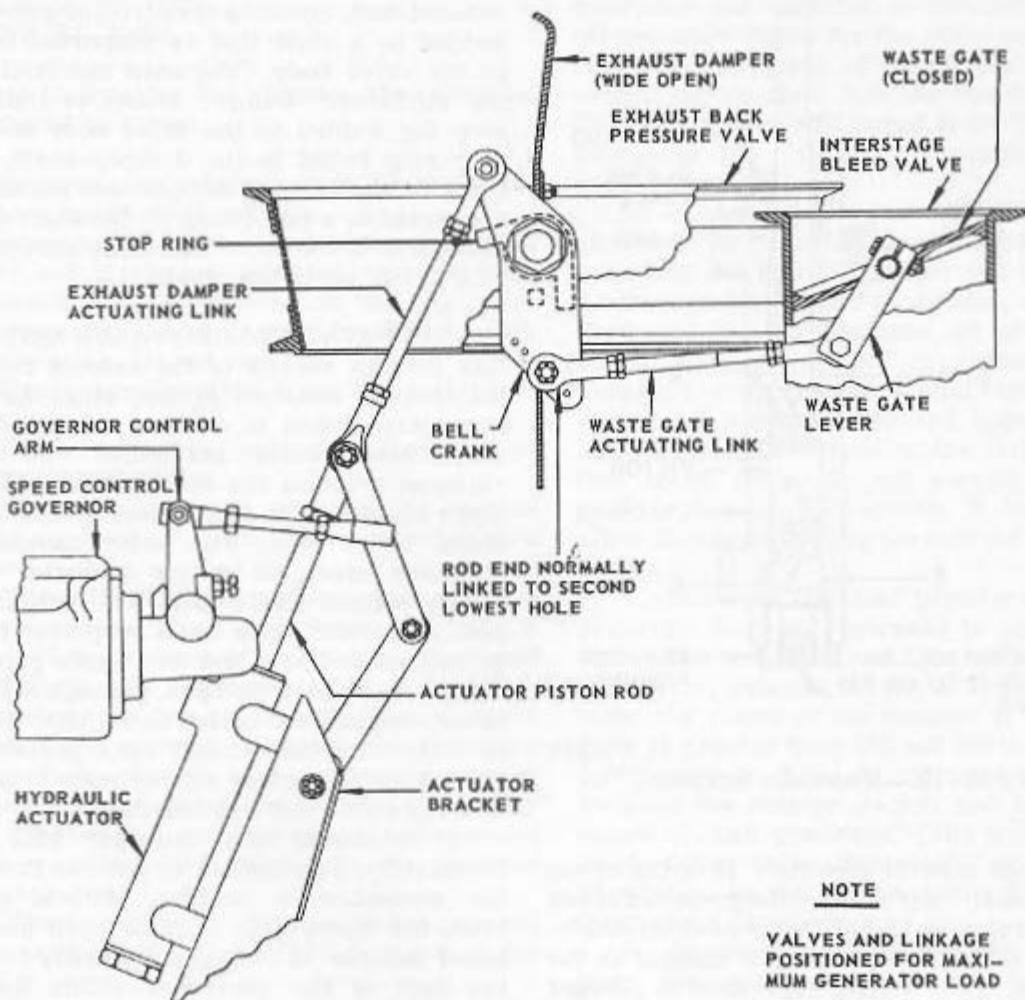


Figure 16-11.—Speed control system linkage.

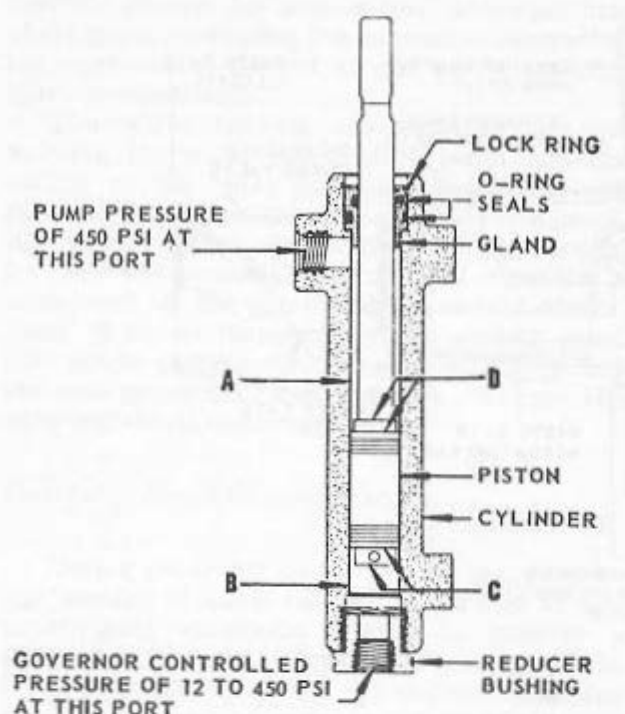
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the input end of the combining gear upper housing, is driven at a ratio of 1.5 to 1 of the generator. The pump receives oil from the combining gear pressure galleries and transmits it to the inlet port of the governor and to the upper end of the actuator cylinder at an approximate system pressure of 450 psi.

PRESSURE RELIEF VALVE.—An adjustable relief valve, attached to a bracket bolted on one of the inspection plates of the combining gear upper housing, limits the system pressure. The inlet port of the valve is connected to the pressure line between the pump and the governor. At a pressure above 450 psi, the discharge port

of the valve opens and the oil is returned to the combining gear pressure galleries.

SPEED CONTROL GOVERNOR.—This unit is attached to the end of the pump body mounted on a drive pad on the input end of the combining gear upper housing. The governor and pump shafts are connected together and driven at the same speed. As shown in figure 16-13, the governor inlet port receives oil under pressure from the pump, and the governor outlet port is connected to the lower end of the actuator cylinder. A separate passage (return) in the governor shaft bore allows oil to be returned to the inlet side of the pump.



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Figure 16-12.—Hydraulic actuator.

The speed control governor is of the droop or proportional control type; the governed speed of the generator is higher under no-load conditions than at full load. (Droop is defined as the variation in speed setting expressed in percent of the average speed.)

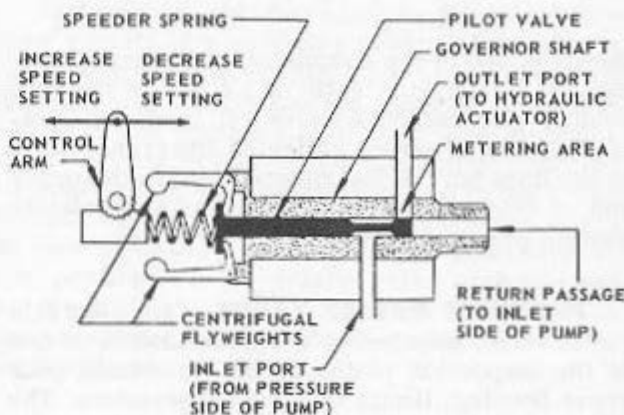
HYDRAULIC ACTUATOR.—This unit consists of an aluminum-bronze cylinder and a chromium-plated aluminum-bronze piston. The piston rod, which is integral with the piston, extends through a lock-ringed aluminum-bronze gland at the top of the cylinder, with an O-ring providing a leakage seal. A brass reducer bushing is threaded into a tee member of the speed control system linkage so that the movement of the piston will operate the governor control arm, and the waste gates as well as the exhaust dampers of both engines.

EXHAUST BACK-PRESSURE VALVE.—The flow of combustion gases through the second-stage turbine is controlled by the exhaust back-pressure valve. The valve assembly, clamped between the exhaust collector and the turbine

exhaust duct, consists of a circular gate (damper) welded to a shaft that is supported by bosses in the valve body. (The shaft has Stellite bearing surfaces.) Damper travel is limited by a stop lug welded to the valve body and a brass stop ring keyed to the damper shaft. Actuated links of the exhaust damper and waste gate are connected to a bell crank on the shaft extension. (All parts of the valve assembly except the stop ring are of stainless steel.)

INTERSTAGE BLEED VALVE ASSEMBLY.—Gas flow in excess of the amount required in maintaining constant second-stage turbine (and generator) speed is dumped through the interstage bleed valve assembly. The latter is clamped between the bleed outlet of the interstage bleed nozzle duct assembly and the interstage bleed duct. The valve assembly is a stainless steel, 45° elbow enclosing an elliptically shaped waste gate. The gate is permanently mounted on a shaft supported by bosses in the valve body, and the waste gate travels from closed to wide open, through a 70° arc. A lever, splined and bolted to the shaft extension, is linked to the exhaust back-pressure valve bell crank to provide synchronous movement of the waste gate and exhaust damper.

At maximum load, the waste gate is closed completely, forcing all of the gas flow through the second-stage turbine. Without generator load, the waste gate is wide open and the exhaust damper is closed sufficiently to maintain the rpm of the generator within the desired speed range.



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Figure 16-13.—Speed control governor.

OPERATION OF GAS TURBINE ENGINES

Prior to starting the engines, the following steps should be taken:

1. Remove protective covers (if installed) from the exhaust stack outlets.
2. Remove the inside panel of the shroud on the port and starboard sides and the outboard port shroud. Check the level of the engine oil and, if necessary, add oil up to the FULL mark on the dip stick. Do not overfill.
3. Drain condensation from the fuel filter drain valve.
4. Close the engine exhaust collector condensation drain valves.
5. Inspect the power package and related systems for fuel or oil leakage, and other fire hazards.
6. Turn the flexible coupling counter to the direction of the drive, and check the ease of rotation of the second-stage turbine wheel and the reduction unit gearing. At the same time, turn the brass outer race clockwise and check the clutch for overrun. (Partial or temporary locking of the clutch may occur and can be overcome by inserting a bar between the engine output shaft and the compression bolts of the flexible coupling, and prying in the overrun direction.)
7. Check the level of the combining gear oil supply. Add oil up to the FULL mark on the dip stick.
8. Turn the ratchet handle on top of the combining gear oil filter clockwise two full turns.
9. Check for oil leakage at the forward end of the main generator bearing.
10. See that the exhaust dampers are wide open by having the servo actuator piston rod full out.

Starting the Engines

The NORMAL STARTING procedure used to start gas turbine engines is as follows:

1. Press the START switch of the fuel supply pump. (The fuel pump running indicator light should turn on, indicating that fuel is being supplied to fuel inlets of all engines.)
2. Turn on both master switches. (The oil pressure warning lights should turn on for the

generator set selected to be started first. The oil pressure lights for the other set should turn on after the output of the ship's service generator on the first set has reached 120 volts. The alarm horn will sound if any throttle is not locked in the "CLOSED" position, or is not pushed inward.)

3. Press and hold the engine START switch closed. (The starting fuel-bypass valve will open and the ignition circuit will be completed. As the cranking speed increases, the fuel pressure and the turbine lube oil pressure gages should indicate a rise in pressure. The oil pressure warning light should turn off when the engine oil pressure reached approximately 20 psi.) To avoid overheating the starter and ignition boost coils, do not exceed any cranking periods beyond 30 seconds. It is advisable to allow 5-minute cooling periods between cranking cycles.

4. Observe the fuel pressure gage. If the pressure does not increase to at least 50 psi before the turbine speed reaches approximately 5,000 rpm, release the START switch and determine the cause of the trouble. If the fuel pressure is greater than 150 psi during cranking, at 5,000 rpm or less, do not open the fuel valve. Release the starter switch and investigate the cause of high pressure. (The trouble may be a faulty bleed valve, too small an orifice in the bleed line, an obstruction in the line, or a faulty first-stage governor.)

5. Observe the turbine lube oil pressure gage. Oil pressure should begin to register and increase with turbine speed. However, if the instrument is lagging, the pressure increase may not be evident until idling speed is reached.

6. At 5,000 turbine rpm, pull the throttle outward (unlock the throttle). This positions the throttle at the idle speed setting and opens the fuel nozzle shutoff valve, permitting fuel to flow to the burners. The engine should fire and accelerate, within 5 seconds, to approximately 15,000 rpm. (If the engine does not accelerate to 15,000 rpm within 5 seconds, an abnormal start has been encountered. In this case, push the throttle inward, continue to press the START switch for a few seconds in order to clear the combustion chambers and allow accumulated fuel to be discharged through the nozzle box drain line.)

7. If the oil pressure warning light is off when an idling speed of approximately 15,000 rpm is reached, release the START switch. (The starting and ignition circuits will be

deenergized and the starting fuel-bypass valve will close. Engine operation should now be self-sustaining.)

8. If the oil pressure is increasing and the warning light remains on at idling speed, continue to hold the switch closed until the light goes off. If the START switch is released prematurely, the engine will shut down automatically because of a low oil pressure. However, if no oil pressure is indicated at idling speed, stop the engines and determine the cause of the trouble.

The types of ABNORMAL STARTING which may occur are as follows:

COLD WEATHER STARTING, at low ambient temperatures (10° to 0°F), may be difficult due to low cranking speed and insufficient vaporization of fuel. To provide easier starting under such conditions, engine frictional losses can be reduced by using a lighter lubricating oil of Specification MIL-0-2104. Fuel vaporization can be improved by using a low-temperature diesel fuel of Specification MIL-F-16884.

1. **FALSE STARTING.**—The engine will not start. Combustion fails to occur as a result of either fuel or ignition trouble. If lack of ignition is the cause, fuel will accumulate in the bottom of the burners and the nozzle box.

2. **ONE BURNER STARTING.**—The engine fails to accelerate from low-speed range because of insufficient fuel or ignition. Combustion may not exist in one burner due to lack of either fuel or ignition.

3. **HOT STARTING.**—The engine starts with a low rumbling noise due to (1) igniting fuel accumulated from a previous false or hot start; (2) igniting fuel accumulated from a leaking fuel nozzle shutoff valve; or (3) poor combustion resulting from carbon deposits either on the fuel nozzles or the burner liners. (All hot starts should be logged.)

Operating Limits

The limits tabulated in the accompanying chart have been established for engine operation. If any of these limits are exceeded, the engine should be stopped, and the cause investigated and corrected.

Stopping the Engines

The **NORMAL SHUTDOWN** procedure for stopping the gas turbine engines is as follows:

1. Turn off the generator loads by pressing the STOP switch on the generator control panel.

2. Retard all four throttles to approximately 24,000 rpm. Then retard the two throttles to the generator set not supplying 120-volt d-c power, to **CLOSED** position, but do not lock. Allow the engines to operate at idle speed (approximately 15,000 turbine rpm) for one minute. Then lock the throttles by pushing them inward.

3. Retard the throttles of the generator set that is still operating, to the **CLOSED** position for one minute. Then lock the throttles by pushing them inward. (Combustion should cease immediately and exhaust temperatures should drop rapidly. The oil pressure of the engines will decrease, turning on the oil pressure warning lights. The engine rotors should stop in approximately one minute. These changes will occur for each generator set when the throttles are locked. Retarding all four throttles to the closed position will cause the generator set, not supplying 120-volt d-c power, to be automatically shut down due to the loss of voltage causing the interlock relay to open.)

4. Turn off the master switches.

5. Depress the fuel supply STOP switch. (The fuel supply pump running light will turn off.)

In an emergency, all engines can be stopped simultaneously by pressing either of the two **EMERGENCY OFF** switches. (One of the switches is on the engine control panel and the other is in the generator room.) Either switch opens the circuits to the fuel supply pump and power package master switches. When one of the emergency switches is pressed, the fuel supply pump will stop, the fuel nozzle shutoff valves of all engines will close, and all warning and indicator lights will turn off.

If **AUTOMATIC SHUTDOWN** occurs on one engine, the other engine should be stopped by following the normal shutdown procedure. The cause of the automatic shutdown is indicated by a warning light which will remain on until the master switch is turned off. (In event of a low engine oil pressure, only the low oil-pressure warning light will be on. If automatic shutdown results from an excessive speed or temperature, the corresponding warning light as well as the oil pressure warning light will be on.)

OPERATING LIMITS FOR GAS TURBINE ENGINES

Operating factors	Condition	Minimum	Normal	Maximum
Generator RPM . .	Rated load	1,860 rpm	1,920 rpm	.....
	No load	.....	2,120 rpm	2,140 rpm
	Auto. shutdown	.....	.....	2,300 rpm
Turbine RPM . .	Cranking	4,000 rpm	5,000 rpm	.....
	Idling	15,000 rpm	.....	.....
	Rated speed	.....	.....	36,500 rpm
	Momentary	.....	.....	37,500 rpm
Turbine oil pressure . .	Rated speed	35 psi	50 psi	70 psi
	Auto. shutdown	20 psi	.....	.....
Fuel pressure . .	Starting	50 psi	100 psi	150 psi
	Rated speed	.....	350 psi	500 psi
	Idling speed	.....	10-50 psi	.....
Exhaust temperature . .	Continuous	.....	1150° F (621° C)	1225° F (663° C)
	Auto. shutdown	.....	.....	1300° F (704° C)
Gear box oil pressure . .	Rated speed	12 psi	15 psi	17 psi

In addition to the engine warning lights, an amber warning light burns when the combining gear oil temperature rises above 180°F. If the gear oil temperature warning light is on, the engines of that power package should be stopped by following the NORMAL shutdown procedure.

If the automatic shutdown occurs on the generator set started first and the other engine of that set is stopped, the generator set started last will also shut down automatically because the power relay to the cooling pumps will be

interrupted due to the position of the 120-volt, manual transfer switch.

Immediately after an automatic shutdown, a check must be made for free operation of the overrunning clutch on the dead engine. If the flexible coupling and outer brass cylinder of the overrunning clutch are not rotating, free-wheeling is taking place. If the unit continues to rotate, the clutch is locked and the operating engine must be stopped immediately; otherwise the engine will drive the second-stage of the dead engine without lubrication. (Second-stage

lubrication is provided by the first-stage oil pump.)

MAINTENANCE OF GAS TURBINE ENGINES

Detailed information on the maintenance of a specific turbine installation must be obtained from the appropriate manufacturer's manual. General information is provided in this chapter on maintenance of gas turbines.

Adjustment of Engine Components

The following adjustments and tests may be accomplished, as required—at initial installation, after major overhaul, or during periodic maintenance.

THROTTLE CONTROL.—Moving the throttle from idle to full-speed position produces a corresponding movement of the governor control arm between the low-speed and the high-speed stops on the end of the governor housing. If the travel limits of the throttle and governor arm are not synchronized or throttle movement is partially restricted at either limit, inspect the throttle cable for binding and rubbing. In addition, check the cable support bracket and the governor control arm for proper position. Restricted throttle movement caused by interference between the governor control arm and the heat shield of the nozzle box can be corrected by bending the heat shield to obtain sufficient clearance. If the bolt clamping the cable support bracket around the end of the governor housing is not tightened securely, the bracket may shift; this results in the bending of the cable. However, excessive tightness of the clamping bolt may distort the governor housing. For ease of throttle operation, the governor control arm should be positioned on the serrations of the governor shaft so that it is perpendicular to the cable bracket when the throttle is centered on its range of travel.

If the inspection indicates that slack exists in the throttle cable, and the cable support bracket and governor control arm are properly positioned, it will be necessary to readjust the cable length. Disconnect the throttle cable rod at the governor control arm and rotate the rod end in the proper direction. Reconnect the rod end to the governor control arm. The throttle cable clevis under the engine control panel permits similar adjustment if threading is insufficient in the rod end at the governor.

STARTING FUEL FLOW ADJUSTMENT.—During engine starting, fuel pressure is restricted at 50 to 150 psi, by an orifice in the starting fuel-bypass line. If difficulty is encountered with engine starting, particularly if any parts which affect fuel flow or pressure have been overhauled or replaced, check the starting fuel pressure. With the throttle depressed, in idle position, to close the fuel nozzle shutoff valve, crank the engine to a starting speed of 5,000 rpm and observe the fuel pressure indicator. If the fuel pressure is lower than 50 psi, replace the existing orifice with the next smaller size. If the pressure exceeds 150 psi, install the next larger size to reduce the pressure to within the desired range. (Interchangeable orifices are made in 0.030, 0.035, and 0.040-inch sizes; a 0.035-inch orifice is generally installed. If the orifice is changed, the fuel pressure should be rechecked.)

ENGINE OIL PUMP.—The engine oil pressure-scavenge pump should deliver oil, through the engine oil cooler and filter, to the oil manifold at a pressure not less than 20 psi at idling speed or greater than 70 psi at maximum speed. (The normal operating pressure ranges from 35 to 70 psi.) The pump discharge pressure is limited by the compression of a spring acting against the poppet of an integral relief valve within the pump housing. If the normal engine oil pressure is not within these operational limits, the relief valve should be set to provide the proper pressure. Readjustment can be made with the engine at idling speed. (The engine oil pressure can be increased by turning the adjusting screw, on the left side of the oil pump, in a clockwise direction; turning the screw in a counterclockwise direction will decrease the pressure.)

ENGINE OIL THERMOSWITCH.—This switch is adjusted to open the safety circuit to the sealing relay and to turn on an amber warning light whenever the engine oil temperature exceeds 265°F. When maladjustment of the thermoswitch is suspected, the unit should be removed from the oil supply reservoir strainer mounting plate and bench-checked. Remove the thermoswitch cover and attach a continuity light or de-energize the circuit and check with an ohmmeter across the switch terminals. Insert the tube of the thermoswitch into an oil bath heated to 265° (±5) F and allow several minutes for temperature stabilization. If the

meter indicates a premature closing of the switch, turn the adjusting screw on the back of the thermoswitch to first open and then close the switch contacts at this temperature. A full turn changes the temperature setting approximately 4°F. This switch should be calibrated after it has been operated a total of 150 hours.

IGNITION BOOST COIL.—If the boost coil spark is weak, or there is no sound when the ignition test switch is held in the momentary TEST position, remove the coil from the engine and connect the primary terminal of the coil to a 24-volt d-c power supply. The ignition boost coil, which provides high voltage for the igniter plug, should be tested in conjunction with the igniter plug. When an inspection shows that most of the contact material has burned away, the points on the boost coil should be replaced. (To avoid damage to the ignition boost coil, the igniter plug must be grounded to the coil body when the coil is tested on the bench. In addition, the plug must be grounded to the engine when the coil is tested while installed on the engine.)

IGNITER PLUG.—When the spark gap of the igniter plug is suspected as the cause of faulty ignition during engine starting, disconnect the glow coil and high-voltage wiring. Remove the igniter plug from the burner elbow. The electrode gap of the igniter plug should be 0.070 to 0.080 inch. If the wire feeler gage measurement shows that the spacing is not within these limits, the gap should be reset by bending the ground electrode only. Prying against the center electrode may crack the porcelain insulator. When the igniter plug is being reinstalled, the gasket should be replaced.

SWITCHES.—As far as EXHAUST COLLECTOR THERMOSWITCHES are concerned, test kits are provided for calibration which should be accomplished every 150 hours of operation or monthly, whichever occurs first.

The ENGINE OVERSPEED SWITCH, which functions to open the safety circuit to the sealing relay and turn on an amber light, should be checked as follows:

1. Disconnect the actuating cylinder linkage rod end at the exhaust damper bell crank and safety wire the bell crank around the interstage bleed assembly (single hole in bell crank up) to hold the interstage bleed damper closed.

2. Start the engine and gradually increase the speed until the overspeed switch trips closed and shuts down the engine. (A first-stage speed of 30,000 is usually more than sufficient to overspeed the generator to about 2,300 rpm.)

If the switch closes prematurely, loosen the setscrew in the side of the switch housing and the two clamp screws which lock the large knurled speed-adjusting ring around the switch housing. With the overspeed switch mounting bracket restrained, hold the terminal end of the switch housing and turn the knurled speed-adjusting ring clockwise, as viewed from the terminal end. One-half turn of the speed-adjusting ring will affect the overspeed limit of the engine approximately 200 rpm (approximately 145 rpm of generator shaft). When proper adjustment is achieved, tighten the two locking screws and the setscrew. If switch closing is delayed beyond 1,640 rpm, the speed-adjusting ring should be turned in a counter-clockwise direction.

If shutdowns occur, within maximum limits, during engine operation, the overspeed switch can also be readjusted while it is installed on the engine. For example, if the switch closes and causes automatic shutdown when the generator speed is 2,100 rpm, the knurled speed-adjusting ring can be rotated clockwise approximately 2/3 of a turn to restore switch actuation to the desired setting. This switch should be calibrated after every 50 hours of operation.

GENERATOR SPEED CONTROL.—The speed control system must be adjusted so that, at full generator load, the entire gas flow passes through the second-stage turbine and the exhaust collector, and the governor controls at the required speed.

With the exhaust back-pressure valves and interstage bleed valves installed and aligned, and the exhaust ducting removed, linkage adjustment should be accomplished in accordance with the manufacturer's instructions for the specific system.

Cleaning and Inspection of Gas Flow Components

The gas flow components of the engine include the burner shells and liners, cross fire tube, nozzle box, interstage bleed assembly, exhaust collector, and first-stage and second-stage turbine wheels. These components must

be thoroughly cleaned after they are removed from the engine. In reassembling the engine, cleanliness is a major factor. Cleaning is essential for proper inspection because it contributes to the life and efficiency of the engine. Dirt and grease deposits on the surfaces of the component parts are fire hazards and reduce the amount of heat radiated from the surfaces. Carbon deposits reduce gas flow and thereby reduce burning efficiency.

When parts are coated with a carbon deposit, baked oil-residue, scale, or other foreign matter, and where surface finishing requirements permit, the best method of cleaning is by blast cleaning with a water and grit mixture, using a 625 mesh (or finer) grit. If water and grit blast cleaning equipment is not available, fine dry sand or garnet grit (No. 90 or finer) are permissible for blast cleaning.

Threaded or bearing surfaces must not be blast cleaned. These surfaces must be protected by masking with heavy tape or with a fiber soft aluminum, or copper sleeve. Unless extreme care is used during the cleaning operation, blast cleaning tends to hide fine defects by peening-over or smearing. Always use the lowest possible air pressure, consistent with thorough cleaning, and do not concentrate the blast in any one area, especially on thin sections such as blade edges. In order that the fine defects associated with turbine wheels and nozzle vanes will not be hidden, these components must be cleaned with extreme care.

Parts that are to be inspected by using any penetrant method, must be thoroughly degreased immediately prior to inspection. Vapor degreasing, or washing the parts in naphtha are suitable degreasing methods. Acid or alkali solutions should NOT be used to clean the engine parts because such solutions impair the efficiency of the inspection operation. Any areas which are to be welded must first be mechanically cleaned and degreased.

If blast cleaning equipment is not available, the parts must be cleaned with a wire brush, emery paper, steel wool, or cleaning solvent. Stainless steel wire brushes or stainless steel wool should be used in order to avoid contaminating the surfaces of the parts. (All gas flow components are corrosion- and heat-resistant alloy steel.)

Additional information concerning inspections of gas flow components, as well as inspection schedules, may be obtained from either

the ship's Inspection Guide or the manufacturer's technical manual.

SAFETY PRECAUTIONS

When working with a gas turbine installation, give special consideration to the inlet pressure and the exhaust gases, as well as to the relatively high speed and temperature of certain sections of the gas turbine engine.

Inlet Pressure

During engine operation, a negative pressure area is created immediately forward of the engine air inlet. When the engine is installed in the power package, adequate screening at the air inlet bell prevents articles from entering the compressor. When operating the engine on a test stand, the screened air inlet bell should always be secured to the engine. Loose clothing, white hats, and ties should not be worn or carried near the air inlet, while the engine is running. In addition, shirt pockets should be free of any articles.

Overspeed Damage

Excessive overspeed of the engine can result in the failure of the compressor impeller or either of the two turbine wheels, with the possibility of pieces being thrown outward by centrifugal force. Failure of the compressor impeller may shatter the compressor case or elbows. If a blade is thrown from a turbine wheel, it will probably be discharged with exhaust gases and cause no external damage. At maximum engine speeds, stand clear of those areas adjacent to the planes of rotation of these components.

Surface Heat

Heat shields around the nozzle box and exhaust collector, as well as the insulation on the exhaust ducts, provide reasonable protection from surface heat. However, touching any portion of the engine which conducts combustible gases, or adjacent parts, can result in severe burns. A cooling period of approximately 30 minutes is required before inspecting or performing major maintenance.

Exhaust Gases

Direct contact with the high temperatures and velocities of the engine exhaust gases can result in severe burns and/or shock. Even

though the toxic effect of the small amount of carbon monoxide present in the engine exhaust is negligible, avoid continuous exposure to the exhaust fumes because they may cause headaches, eye smarting, or other irritations.

CHAPTER 17

ENGINEERING CASUALTY CONTROL

The mission of engineering casualty control is to maintain all engineering services in a state of maximum reliability, under all conditions. To carry out this mission, it is necessary for the personnel concerned to know the action necessary to prevent, minimize, and correct the effects of operational and battle casualties on the machinery and the electrical and piping installations of their ship. The prime objective of casualty control is to maintain a ship as a whole in such a condition that it will function effectively as a fighting unit. This requires effective maintenance of propulsion machinery, electrical systems, interior and exterior communications, fire control, electronic services, ship control, firemain supply, and miscellaneous services such as heating, air conditioning, and compressed air systems. Failure of any of these services will affect a ship's ability to fulfill its primary objective, either directly by reducing its power, or indirectly by creating conditions which lower personnel morale and efficiency. A secondary objective—which contributes considerably to the successful accomplishment of the first—is the minimization of personnel casualties and of secondary damage to vital machinery.

The details on specific casualties are beyond the scope of this course. Detailed information on casualty control can be obtained from the Engineering Casualty Control Manual, the Damage Control Book, the Ship's Organization Book, and the Damage Control Bills. These publications may vary on different ships, but in all cases they give the organization and the procedures to be followed in case of engineering casualties, damage to the ship, and other emergency conditions.

FACTORS INFLUENCING CASUALTY CONTROL

The basic factors influencing the effectiveness of engineering casualty control are much

broader than the immediate actions taken at the time of the casualty. Engineering casualty control reaches its peak efficiency by a combination of sound design, careful inspection, thorough plant maintenance (including preventive maintenance), and effective personnel organization and training. CASUALTY PREVENTION IS THE MOST EFFECTIVE FORM OF CASUALTY CONTROL.

FAMILIARITY OF PERSONNEL WITH PLANT OPERATION

Thorough instruction in the proper and normal operating procedures is the foundation upon which instruction in casualty procedures should be based. Before any attempt is made to carry out simulated casualties, complete familiarity with normal operation should be gained by all personnel involved. From the design viewpoint, full information upon which to base improved designs should be contributed by the operating forces.

INFLUENCE OF DESIGN

Sound design influences the effectiveness of casualty control in two ways: (1) by the elimination of weaknesses which may lead to material failure, and (2) by the installation of alternate or standby means for supplying vital services in the event of a casualty to the primary means.

Both of these factors are considered in the design of naval ships. Individual plants aboard ship are equipped with duplicate vital auxiliaries, loop systems, and cross connections. Complete propulsion plants are designed to operate as isolated units (split-plant design).

PREVENTIVE MAINTENANCE

Preventive inspection and maintenance are vital to successful casualty control, since these

activities minimize the occurrence of casualties by material failures. Continuous and detailed inspection procedures are necessary not only to discover partly damaged parts which may fail at a critical time, but also to eliminate the underlying conditions which lead to early failure (maladjustment, improper lubrication, corrosion, erosion, and other enemies of machinery reliability). Particular and continuous attention must be paid to the following symptoms of malfunctioning:

1. Unusual noises.
2. Vibrations.
3. Abnormal temperatures.
4. Abnormal pressures.
5. Abnormal operating speeds.

Operating personnel should thoroughly familiarize themselves with the specific temperatures, pressures, and operating speeds of equipment required for normal operation, in order that departures from normal operation will be more readily apparent.

If a gage, or other instrument for recording operation conditions of machinery, gives an abnormal reading, the cause must be fully investigated. The installation of a spare instrument, or a calibration test, will quickly indicate whether the abnormal reading is due to instrument error. Any other cause must be traced to its source.

Because of the safety factor commonly incorporated in pumps and similar equipment, considerable loss of capacity can occur before any external evidence is readily apparent. Changes in the operating speeds from normal for the existing load in the case of pressure-governor-controlled equipment should be viewed with suspicion. Variations from normal pressures, lubricating oil temperatures, and system pressures are indicative of either inefficient operation or poor condition of machinery.

In cases where a material failure occurs in any unit, a prompt inspection should be made of all similar units to determine if there is any danger that a similar failure might occur. Prompt inspection may eliminate a wave of repeated casualties.

Abnormal wear, fatigue, erosion, or corrosion of a particular part may be indicative of a failure to operate the equipment within its designed limits or loading, velocity, and lubrication, or it may indicate a design or material deficiency. Unless corrective action can be

taken which will ensure that such failures will not occur, special inspections to detect damage should be undertaken as a routine matter.

Strict attention must be paid to the proper lubrication of all equipment, and this includes frequent inspection and sampling to determine that the correct quantity of the proper lubricant is in the unit. It is good practice to make a daily check of samples of lubricating oil in all auxiliaries. Such samples should be allowed to stand long enough for any water to settle. Where auxiliaries have been idle for several hours, particularly overnight, a sufficient sample to remove all settled water should be drained from the lowest part of the oil sump. Replenishment with fresh oil to the normal level should be included in this routine.

The presence of salt water in the oil can be detected by drawing off the settled water by means of a pipette and by running a standard chloride test. A sample of sufficient size for test purposes can be obtained by adding distilled water to the oil sample, shaking vigorously, and then allowing the water to settle before draining off the test sample. Because of its corrosive effects, salt water in the lubricating oil is far more dangerous to a unit than is an equal quantity of fresh water. Salt water is particularly harmful to units containing oil-lubricated ball bearings.

CASUALTY CONTROL TRAINING

Casualty control training must be a continuous step-by-step procedure with constant refresher drills. Realistic simulation of casualties must be preceded by adequate preparation. The amount of advance preparation required is not always readily apparent; care must be exercised to visualize fully the consequences of any error which may be made in handling simulated casualties originally intended to be of a relatively minor nature. The simulation of major casualties and of battle damage must be preceded by a complete analysis and by careful instruction to all participants. A new crew must be given an opportunity to become familiar with the ship's piping systems and equipment, prior to simulating any casualty which may have other than purely local effects.

In the preliminary phases of training, a "dry run" is a useful device for imparting a knowledge of casualty control procedures, without

endangering the ship's equipment by too realistic a simulation of a casualty. Under this procedure, a casualty is announced, and all individuals are required to report as though action were taken (an indication must be made that the action was simulated). Definite corrective action motions can be made, and with careful supervision the timing of individual actions can appear to be very realistic. Regardless of the state of training, such dry runs should always be carried out before actually attempting to simulate realistically any involved casualty. Similar rehearsals should precede the simulation of relatively simple casualties whenever an appreciable proportion of men new to the ship are involved, and particularly after an interruption (such as is occasioned by periods of naval shipyard overhauls) or regularly conducted casualty training.

PROMPT CORRECTION OF CASUALTIES

The speed with which corrective action is applied to an engineering casualty is frequently of paramount importance. This is particularly true when dealing with casualties which affect the propulsion power, steering, and electrical power generation and distribution. If casualties associated with these functions are allowed to become cumulative, they may lead to serious damage to the engineering installation—damage which often cannot be repaired without loss of the ship's operating availability. Where possible risk of permanent damage exists, the CO has the responsibility of deciding whether to continue operation of equipment under casualty conditions; and such action can be justified only where the risk of even greater damage, or loss of the ship, may be incurred by immediately securing the affected unit.

To reemphasize, whenever there is no probability of greater risk, the proper procedure is to secure the malfunctioning unit as quickly as possible even though considerable disturbance to the ship's operations may occur. Although speed in controlling a casualty is essential, action should never be undertaken without accurate information; otherwise the casualty may be mishandled, and irreparable damage and possible loss of the ship may result. War experience has shown that the cross-connecting of intact systems with a partly damaged one must be delayed until it is certain that such action will not jeopardize the intact systems. Speed in the handling

of casualties can be achieved only by a thorough knowledge of the equipment and associated systems, and by thorough and repeated training in the routine required to handle specific predictable casualties.

PHASE NATURE OF CASUALTY CONTROL

The handling of any casualty can usually be divided into three phases: limitation of the effects of the damage, emergency restoration and complete repair.

The first phase is concerned with immediately controlling the casualty so as to prevent further damage to the unit concerned and to prevent the casualty from spreading through secondary effects.

The second phase consists of restoring, as far as practicable, the services which were interrupted as a result of the casualty. In many cases, the completion of this phase eliminates all operational handicaps, except for the temporary loss of standby units—i.e., ability to withstand further failure. If no damage to, or failure of, machinery has occurred, this phase usually completes the operation.

The third phase of casualty control consists of making repairs which will completely restore the installation to its original condition.

SPLIT-PLANT OPERATION

A fundamental principle of engineering casualty control is SPLIT-PLANT operation. The purpose of split-plant design is to minimize the damage that might result from any one hit.

Most naval ships built primarily as warships have at least two engineering plants. The larger combatant ships have four individual engineering plants.

The major piping systems on most naval ships are so arranged that the engineering plants may be operated either separately (split-plant) or together (cross-connected). In split-plant operation, the boilers, turbines, pumps, and other machinery are so divided that there are two or more complete and separate engineering plants. Split-plant operation is used when maximum reliability is necessary, as when a ship is operating in enemy waters in time of war, operating in heavy weather, maneuvering in restricted waters, or engaged in underway replenishment.

Cross-connection valves are provided for the main and auxiliary steam systems and other engineering systems so that any boiler or group of boilers, either forward of aft, may supply steam to each engine room. Cross-connected operation was formerly standard for peacetime operation, since it is far more economical than split-plant operation. However, many ships built since World War II operate split-plant under all conditions.

Split-plant operation is no guarantee against devastating or widespread damage that would completely immobilize the entire engineering plant, but it does reduce the chance of such an over-all casualty. If a ship should be operating cross-connected, for example, when a shell ruptures the main steam line to the forward turbine, all steam would be lost, at least temporarily, until the damaged spaces could be isolated. If the ship should be operating split-plant when it receives the same damage, it would be able to carry out its mission on the remaining engines. It is for this reason that doctrine calls for split-plant operation whenever a ship is engaged in potentially hazardous operations such as combat, entering or leaving port, and maneuvering in formation with other ships.

Split-plant operation has proved its value on more than one occasion. When a torpedo explosion wrecked one engine room and destroyed half the boilers on a cruiser, the ship was able to steam away under its own power by using the undamaged plant. Had the plant not been split, steam from the undamaged boilers would undoubtedly have escaped through the wrecked engine room. The result would have been loss of propulsive power, loss of the power required to control flooding, and possibly even loss of the entire ship.

Failure to understand the full meaning of split-plant operation may be the cause of unwarranted casualties. Such lack of understanding caused heavy damage to one destroyer's main engine. The ship was operating with the plant split, when one boiler lost feed water. In the process of handling the low-water casualty, fireroom personnel secured the bulkhead steam stops of both boilers. This cut off all steam to one engine room. The lubricating oil pump stopped, while the main turbine was still turning over; and consequently the turbine bearings were wiped and the turbine blading was ruined. If the fireroom personnel had thoroughly understood the split-plant arrangement,

they could have secured the stops only on the boiler that had low water, and thus kept steam going to the engine room.

This casualty to the turbine would not have occurred in a ship that had a chain-drive lube oil pump, since the pump would have continued to operate as long as the shaft was turning. Even in a ship that did not have a chain-driven lube oil pump, however, this casualty should never have occurred. A well-trained engine room force would have been able to stop the shaft with backing steam while the bulkhead stops were being closed and, at the same time, to cross-connect the plant so as to supply main steam from the remaining fireroom. And finally, bulkhead stops are operable from each side of the bulkhead.

Split-plant operation may have to be suspended because of a casualty. A destroyer steaming at high speed with all boilers in operation might be forced to secure one boiler because of a ruptured tube. The ship should continue steaming with two boilers supplying one engine and one boiler supplying the other, accepting the small shaft speed differential that would result. If both boilers in one fireroom must be secured because of casualties, the two plants should then be cross-connected so that the boilers in the intact fireroom are supplying steam to both engine rooms.

The foregoing examples prove the value of operating ships with the machinery plant split, and also indicate the need for a complete understanding of all that is involved in split-plant operation. The intelligent application of good engineering principles should prevent serious damage to associated machinery when a single unit suffers a casualty.

FUEL OIL SYSTEM

The fuel oil system is generally so arranged that, by means of fuel oil booster and transfer pumps, suction can be taken from any fuel oil tank on the ship and the oil pumped to any other fuel oil tank. Fuel oil service pumps are then used to supply oil to the boilers from the service tanks. In split-plant operation, the forward fuel oil service pumps are lined up with the forward service tanks and the after service pumps are lined up with the after service tanks. The cross-connecting valves in the fuel oil transfer line must be closed except when oil is being transferred.

The main reason for securing the fuel oil cross-connecting lines is to prevent major casualties. For example, if all boilers were being supplied fuel oil from the same set of tanks and one tank was ruptured by a torpedo, or a near-miss bomb or shell, the entire fuel oil system would become contaminated with salt water, the fires would go out, propulsive power would be lost, and the ship would stop dead in the water.

Some ships are provided with sluicing lines that make it possible to sluice oil (or water) from one side of the ship to the other. These sluicing valves should be kept closed when they are not being used. This is also true for all manifold valves. This precaution will prevent the movement of any liquid from one tank to another in the event of damage.

On some ships, the fuel oil service system is so arranged that it can be operated either split-plant or cross-connected, all the way up to the burners.

FEED WATER SYSTEM

Because of the need for entire reliability of the feed system, feed and condensate systems are usually operated split-plant rather than cross-connected. In fact, on some ships it is not possible to cross-connect the feed systems at all.

During split-plant operation the main feed system may be divided into two or more separate and complete systems. In an operation of this type the after boilers would be supplied from the after deaerating feed tank by means of the after booster and main feed pumps; the same principle would apply to the forward system. In splitting the plant, use as little of the feed piping system as possible and isolate the rest of the system so as to reduce the area subject to casualties. Keep the emergency feed pumps warmed up and in a standby condition, recirculating on cold suction, ready to supply feedwater to the boilers in the event of a casualty to the main feed and booster pumps.

MAIN STEAM SYSTEM

The main steam system varies somewhat from one ship to another, depending upon the distribution and arrangement of the boilers and the main engines. The main steam system is usually a relatively simple system.

Smaller types of ships may have the forward and the after system cross connected to form a complete system throughout the enginerooms and firerooms, whereas larger types of ships have independent forward and after systems. The method of supplying steam to the propulsion turbines, however, remains essentially the same. On small combatant ships the main steam system is split fore and aft to form two separate systems. On large combatant ships there are no main steam connections between the two forward and the two after plants, and the main steam is split athwartships; this gives a total of four separate main steam systems. Valves are provided at strategic points, such as at bulkheads and at the boilers, to permit effective isolation in case of damage.

AUXILIARY STEAM SYSTEM

The auxiliary steam system that supplies saturated steam for the operation of auxiliary machinery is one of the most complex engineering systems on the ship. On ships having M-type boilers, auxiliary steam is taken from the steam drum and is at approximately steam drum pressure. On integral superheater boilers, auxiliary steam comes from the desuperheater outlet. On ships having high-pressure boilers, the auxiliary steam is taken through reducing valves that lower the pressure to about 600 psi. In each case, the 600-psi auxiliary steam system also supplies steam to a number of reduced-pressure systems.

Since all auxiliaries except the turbogenerators operate on steam taken from the 600-psi system or one of its reduced-pressure branches, an adequate pressure must always be maintained in this system. Emergency demands for steam (such as a sudden requirement for full-power astern operation) could reduce the pressure in the auxiliary steam system to the point where fuel pumps, feed pumps, forced draft blowers, circulating pumps, and all other vital auxiliaries would be seriously endangered.

ENGINEROOM CASUALTIES

For each class of ships, the type commander formulates engineering casualty procedures which are applicable to the specific type of engineering plant. This section contains information on typical engineroom casualties and the

general procedures recommended by the Naval Ship Systems Command for the control of each. Consult the ship's Engineering Casualty Control Manual for engineering casualty procedures on your ship.

PROPULSION AND AUXILIARY MACHINERY

In the event of a casualty to a component part of the propulsion plant, the principal doctrine to be impressed upon operating personnel is the prevention of additional or major casualties. Under normal operating conditions, the safety of personnel and machinery should be given first consideration. Where practicable, the propulsion plant should be kept in operation by means of standby pumps, auxiliary machinery, and piping systems. The important thing is to prevent minor casualties from becoming major casualties, even if it means suspending the operation of the propulsion plant. It is better to stop the main engines for a few minutes than to put them completely out of commission, so that major repairs are required to place them back into operation. In case a casualty occurs, the officer or CPO in charge of the watch should be notified as soon as possible; he in turn must notify the OOD if there will be any effect on the ship's speed or on the ability to answer bells.

JAMMED THROTTLE

If the ahead throttle valve jams open, close the guarding valve or the main line stop valve. To remedy the situation in an extreme emergency, the astern throttle may be used.

If the astern throttle valve jams open, close the line stop valves. To remedy the situation in an extreme emergency, open the ahead throttle. If necessary, the ship can be operated by means of the guarding valve.

NOTE: On some new combatant ships, the guarding valve controls the steam to both the ahead and astern throttles. In such cases, should either throttle jam, the casualty is controlled by closing the guarding valve. The shaft cannot be stopped by using the opposite throttle.

Loss of Steam Pressure in the Engine Room

In the event of a loss of steam pressure, the following action should be taken:

1. Close the main throttle and trip the turbogenerator to prevent the main steam pressure from dropping below the designated minimum operating pressure, normally about 75 percent of the rated pressure. If the electrical load is split, the bus tie between the two main switchboards must be closed immediately, pending supply of steam to the turbogenerator from the other plant.
2. Open the main and the turbogenerator steam cross connections.
3. Open both auxiliary steam cross-connection valves.
4. Secure the boiler stop valves.
5. Shift to electrical auxiliaries as desired.

Locking and Unlocking of Shaft Underway

In locking the shaft, the following action should be taken:

1. Stop the main shaft by means of the astern turbine.
2. Slow ship's speed to one-half full power speed or less, if necessary, or to the designated locking speed.
3. Engage the turning gear at locking shaft speed, and immediately apply the brake.
4. Note the astern steam pressure and the ship's rpm on the other shaft(s), when the shaft is held stationary for locking.
5. Close the astern throttle slowly.

In unlocking the shaft, the following action should be taken:

1. Reduce the temperature of the main steam as much as practicable.
2. Bring the ship to the same speed (rpm) at which the shaft was locked.
3. Open the astern throttle until the same astern steam pressure, used when the shaft was locked, is obtained.
4. Disengage the turning gear immediately. (It may be necessary to adjust the astern throttle pressure slightly in order to disengage the turning gear. The turning gear brake may then be released.)
5. Slowly close the astern throttle.
6. Open the ahead throttle and slowly bring the main shaft up to the speed required for the operation of the ship.

CAUTION: If the shaft has been locked for 5 minutes or more, the turbine rotors may have become bowed, and special precautions are recommended. Before the shaft is allowed to turn, men should be stationed at the turbines to check for unusual noises and vibration. When the turning gear is disengaged, the astern throttle should be slowly closed, the torque produced by the propeller passing through the water will start the shaft rotating. If, when the propeller starts to turn, vibration indicates a bowed rotor, the ship's speed should be reduced to the point where little or no vibration of the turbine is noticable and this speed should be maintained until the rotor is straightened. If operation at such a slow speed is not practicable, the turbines should be slowed by use of the astern throttle, to the point of least vibration but with the turbines still operating in the ahead direction. When the turbines are slowed to the point of little or no vibration, the shaft should be operated at that speed and the ahead throttle should be opened slightly to permit some steam flow through the affected turbine. The heat from the steam will warm the shaft and aid in straightening it. Lowering the main condenser vacuum will add additional heat to the turbines; this will increase the exhaust pressure and temperature.

As the vibration decreases, the astern throttle can be closed gradually, allowing the speed of the shaft to increase. The shaft speed should be increased slowly and a constant check for vibration should be maintained. The turbine is not ready for normal operation until vibration has disappeared at all possible speeds.

Vibration

If the **TURBINE BEGINS TO VIBRATE**, the following action should be taken:

1. Slow the turbine and reduce the super-heat temperature. A rumbling noise probably indicates the presence of water in the casing, either from boiler priming or from inadequate casing drainage.
2. If the turbine has been standing more than 5 minutes without being spun, it is probable that the rotor has bowed temporarily. Usually a brief slowing of the turbine will permit the rotor shaft to straighten.

If the **SHAFT VIBRATES EXCESSIVELY**, the following action should be taken:

1. Slow the engine. Speed up the other engine to maintain speed.
2. If vibration continues, slow all engines until the cause of the trouble can be determined.
3. Inspect the main shaft bearings and the bulkhead stuffing glands.
4. If feasible, investigate the propeller, the fairwaters, and the rope guards.
5. If vibration continues and is excessive at required speeds, stop the shaft and lock it.

Noises

In the event of a **METALLIC NOISE** in the turbine, the following action should be taken:

1. Stop the turbine.
2. Lock the shaft and do not operate until the cause of the noise has been determined and remedied.

In the event of an **UNUSUAL NOISE IN THE REDUCTION GEAR** and if tooth failure is not probable, the following action should be taken:

1. Slow the engine immediately, and stop it if the noise persists.
2. Check the oil discharge pressure, the temperature of the bearings, and the operation of oil sprays; check the strainers for the presence of babbitt or foreign matter.

If a **LOUD OR ROARING NOISE** is heard, proceed to (1) stop the engine and check the shaft immediately, and (2) lock the shaft and as far as the ship's operations permit, make a preliminary investigation.

Hot Bearings

If the turbine bearings are hot, the following action should be taken:

1. Check to see that a proper amount of oil is being discharged from the cooler and that an adequate supply is being discharged to the bearings.
2. Slow the engine, if necessary, to maintain a bearing temperature within the limit defined by the manufacturer, or as experience dictates.
3. Place burlap or rags over the top of the bearing housing, and run a slow stream of salt water over the housing. Care should be

taken that the water is not splashed into the oil or into the gland sealing systems. Spraying water on a bearing should not be resorted to except in an emergency, as cold water causes contraction of the bearing, further reducing the clearance.

In the case of reduction gear bearings, do not operate gears, except in an emergency, until the bearings have been examined. Wiped bearings would permit pinion or shaft misalignment, and thereby result in uneven wear of the gears.

If the TURBINE OR SHAFT BEARING BECOMES OVERHEATED, the following treatment is recommended:

1. Once the bearing temperature has been reduced from the critical range by methods listed under turbine bearings (mentioned previously), proceed at a speed that will keep the bearing temperature satisfactory.

2. If overheating has not caused damage to shaft packings, overheated bearings may be operated at moderate speeds; however, the bearing should be replaced as soon as possible.

3. If the bearing damage is believed to be greater than assumed above, turn over the shaft at a minimum speed to prevent the bearing from freezing. Then stop and lock the shaft. Continue operation of the forced lubrication system.

4. Operate the lubricating oil purifier continuously to remove any flakes of babbitt, or other foreign matter, which might become entrained in the oil system.

Cruising Turbine Out of Commission

If the cruising turbine doesn't operate properly, the following action should be taken:

1. Disconnect the cruising turbine.
2. Insert the locking device.
3. Secure the valves, gland seal, gland leak-off, and drains of the cruising turbine.

Loss of Vacuum

The major causes of a loss of vacuum are: excessive air leakage into the vacuum system, improper functioning of the air-removal equipment, improper drainage of condensate from the condenser, insufficient flow of circulating water, and high injection temperature.

1. EXCESSIVE AIR LEAKAGE INTO THE VACUUM SYSTEM may be caused by:

- a. Insufficient gland sealing steam.
 - b. Vent valve on idle condensate pump open.
 - c. Loop-seal filling valve open.
 - d. Bypass valve on drain tank open.
 - e. Drain tank float valve stuck open.
 - f. Taking make-up feed from empty feed bottom.
 - g. Leakage of flanges, fittings, or valve stem packings under vacuum.
2. IMPROPER FUNCTIONING OF THE AIR-REMOVAL EQUIPMENT may be due to:
 - a. Insufficient steam to the air ejectors.
 - b. Foreign matter lodged in the air ejector nozzle(s).
 - c. Erosion of the air ejector nozzle, over a period of time.
 3. IMPROPER DRAINAGE OF CONDENSATE FROM THE CONDENSER may be caused by:
 - a. Low speed of condensate pump, indicating malfunctioning of the pump's speed-limiting governor.
 - b. Condensate pump air-bound because of the vent connection from the first stage being closed or not opened wide.
 4. INSUFFICIENT FLOW OF CIRCULATING WATER may be caused by:
 - a. Improper adjustment of the overboard discharge valve (the main injection valve being wide open whenever the condenser is under vacuum).
 - b. Inadequate speed of the main circulating pump.
 - c. Plugged tubes, resulting from mud, shells, small fish, or kelp being trapped against the injection strainer bars or in the inlet water chest.
 - d. Air trapped in condenser.
 5. HIGH INJECTION TEMPERATURE

Basically, the injection temperature limits the maximum vacuum (minimum absolute pressure) obtainable in a specific plant, assuming the condenser, associated equipment, and piping under vacuum to be clean and properly operated.

Whenever there is a loss of vacuum, the first step in correcting the trouble is to locate the cause of the casualty. The major possible causes are so numerous that no attempt will be made to list the proper action required for each one. The required action may be very simple, such as closing the loop seal filling valve, or it may be much more complicated, such as cleaning the main condenser or replacing air ejector nozzles.

Leak in Condenser

If a condenser salinity indicator shows a rise in the chloride content, the source of the contamination must be determined immediately. To locate these sources, test the fresh water from different units in the system by checking the proper salinity indicators (if installed) and by making chemical chloride tests. There are four major causes of a salty condenser:

1. Leaky tube(s) in the condenser.
2. Make-up feed tank salted up.
3. Low pressure drain tank salted up.
4. Leaky feed suction and drain lines which run through the bilges.

Each of the aforementioned possibilities must be investigated to determine the source of the contamination and its elimination.

If it is determined that there is a minor leak in the condenser and the ship's prospective arrival time is less than 24 hours, the affected plant will probably be continued in operation. Isolate the condensate system, and limit the number of boilers on the engine involved. When operating under these conditions it will be necessary to blow down the boiler(s) as necessary, to keep the boiler salinity within the specified limit.

However, if the leak is serious, the following action should be taken:

1. Stop the engine and lock the shaft.
2. Shift drains, auxiliary exhaust, and turbo-generator exhaust to the auxiliary condenser.
3. Retain the main lubrication oil system in operation, and proceed on the other engine(s).
4. Test the condenser and plug the leaking tube(s).

For the procedure in locating and plugging leaking condenser tubes, refer to either the manufacturer's technical manual for the specific equipment or the Bureau of Ships Technical Manual.

Cooling Water to Auxiliaries Fails

If the cooling water to the auxiliaries fails, proceed as follows:

1. Take cooling water from the firemain or (a) cross-connect cooling main, (b) start pump(s) as necessary.

2. A portable gas-driven pump and hose may be used if other means fail.

FEED WATER SYSTEM

In this section, discussion of feed water system casualties is limited to the procedure to follow when suction is being taken from an empty feed bottom and the deaerating feed tank.

Casualty to Deaerating Feed Tank (DFT) Split-Plant

In the event of a casualty to a deaerating feed tank when steaming split-plant with all deaerating feed tanks in use, the following action should be taken:

1. Open to the unaffected plant the cross-over valves in the condensate system, the main-feed system, the auxiliary exhaust steam line, the high pressure drains, and the fuel-oil heater drains.
2. Secure the boiler.
3. Secure the main-feed pump(s) and the booster pump(s).
4. Secure the exhaust steam to the damaged DFT.
5. Secure the high pressure drains to the damaged DFT.
6. Secure the fuel oil heater drains to the damaged DFT.
7. Secure the condensate discharge valve to the damaged DFT.
8. Secure the recirculating system and all the vent valves on the damaged DFT.

Casualty to Deaerating Feed Tank (Cross-Connected Plant)

If a casualty to the DFT occurs when the ship is steaming with a cross-connected plant and has one deaerating feed tank in use, the following action should be taken:

1. Start the main-feed booster pump and then the booster pump(s) in the opposite engine room.
2. Secure the main-feed pump(s), and the main-feed booster pumps in the engine room having the casualty to the DFT.
3. Secure the condensate discharge to the damaged DFT, and discharge it into the opposite DFT.
4. Secure the exhaust steam to the damaged DFT and route it to the opposite DFT.

5. Secure the high pressure drains to the damaged DFT, and route them to the opposite DFT.
6. Secure the fuel-oil heater drains to the damaged DFT, and route them to the opposite DFT.
7. Secure all the vent valves and the recirculating valves on the damaged DFT.
8. Open the vent on the DFT being placed in service, and shift make-up feed to the opposite engine room.

Deaerating Feed Tank Water Level Drops During Steady Steaming

If the deaerating feed tank water level drops during steady steaming, ACTION to be taken is as follows:

1. Check operation of main condensate pump.
2. Check recirculating valves on main condensate line. (Close valves if they are open.)
3. Check water level in main condenser and start standby main condensate pump if water level is too high.
CAUTION: This is to be done gradually, keeping close watch on auxiliary exhaust pressure.
4. Check other engine room(s) for excess feed water conditions.
5. If all these conditions are normal, take on make-up feed.

Deaerating Feed Tank Too Full

If the deaerating feed tank is too full, the ACTION to be taken is as follows:

1. Check feed booster pump operation.
2. Check make-up feed valve, ensure it is closed.
3. Open excess feed valve, deaerating feed tank to feed bottom, or if other engine room can take the excess feed, open condensate crossover and secure condensate to deaerating feed tank.

Empty Feed Bottom in Use for Make-Up Feed

The following actions should be taken with an empty feed bottom in use for make-up feed.

1. Shift to another reserve feed bottom for make-up feed.

2. Refill the empty feed bottom by one of the following methods:
 - a. Distill to the empty feed tank.
 - b. Use the emergency feed pump to transfer feed water from the opposite feed tank to the empty feed tank.
 - c. Open the excess feed valve or the DFT run-down valve to the empty feed tank.

LUBRICATING SYSTEM

It must be impressed on all operating personnel concerned with the ship's lubrication system that even a momentary loss of flow of lubricating oil will result in localized overheating and probable slight wiping of one or more bearings. Such wiping may result in only a momentary rise in the temperature of the lubricating oil discharge from the bearing(s). Damage can be prevented or minimized by stopping the shaft rotation and quickly restoring the lubricating oil flow. Continued operation with wiped bearings will cause serious derangement to the shaft packings, oil seals, and blading.

Loss of or Low Lube Oil Pressure

Operating personnel must thoroughly understand the precautions and the procedures to prevent low lubricating oil pressure.

The loss of lubricating oil pressure may be caused by: (1) The failure of the system itself, including the main lubricating oil pumps; or (2) the failure of steam or electrical power supply to the main lubricating oil pumps.

Component parts of the lube oil system may fail because of the presence in these parts of dirt, rags, or other foreign matter. Failure of the system may be caused by a piping failure, by a failure of the operating pump, or by failure of the standby pump to start. Standby pumps should be maintained ready to start the moment the pressure drops below the prescribed operating range. If automatic-starting devices are not available on steam-driven pumps, the pumps must be lined up so that opening the throttle is the only action required to start the pumps. Steam supply lines to standby pumps should be drained continuously. Where electrical pumps are installed, personnel must be thoroughly familiar with alternate sources of power.

The general procedure to be followed when lube oil pressure is lost is as follows:

1. Close the ahead throttle.
2. Open the astern throttle until the shaft stops.
 - a. Simultaneously with steps 1 and 2, attempt to regain lube oil pressure.
 - b. Slow the ship's speed to 1/2 power or less, if ship has more than one screw.
3. When the shaft is completely stopped, engage the jacking gear and apply the brake. Secure gland sealing steam and main air ejectors.
4. Close the astern throttle slowly. If ship has two or more screws, speed may now be increased to the limit for locked shaft operation.
5. Every effort should be made to regain lube oil pressure.
 - a. Check the lube oil pump in use. (If motor-driven, check normal and alternate power supplies; if turbine-driven, check the throttle valve and constant pressure governor.)
 - b. Shift and inspect the duplex strainers, check for flakes of babbitt and other metal.
 - c. Any oil leaks should be found and repaired. If there is an oil leak, bilges should be flushed and pumped.
6. If, during split-plant operation, a lube oil casualty is due to a loss of steam pressure, take WAY off the ship by backing the other engine(s). If cross-connecting will not cause a loss of steam to the other plant, open the main steam and auxiliary steam cross-connecting valves. If cross-connecting would affect the other plant, isolate the damage and then cross-connect the main and auxiliary steam systems.
7. Inspect all bearings to see if any have overheated.
8. Start the purifier if it is not in use.

Following a machinery derangement caused by the failure of the lubricating oil supply, a thorough examination of the main reduction-gear bearings may be impracticable; however, the following information should be considered when such a casualty is being investigated:

1. The oil-strainer basket in use should be examined for the presence of babbitt flakes.
2. All turbine and cruising reduction-gear bearings should be thoroughly inspected. (In the event of loss of oil pressure, the cruising reduction-gear bearings are the first to be damaged.)
3. The main reduction-gear bearings can be divided into three groups, in accordance with the rotational speed of the journals and the probability of the bearings becoming wiped. The rotational speed of the two high-speed pinions is the same as that of the respective turbine rotors. The speed of the bull-gear shaft is the same as that of the propeller shaft. The speed of the four intermediate-speed gear and pinion assemblies is approximately one-half the speed of the low pressure turbine rotor.
4. The high-speed pinion and the intermediate-speed pinion bearings of the main reduction gear should be examined, through the inspection openings, for possible flow of babbitt from the bearings.
5. Check for oil flow through the reduction gear bearing sight flow indicators. An absence of flow or a reduced flow through a sight flow indicator indicates that the bearing has been wiped to the extent that the oil passage is blocked or partially blocked. When such a condition exists, a below normal reading may be shown on the thermometer.
6. If the turbine bearings are found to be in good condition, it can be assumed that the main reduction-gear bearings are also in good condition.
7. If a partial examination of the main reduction-gear bearings shows no indication of wiping and only one of the turbine and cruising gear bearings is found to be wiped, the shaft may be operated at the minimum speed which the tactical situation will permit until such time as a thorough examination of the main reduction-gear bearings can be made by a repair activity.
8. If several of the bearings for the high-pressure turbine, and especially those for the low-pressure turbine, are found to be wiped, it is likely that the high-speed pinion bearings for the main reduction gear are also wiped. In this case, the

shaft should not be operated until the high-speed pinion bearings have been thoroughly examined. If these bearings are wiped, the intermediate-speed gear and pinion bearing should be inspected. Whenever possible, these inspections and repairs should be made at a naval shipyard.

The preceding procedure applies when the lubricating oil pressure of the entire system is lost. However, if it is noted that a turbine bearing is overheated because of a local loss of oil or because of the presence of foreign matter, and it becomes necessary to shut down the turbine, it should be slowed down, and kept operating at a slow speed, until the bearing and journal have cooled to a safe temperature. If the shaft is stopped quickly, the bearing metal may freeze to the shaft and thereby make repairs much more difficult.

Cooler Tube Carries Away

When a tube of the lubricating oil cooler carries away, the action to be taken is as follows:

1. If it is permissible to reduce the speed of the ship, bypass the cooler; and strike down oil from the storage tank to the sump to restore the working level.
2. If it is not permissible to reduce the speed of the ship sufficiently, or if the oil leak is not serious and there is an adequate supply of oil on board, increase the lubricating oil pressure so that oil will leak into the waterside of the cooler; and pump make-up oil into the sump tank. The cooler can be bypassed, and the water level in the pump, and the condition of the resulting emulsion should be checked immediately prior to making a decision to leave the turbine running.

Lubricating Oil Leak Into Engine Room

When lubricating oil leaks into the engine room, the action to be taken is as follows:

1. If permissible, stop the engine.
2. If it is not permissible to secure the engine, plug or patch the leak so as to stop oil loss and prevent the creation of a fire hazard.
3. Inspect the oil level in the sump; strike down purified make-up oil as necessary.

High Oil Level in Reduction Gear Sump

If a casualty of this type occurs, the action to be taken is as follows:

1. Obtain permission from the OOD to slow the engine.
2. Pump down the sump tank to the proper level.
3. Determine the source of trouble and correct it.

Excessive Oil Pump Discharge Pressure

If the discharge pressure of the oil pump becomes excessive, the action to be taken is as follows:

1. Inspect the constant-pressure pump governor for proper operation.
2. Inspect the strainer and all parts of the lubricating oil system for restrictions of oil flow.
3. Check all bearing and reduction gear temperatures. A clogged strainer or a pipeline restriction may greatly reduce the amount of oil being delivered to the lubrication system, thus causing overheating of the bearings and gears.

DIESEL ENGINE CASUALTIES

Because of the complexity of diesel engine installations in the Navy, personnel should be familiar with casualty control procedures. Such information can be obtained from manufacturers' technical manuals, pertinent type commanders instructions and the ship's Engineering Casualty Control Book. Typical diesel engine casualties are discussed in the paragraphs which follow.

Broken Injector Tip

If an injector tip has broken, the following procedure should be used:

1. Cut out the faulty injector.
2. Notify the engineer officer and the bridge of the casualty and request permission to secure the engine for repairs.
3. After permission has been obtained, secure the engine, remove the injector and replace it with a spare, following the procedure as outlined in the appropriate maintenance manual.

4. After repairs are completed, test the engine operation. If it is operating properly, report to the engineer officer and the bridge.

Broken Cylinder Liner

If a cylinder liner has broken, the following procedure should be used:

1. Secure the engine.
2. Report to the engineer officer and the bridge and request permission to proceed with repairs.
3. Remove the head and piston; pull the liner which has broken, and replace it with a spare liner, following the procedure as outlined in the engine maintenance manual.

Main Engine Lube Oil Pressure Fails

If the main engine lube oil pressure has failed, the following procedure should be used:

1. Secure the engine immediately.
2. Notify the engineer officer and the bridge.
3. Check the system thoroughly, including the oil level, piping, filters and strainers, and the lube oil pump.
4. After repairs have been completed, notify the engineer officer and the bridge.

Fresh Water Leakage in a Designated Cylinder

If fresh water has leaked into a cylinder, the following procedure should be used:

1. Notify the engineer officer and the bridge, and request permission to secure the engine.
2. When permission is granted, remove the inspection plate from the cylinder. Inspect the gaskets and seals and the cylinder liner thoroughly.
3. If the trouble is not located, the engine head must be removed and inspection made to locate trouble.
4. Repair as necessary.
5. Test the engine.
6. If the engine tests satisfactorily, report to the engineer officer and the bridge.

Fresh-Water Pump Fails

If the fresh-water pump has failed, the following procedure should be used:

1. Check the pump. Be sure that the pump is not airbound.

2. If the pump is not airbound, report the casualty to the engineer officer and the bridge, and request permission to secure the engine for repairs.

3. When permission is granted, secure the engine, remove the pump and repair or replace with a spare.

4. Test the engine; if it is operating properly, notify the engineer officer and the bridge.

Speed Governor Fails

If the speed governor has failed, the following procedure should be used:

1. Control the engine manually.
2. Notify the engineer officer and the bridge, and request permission to secure the engine for repairs.
3. Check the governor control mechanism.
4. Check the linkage for binding or sticking.
5. Check the lubrication.
6. Make repairs. When they are completed, start the engine and check its operation. If it is operating properly, notify the engineer officer and bridge.

Fuel Oil Pressure Fails

If the fuel oil pressure has failed, the following procedure should be used:

1. Use the hand priming pump to keep the engine operating while inspection is being made to determine the cause of failure.
2. Check the entire fuel system, including strainers, amount of fuel in day tank, fuel lines, pump, and relief valve.
3. Notify the engineer officer and the bridge, when the trouble is located. Request permission to secure for repairs.
4. Test the engine. If it is operating properly, report to the engineer officer and the bridge.

Lube Oil Temperature Rises Above Normal

If the lube oil temperature has risen above normal, the following procedure should be used:

1. Check the lube oil pressure.
2. Check the salt-water pump discharge pressure and the temperature of the cooling water.

3. Check the fresh-water level in the expansion tank.

4. Check the sea suction and overboard valves.

5. Vent the fresh- and salt-water pumps.

6. Check the thermostat control valve to the salt-water and fresh-water heat exchanger, for proper operation.

7. Report any trouble found to the engineer officer and the bridge, and request permission to secure the engine for repairs.

8. After repairs are completed, check the engine and if it is operating properly, report to the engineer officer and the bridge.

Engine Cooling Water Temperature Rises Above the Allowable Limit

If the engine cooling water temperature has risen above the allowable limit, the following procedure should be used:

1. Check the fresh-water level in the expansion tank.

2. Check the salt-water discharge pressure.

3. Check the sea suction and discharge valves.

4. Vent the fresh- and salt-water pumps.

5. Check the temperature regulating valve setting and operation.

6. If at any time conditions warrant securing engine, secure and notify the bridge and the engineer officer.

7. Make repairs, test out the engine, and if it is operating properly, notify the engineer officer and the bridge.

FIREROOM CASUALTIES

There are many fireroom casualties which require a knowledge of preventive measures and corrective measures. Some are major, some are minor; but all can be serious. These casualties, together with related preventive and corrective measures, are discussed in this section. Many of these casualties can lead to other casualties which can be even more serious. Therefore it is necessary to know instantly and accurately what to do for each casualty. Stopping to find out exactly what must be done for each casualty could

mean loss of life, extensive damage to machinery, and even complete failure of the engineering plant.

This section takes up the procedures for handling some of the most common fireroom casualties. The various casualties are discussed separately, but it is important to remember that casualties tend to be cumulative in effect. One thing leads rapidly to another. Loss of fuel oil suction, for example, will require that the burners be secured. When the burners are out, there is a loss of auxiliary steam and electric power; steam-driven or electrically driven auxiliaries cannot be operated. Without auxiliaries, air cannot be supplied to the furnace or feed water to the boiler. Thus any casualty may lead to others even more serious. Prompt action must be taken to control even minor casualties, in order to avoid a sequence of trouble which could lead ultimately to the total failure of the engineering plant.

The discussion of fireroom casualties in this section is intended to provide a general idea of how casualties should be handled. This information should be supplemented by study of the casualty control information given in the Bureau of Ships Technical Manual, chapter 9880 (88), section III, and by study of the casualty control instructions issued by the engineer officer on your own ship.

Most of the casualties discussed in this section are treated in a step-by-step way: first one step is performed, then another, then another, and so forth. In handling actual casualties, however, this step-by-step approach will probably have to be modified. Different circumstances may require a different sequence of steps for control of a casualty. Also, in handling real casualties several steps will have to be performed at the same time. For example, main control must be notified of any casualty to the boilers or to associated equipment. If "Notify main control" is listed as the third step in controlling a particular casualty, does this mean that the main control is not notified until the first two steps have been completed? Not at all. Notifying main control is a step that can usually be taken at the same time other steps are being taken. It is probably helpful to learn the steps for controlling casualties in the order in which they are given; but do not overlook the fact that the steps may have to be performed simultaneously.

Casualties in the Control of Water Level

Casualties in the control of water level include low water, high water, feed pump casualties, loss of feed suction, and low feed pressure.

Low Water Casualty

Low water is one of the most serious of all fireroom casualties. Low water may be caused by failure of the feed pumps, ruptures in the feed discharge line, defective check valves, low water in the feed tank, or other defects.

However, the most frequent cause of low water is inattention on the part of the checkman and the PO in charge of the watch, or the diversion of their attention to other duties. The checkman's sole responsibility is to keep the water in the boiler at a proper level.

Low water is extremely damaging to the boiler and may endanger the lives of fireroom personnel. When the furnace is hot and there is insufficient water to absorb the heat, the heating surfaces are likely to be distorted, the brickwork damaged, and the boiler casing warped by the excessive heat. In addition, serious steam and water leaks may occur as a result of low water.

Disappearance of the water level from the water gage glasses must be treated as a casualty requiring the IMMEDIATE securing of the boiler!

The question of whether the water has gone out of sight in the bottom of the glass or at the top of the glass should not even be considered until the boiler has been secured, since it is impossible to be SURE about the water level when you cannot see it in a gage glass. An empty glass looks almost exactly the same as a full glass, and serious boiler casualties have occurred when fireroom personnel have used blowdown to cure a condition that they mistakenly assumed to be high water.

By careful observation, it is sometimes possible to distinguish between an empty gage glass and a full one by the presence or absence of condensate trickling down the inside of the glass. The presence of condensate indicates, of course, an empty glass—that is, a low water casualty. However, the boiler must be secured whether the water is high or low. After the boiler has been secured, the location of the water level can be determined by using the gage glass cutout valves and drain valves.

If the water level goes below the lowest visible part of the water gage glass, OR IF THE WATER LEVEL DISAPPEARS AND YOU DO NOT KNOW WHETHER IT IS HIGH OR LOW, the following action must be taken IMMEDIATELY:

1. Shut off the oil supply to the boiler and secure the fires at once.
2. Close the feed check valve and the feed stop valve. Remember, never feed water to a boiler in an attempt to restore the water level after the water has disappeared from sight in the lowest visible part of the glass.
3. Notify the engineroom.
4. Close all boiler stops and guarding valves.
5. Cross-connect the plant, if so ordered by main control.
6. Blow through the water gage glasses to determine whether the water level is high or low.
7. When you are SURE that the casualty is low water rather than high water, lift the safety valves by hand and gradually relieve the boiler pressure. CAUTION: Never lift safety valves in the event of a high water casualty!
8. Close the burner registers and, if practicable, secure the forced draft blowers.
9. Allow the boiler to cool slowly.

It should be noted that when the water level falls low enough to uncover portions of the tubes, the heat transfer surface is reduced. As a rule, therefore, the steam pressure will drop. Ordinarily a drop in steam pressure is the result of an increased demand for steam, and the natural tendency is to cut in more burners to fulfill the demand. If the drop in steam pressure is caused by low water, however, increasing the firing rate will result in serious damage to the boiler and possibly in injury to fireroom personnel. THE POSSIBILITY THAT A DROP IN STEAM PRESSURE INDICATES LOW WATER MUST ALWAYS BE KEPT IN MIND! ALWAYS CHECK THE LEVEL IN THE WATER GAGE GLASSES BEFORE CUTTING IN ADDITIONAL BURNERS, WHEN STEAM PRESSURE HAS DROPPED FOR NO APPARENT REASON.

High Water Casualty

If the water level goes above the highest visible part of the water gage glass, the following action must be taken IMMEDIATELY:

1. Check the feed check valve and the feed stop valve.

2. Shut off the oil supply to the boiler and secure the fires at once.
3. Stop the forced draft blowers.
4. Close all boiler stops and guarding valves.
5. Notify the engineroom.
6. Open the cross-connection valves, if so ordered by main control.
7. Blow through the water gage glasses to be sure that the casualty is actually high water rather than low water.
8. When you are sure that the casualty is high water rather than low water, use the surface blow valve to blow the boiler down until the water is at steaming level.
9. Light off the boiler and cut it in on the line again, when so ordered by main control.

Feed Pump Casualties

Failure of a feed system pump can have drastic consequences. Unless the pump casualty is corrected immediately, the pump failure will lead to low water in the boiler. In addition to the obvious dangers associated with low water, there are some which are equally serious but not so obvious. For example, low water causes complete or partial loss of steam pressure. When steam pressure is lost or greatly reduced, you will lose the services of vital auxiliary machinery—pumps, blowers, and so forth. It is essential, therefore, that feed pump casualties be handled rapidly and correctly.

FEED BOOSTER PUMP FAILURE.—In many installations, the feed booster pump and the main feed pump are in the engineroom. In other installations, the feed booster pump is in the engineroom but the main feed pump is in the fireroom. In this latter type of installation, failure of the feed booster pump will be indicated to the fireroom force by loss of main feed pump discharge pressure and by the sounding of the low pressure feed alarm that is usually fitted where this type of machinery arrangement exists. The casualty to the feed booster pump will be dealt with by engineroom personnel, if the pump is in the engineroom; but fireroom personnel must take the following steps to maintain a supply of feed water to the boiler:

1. Ring for more feed, or otherwise notify the engineroom that additional booster pressure or more feed pressure is required.

2. If the engineroom is unable to remedy the situation immediately, start the emergency feed pump on COLD SUCTION. The emergency feed pump can take a HOT SUCTION from the feed booster pump, or a COLD SUCTION from the reserve feed tanks. In standby condition, this pump should always be lined up on COLD SUCTION.

3. If so ordered by main control, cross-connect the feed system in your own space and take feed from this source.

4. Keep the engineroom informed of the source of feed so that the ship's speed can be held within the limits of boiler capacity.

5. If unable to maintain the proper water level in the boiler, secure the boiler in order to prevent a low water casualty.

MAIN FEED PUMP FAILURE.—Some of the most likely causes of failure of the main feed pump are (1) malfunction of the constant-pressure pump governor, (2) airbound or vapor-bound condition of the main feed pump, (3) faulty pump clearances, and (4) malfunction or improper setting of the speed-limiting governor.

Failure of the main feed pump calls for the following action:

1. Start the standby main feed pump.
2. If no standby pump is available, start the emergency feed pump. If the feed booster pump is working, line up the emergency feed pump to hot suction and continue feeding the boiler.

EMERGENCY FEED PUMP FAILURE.—The procedure for handling failure of the emergency feed pump will vary according to the situation existing at the time the pump fails.

In many ships, the emergency feed pump is normally used for in-port operation, with the main feed pump in standby condition and the feed booster pump providing a hot suction for the emergency feed pump. Under these conditions, emergency feed pump failure can be handled by notifying the engineroom so that the main feed pump can be put on the line and used to feed the boiler.

A more difficult problem will arise if the emergency feed pump fails when it is being used because of a previous casualty to the feed booster pump or to the main feed pump. Under these conditions, it may be possible to deal with the situation by cross-connecting and using a pump in some other space to supply feed to the

boiler. If the operating conditions do not allow this solution of the problem, it will be necessary to secure the boiler immediately in order to prevent a low water casualty.

If the emergency feed pump loses suction, as indicated by a jerky, irregular motion, check to be sure that the suction line is free of obstructions and that all stop and check valves are open. When the emergency feed pump is taking a hot suction, the pump may become vapor-bound and lose suction. To correct this condition, shift to cold suction and open the vents on the water-end valve chest. Cooling can be expedited by directing a stream of salt water around the pump barrel, being careful not to splash it into the pump gland. Continue to cool the pump until a steady flow of water emerges from the vents. Continue using cold suction until the head pressure is restored. If a standby pump is available, shift to the standby while cooling off the first pump.

Loss of Feed Suction

If feed suction is lost, the following action should be taken:

1. Ring for more feed or notify the engine-room that more feed pressure is needed.
2. Start the emergency feed pump on cold suction.
3. If so ordered by main control, cross-connect the main feed system in your own space and continue feeding the boiler from this source.
4. If the water level cannot be maintained, secure the boiler to prevent a low water casualty.
5. Keep the engine-room informed of the source of feed so that the ship's speed can be held within the limits of boiler capacity.

Low Feed Pressure

If the main feed pump discharge pressure is too low, the first three things to be checked are (1) the feed booster pump discharge pressure, (2) the level and pressure in the deaerating feed tank, and (3) the feed stop and check valves on idle boilers. A failure of the feed booster pump will, of course, cause loss of suction and, therefore, loss of discharge pressure of the main feed pump. If the feed stop and check valves on idle boilers have accidentally been left open, the main feed pump discharge pressure may be low merely because water has

been pumped to an idle boiler, as well as to the steaming boiler.

When feed pressure is low, the following action should be taken:

1. Ring for more feed or notify the engine-room that more feed pressure is needed.
2. Start the emergency feed pump and use it to increase the feed pressure to the boiler.
3. Check the discharge pressure of the main feed pumps and booster pumps, the water level in the deaerating feed tank, the pressure of the deaerating feed tank, the auxiliary exhaust pressure, the feed check valves on idle boilers, and the operation of the constant-pressure pump governor on the feed pump.
4. If the cause of the low feed pressure can be determined, notify the engine-room. Cross-connect the main feed system if so ordered.
5. If the water level cannot be maintained, secure the boiler to prevent a low water casualty.
6. Keep the engine-room informed of the source of feed so that the ship's speed can be held within the limits of boiler capacity.

FUEL OIL SYSTEM CASUALTIES

Casualties to any part of the fuel oil system are serious and must be remedied at once. Common casualties include (1) oil in the fuel oil heater drains, (2) water in the fuel oil, (3) loss of fuel oil suction, (4) failure of the fuel oil service pump, and (5) fuel oil leaks.

Oil in the Heater Drains

Oil leakage from the fuel oil heaters into the drains may cause oil contamination of the drain lines, the reserve feed tanks, the deaerating feed tank, and the feed system piping and pumps. The presence of oil in any part of the feed system is dangerous because of the possibility that the oil will eventually reach the boilers, where it will cause steaming difficulties and serious damage to the boilers.

Fuel oil heater drains must be inspected hourly for the presence of oil. If oil is found in the drains, the following action must be taken immediately:

1. Shift the drains to the bilges.
2. Notify the engine-room.
3. If more than one heater is in use at the time of the casualty, locate the defective unit

and secure it immediately. If no other heater is already in use, cut in another heater before securing the one which is leaking.

4. After the drains have become free of oil, shift the drains back to the drainage system.

Water in the Fuel Oil

The presence of an appreciable amount of water in the fuel oil is indicated by hissing and sputtering of the fires and atomizers and by racing of the fuel oil service pump. The situation must be remedied at once; otherwise, choked atomizers, loss of fires, flarebacks, and refractory damage may result. The following steps must be taken immediately:

1. Shift suction to another tank.
2. Discharge the contaminated oil, using the recirculating line, to the contaminated oil tank; or discharge it overboard until the oil becomes free of water.
3. Observe the fires carefully. If they go out, secure the burners at once. If the burners have already been secured, drain the oil from the system between the burner manifold and the atomizers. Watch the oil as the system is being drained, so that you can tell when the oil becomes free of water.
4. Purge the furnace by blowing through it with air before lighting off again.

Loss of Fuel Oil Suction

A loss of fuel oil suction usually indicates that the oil in the service suction tank has dropped below the level of the fuel oil service pump suction line. This causes a mixture of air and oil to be pumped to the atomizers. The atomizers begin to hiss and the fuel oil service pump begins to race. Loss of fuel oil suction must be remedied immediately by the following action:

1. Secure all burners. Leave at least one register open to expel all gases of combustion and to burn up any oil that may have accumulated on the furnace deck. On double-furnace boilers leave at least one register open on the saturated side and at least one open on the superheater side. Leave the blowers running to provide an air pressure of approximately 2 inches of water between the air casings.
2. Start the standby fuel oil pump, making

sure that it is lined up on the standby service suction tank.

3. Notify the engineroom as soon as possible.
4. Open the cross-connecting valves if ordered to do so by main control.
5. After all oil has been burned from the furnace floors, slow down the forced draft blowers and close the registers.
6. Check the fuel oil service system for water or air. Take necessary action to rid the system of water or air if they are present.
7. Check the fuel oil service pump to see if it is airbound. If it is airbound, it will be very noisy and erratic in operation. In this event the pump must be vented and then be primed by lining up the fuel oil booster and transfer pump discharge to the service pump suction.
8. After fuel oil suction has been regained, notify the engineroom, light off again, and put the boiler back on the line.

If only one boiler is in use when fuel oil suction is lost, the preceding procedure must be modified as follows:

1. Do not leave the forced draft blowers running after the burners have been secured.
2. If fuel oil suction has not been regained by the time the steam pressure has dropped to 85% of operating pressure, secure all boiler stops and guarding valves.
3. After suction has been regained, purge the furnace with air and light off again, using only one atomizer.

It must be strongly emphasized that the loss of fuel oil suction can cause serious results. Related casualties may include loss of auxiliary steam and electric power, with the complete loss of all electrically driven and steam-driven machinery.

Failure of Fuel Oil Service Pump

Failure of the fuel oil service pump can cause the same progressive series of casualties as those which result from loss of fuel oil suction. If the fuel oil service pump fails, the following action should be taken:

1. Cut in the standby fuel oil service pump, making sure that it is lined up to take suction from the reserve or standby service suction

tank. Make every effort to maintain fuel oil pressure until the difficulty can be located and remedied.

2. Notify the engineroom what action is taken so the ship's speed can be held within the capacity of the engineering plant.

3. Open all cross-connection valves, if so ordered by main control.

4. Secure the boiler and all stop valves if fuel oil service cannot be reestablished by any fuel oil pump.

Major Fuel Oil Leaks

Fuel oil leaks are very serious, no matter how small they may be. Fuel oil vapors are very explosive. Any oil spillage or leakage must be wiped up immediately. If a leak occurs on the suction side of the fuel oil service pump, the following action should be taken:

1. Secure the fuel oil service pump and notify the engineroom of the casualty.

2. Secure the boiler or boilers affected by the casualty.

3. Get firefighting equipment to the scene and wipe up all oil. Flush the bilges if necessary.

4. Line up and use a different section of suction line.

If a leak occurs on the discharge side of the fuel oil service pump, the following action should be taken:

1. Secure the fuel oil service pump.

2. Close the pump discharge valve and the quick-closing cutout valve.

3. Notify the engineroom of the casualty.

4. Secure the boiler or boilers affected by the casualty.

5. Get firefighting equipment to the scene and wipe up all spilled oil. NOTE: If a service tank has been ruptured, shift to the standby tank.

FORCED DRAFT BLOWER FAILURE

If a forced draft blower fails, take the following action:

1. If one blower fails when two blowers are in use, speed up the other blower.

2. If only one blower is in use, secure the burners immediately to prevent a flareback.

3. Start the standby blower and notify the

engineroom of the casualty because of a possible need for a reduction in speed.

4. Determine the cause of the failure and remedy the trouble as soon as possible.

The rupture of a forced draft blower lube oil line is a casualty in itself, as well as one which can lead to blower failure. The rupture of a lube oil line is discussed here separately because of the special hazard of fire that is involved. If a forced draft blower lube oil line is ruptured, take the following action immediately.

1. If two blowers are in use, secure the affected blower and speed up the other. If only one blower is in use, secure the burners immediately to prevent a flareback. Secure the affected blower and light off the standby blower.

2. Notify the engineroom because of a possible need for a reduction in speed.

3. Get firefighting equipment to the scene.

4. Wipe up all oil that has spilled out. Flush out and wipe out the bilges as necessary.

5. Repair or renew the ruptured section as soon as possible.

6. Refill the reservoir with clean oil. Test the new section; if it is satisfactory, the blower can be returned to service.

FLAREBACKS

A flareback is likely to occur whenever the pressure in the furnace momentarily exceeds the pressure in the boiler air casing. Flarebacks are caused by an inadequate air supply for the amount of oil being supplied, or by a delay in lighting the mixture of air and oil.

Situations which commonly lead to flarebacks include: (1) attempting to light off or to relight burners from hot brickwork; (2) gunfire or bombing which creates a partial vacuum at the blower intake, thus reducing the air pressure supplied by the blowers; (3) forced draft blower failure; (4) accumulation of unburned fuel oil or combustible gases in furnaces, tube banks, uptakes, or air casings; and (5) any event which first extinguishes the burners and then allows unburned fuel oil to spray out into the hot furnace. An example of this last situation might be a temporary interruption of the fuel supply which would cause the burners to go out; when the fuel oil supply returns to normal, the heat of the furnace might not be sufficient to relight the burners immediately.

In a few seconds, however, the fuel oil sprayed into the furnace would be vaporized, and a flareback or even an explosion might result.

To reduce the danger of flarebacks, THE FOLLOWING PRECAUTIONS MUST BE OBSERVED:

1. Oil must not be allowed to accumulate in the furnace. The furnace must be blown through with air before lighting off the atomizers. The atomizer valves on secured burners must be kept tight at all times to prevent leakage of oil into the furnace. If a large amount of oil accumulates in the furnace, it may be necessary to open up the boiler and clean up the oil before lighting off the boiler.

2. Whenever atomizers are accidentally extinguished, shut off the oil and blow through the furnace with air before relighting the atomizers.

3. NEVER ATTEMPT TO RELIGHT AN ATOMIZER FROM A HOT BRICK WALL. USE A TORCH.

4. The man handling the torch must stand well clear to avoid injury in case a flareback occurs.

The following action should be taken for a major flareback which involves possible boiler damage or extinguishment of furnace fires.

1. Close the quick-closing master fuel oil valve to the burner manifold and the burner supply valves, and notify the engineroom.

2. Use firefighting equipment as necessary.

3. Secure the boiler main steam stop.

4. Adjust the feed stop and check valves, or stop the feed pumps, as necessary to prevent high water.

5. Speed up the forced draft blowers to purge the furnace of unburned gases and to burn any oil accumulations from the furnace floor.

6. Open the auxiliary steam cross-connection valves if necessary to maintain auxiliary steam service, and secure the auxiliary steam stop.

7. Inspect the boiler and light off, using normal procedure if conditions permit.

Minor flarebacks, or those which do not involve furnace fires being extinguished, do not necessarily require carrying out the previous procedure. However, inspect the boiler carefully for signs of damage, particularly to the refractories.

SUPERHEATER CASUALTIES

If the distant-reading superheater thermometer does not register a normal increase in temperature when the superheater is first lighted off, the trouble may be either lack of steam flow or failure of the distant-reading thermometer. Lack of steam flow must be considered as a possible cause even if the superheater steam flow indicator (if installed) shows that there is a flow. If the thermometer does not register a normal increase in temperature, the following steps should be taken:

1. Secure all superheater burners.

2. Make certain that the superheater steam flow indicator is properly cut in.

3. Check the distant-reading thermometer against the direct-reading superheater thermometer. If the two thermometers have previously been working properly, and if they now agree, the chances are overwhelmingly against the trouble being in the distant-reading thermometer.

4. To find out if there is a flow of steam through the superheater, lift the superheater safety valves by hand for a SHORT blow. This will establish a positive steam flow past the thermometers. Then recheck the thermometers. If they still agree, but at a different temperature, there is no flow through the superheater.

When operating with superheat, it is essential to keep a constant check on the flow of steam through the superheater and on the superheater outlet temperature. Any deviation from normal conditions must be corrected without delay.

It is important to remember that a casualty to some other part of the engineering plant may reduce or entirely stop the flow of steam through the superheater, and so cause a superheater casualty, unless appropriate action is taken to prevent damage. For example, a casualty to the main engines might call for a sudden large reduction or even a complete stoppage of steam flow. Even if the superheater burners are secured, there will still be a need for steam flow to protect the superheater from the heat of the furnace. In this event, or whenever a greater flow is required than can be obtained by ordinary means, LIFT THE SUPERHEATER SAFETY VALVES BY HAND TO ENSURE A POSITIVE FLOW OF STEAM THROUGH THE SUPERHEATER.

When the superheater thermal alarm sounds, the superheater fires must be immediately decreased to bring the temperature below alarm temperature. Do NOT decrease the temperature further than necessary. It is very seldom necessary to secure all superheater burners in order to bring the temperature down to the prescribed point.

CASUALTIES TO REFRACTORIES

If brick or plastic falls out of the furnace walls and goes unnoticed, burned casings may result. If brick or plastic falls out of a furnace wall, the following action should be taken:

1. If practicable, secure all the burners. If it is not practicable to secure all the burners, secure those burners which are adjacent to the damaged section. NOTE: It may be necessary to continue operating the boiler until another boiler can be brought in on the line.
2. Notify the engineroom and cross-connect the plant if so ordered by main control.

CASUALTIES TO BOILER PRESSURE PARTS

When boiler pressure parts, such as tubes, carry away or rupture, escaping steam may cause serious injury to personnel and damage to the boiler. It is urgent that the boiler be relieved of its pressure and cooled until no more steam is generated. If a boiler pressure part carries away or ruptures, take the following steps immediately upon discovery of the casualty, to minimize and localize the damage as much as circumstances will allow.

1. Shut off the oil supply to the boiler.
2. Speed up the forced draft blowers to drive escaping steam up the stack and keep it from entering the fireroom.
3. While the first two steps are being taken, the following steps should be taken simultaneously:
 - (a) Close all boiler steam stop valves (main, turbogenerator, and auxiliary).
 - (b) Notify the engineroom and cross-connect the plant if so ordered by main control.
4. Gradually lift the safety valves by hand to relieve the pressure.
5. Close the burner registers.

6. Continue to feed the boiler until it has cooled. Remember that a damaged pressure part can lose water at a very rapid rate. If other operating boilers are being fed from the same main feed system as the damaged boiler, take special precautions to see that the undamaged boilers do not suffer low water casualties because of loss of main feed. Start the emergency feed pump and feed the damaged boiler from a reserve feed tank. Any water lost because of the damaged pressure part will thus be lost from the reserve feed tank rather than from the main feed system.

7. After the pressure has been reduced, stop the blowers and close up all possible sources of air entry into the boiler. Allow the boiler to cool off slowly.

Casualties to Water Gage Glasses

Gage glasses are connected to the water and steam spaces of the steam drum. If a water gage glass carries away, the mixture of steam and water escaping from the gage connections may seriously burn personnel in the area. A ball check valve in the high pressure gage line functions when the flow is excessive. In addition, the hazard of flying particles of glass makes this casualty very serious. The particles of glass could lodge in your eyes and blind you, or they could lodge elsewhere in your body and cause serious injury. If a gage glass casualty occurs, throw a large sheet of asbestos cloth, rubber matting, or similar material over the glass. Then take the following action:

1. Close the top cutout valve.
2. Open the drain valve.
3. Close the bottom cutout valve.
4. Replace the glass. Slowly crack open the bottom cutout valve and allow the new glass to warm up slowly. Open the top cutout valve and close the drain valve. If there is no leakage, and if the new glass shows the same water level as the other glass on the boiler, the water gage can be considered back in service.

OIL FIRES

An oil fire may be caused by the ignition of oil or oil vapor in any place where oil is allowed to collect. Oil may accumulate in the double casings from partially plugged atomizers, from continued drip when atomizers are secured and not removed from the burners, or from allowing

manifold pressures to drop excessively. Frequent observations through burner and furnace sight glasses and the correct settings of atomizers and register doors are helpful in preventing oil accumulations.

Precautions

The following precautions must be taken to prevent fires:

1. Do not allow oil to accumulate in any place. Particular care must be taken to guard against oil accumulation in drip pans under pumps, in bilges, in the furnaces, on the floor plates, and in the bottom of air-encased boilers. Should leakage from the oil system to the fireroom occur at any time, immediate action should be taken to shut off the oil supply by means of quick-closing valves and to stop the oil pump.

2. Absolutely tight joints in all oil lines are essential to safety. Immediate steps must be taken to stop leaks whenever they are discovered. Flange safety shields should be installed on all flanges in fuel oil service lines to prevent spraying oil on adjacent hot surfaces.

3. No lights should be permitted in the fireroom except electric lights (fitted with steam-tight globes, or lenses, and wire guards), and permanently fitted smoke indicator and water gage lights. If work is being done in the vicinity of flammable vapors, or if rust-preventive compound or metal-conditioning compound is being used, all portable lights should be of the explosion proof type.

Firefighting Equipment

The fireroom force must be thoroughly drilled to handle an oil fire promptly and efficiently, as it is but a matter of minutes before an oil fire assumes serious proportions. Standard firefighting equipment should always be available and ready for use in all fire-rooms. In most shipboard installations, permanently fitted steam smothering lines are provided in the fireroom bilges and inside the casings beneath the boilers. These lines should be examined and tested by steam at least monthly, to ensure satisfactory operating condition. Particular attention should be given to the condition of the line in casings beneath the boiler, because of its importance in the event of a casing fire.

Firefighting Procedures

In the event of a MAJOR FIRE IN THE FIREROOM which prevents boiler operation, the following action must be taken:

1. Shut off the fuel oil supply and stop all fuel oil pumps.

2. Secure the burners and close the registers.

3. Close the main and auxiliary steam stops and the feed stop when the fireroom is abandoned.

4. Stop the forced draft blowers.

5. Secure the ventilation supply and exhaust fans EXCEPT when it is necessary to leave them in operation in order to provide a means of escape for fireroom personnel. The decision as to whether or not to secure the fans must be made by the firefighting personnel.

6. Use the fire-extinguishing equipment provided.

7. Notify the engineroom, and open cross-connection valves if so ordered by main control.

For an OIL FIRE IN THE BILGES, the following action should be taken:

1. Shut off the fuel oil supply to the burners.

2. Stop the fuel oil pumps.

3. Use the fire-extinguishing equipment provided. However, use the steam smothering system ONLY if the fire cannot be controlled by other means. All personnel must be out of the fireroom and all hatches, ventilators, and other openings must be closed before the steam smothering system is used.

For an OIL FIRE IN THE DOUBLE CASINGS, the following action should be taken:

1. Shut off the fuel oil supply to the burners, and stop the fuel oil pumps.

2. Stop the forced draft blowers.

3. Use the casing steam smothering system to extinguish the fire. NOTE: The steam smothering system may be used in the casings without danger to fireroom personnel.

BATTLE CASUALTIES

A thorough knowledge of the ship's engineering plant, its piping systems, and related equipment, and of the correct casualty procedures could be the difference between effective and ineffective action to control battle casualties.

The major battle damage casualties discussed in this section involve the securing and isolation of spaces in which extreme damage has occurred. The control of casualties caused in other spaces by battle damage is not included in this section. The corrective procedures in many cases are almost the same. Therefore, it is recommended that when battle problems are made up, various individual casualties previously mentioned should be included to simulate less than total damage to a particular space.

ENGINE ROOM AND FIRE ROOM CASUALTIES FROM SHELL OR TORPEDO HITS

Shell or torpedo hits in vital engineering spaces usually result in multiple casualties to machinery and systems. The corrective action for any particular situation depends on the location and extent of the damage. While battle casualties differ in some respects, the following procedures apply to any casualty of this type:

1. Secure space or isolate damaged sections of systems as necessary.
2. Cross-connect systems or plants when feasible.
3. Stop the turbine and lock the shaft in event of serious casualty to turbine, reduction gear, or main steam line, or in event of loss of lubricating oil pressure.
4. Carry out applicable casualty control procedures in the event of turbine, reduction gear, propeller, propeller shaft, or turbogenerator damage.
5. DO EVERYTHING POSSIBLE TO PREVENT FLOODING OF SPACE. Put all available pumps on bilges of damaged space; plug holes and establish flooding boundaries to prevent progressive flooding.
6. Repair damaged lubricating oil lines and water lines with soft patches, blank flanges, wooden plugs, or other suitable means.
7. Secure main and auxiliary steam lines and auxiliary exhaust lines into space by remote controls if escaping steam prevents entry of repair party personnel into space.
8. Extinguish all fires and investigate damage.
9. Make repairs to return machinery or space back into service, if possible.
10. Keep the communication lines open and keep main engine control advised of prevailing conditions.

MAIN ENGINE CASUALTY— NEAR MISS

Stop the turbine and lock the shaft. Make repairs if possible. If lubricating oil lines or sump tank are damaged, apply soft patches; calk seam of sump tank if necessary. Carry out turbine and reduction gear casualty procedures if those units are damaged.

The rupture of main steam piping in any space may fill the space with steam, making it untenable. This will necessitate abandoning the space and securing it from outside. Entry into the space will be possible after the steam leak has been stopped and the space has cooled. After reentry into the space is possible, the damage can be isolated, repairs made, and units returned to operation.

If main steam piping is carried away in a fireroom, close the main boiler stop valves and close the throttle on the affected engine; secure fuel oil to burners by closing the master fuel oil valve or by remote control; isolate all steam lines to the damaged fireroom. As practicable, open cross-connection valves to restore main and auxiliary steam to main engines, turbogenerators, and vital auxiliaries; cross-connect the fresh water drain and condensate systems to return water to the plant supplying steam; restore lubricating oil pressure as soon as possible.

If a main steam line casualty occurs in an engine room and personnel are unable to escape, close main and auxiliary boiler stop valves, shut off fuel oil to burners, and close bulkhead valves to isolate the damaged space.

In event of an engine room not becoming immediately untenable because of a break in main steam piping, the main boiler stops and the main throttle should be closed; the ruptured section of main steam piping should be isolated. The space should continue to receive auxiliary steam for the maintenance of lubricating oil pressure; this is not necessary for ships with shaft-driven or electric lubricating oil pumps.

RUPTURE IN AUXILIARY STEAM PIPING

Battle casualty to a section of auxiliary steam piping may cause the space to become filled with steam and be untenable. If possible, secure the steam from within the space;

but if this is not possible, secure steam from outside the space.

If the auxiliary steam casualty occurs in a fireroom, the engineroom personnel should stop and lock the shaft unless other means are available for maintaining lubricating oil pressure; secure the oil supply to the burners, and secure the main and auxiliary steam supplies to the damaged fireroom.

When auxiliary steam piping casualties occur in an engineroom, stop and lock the shaft; close the boiler stop valves to boiler (s), supplying steam to damaged line; and secure the boiler (s); isolate damaged section of auxiliary steam line; make repairs and attempt to resume operation of space as soon as possible.

RUPTURE IN AUXILIARY EXHAUST PIPING

Patches, blank flanges, and plugs may be used freely in repairing damage to the low-pressure auxiliary exhaust system. In the event of a major break in the system, carry out casualty procedures as described for the auxiliary steam system. When a section of the auxiliary exhaust system is damaged, action must be taken to prevent feed water casualties from occurring. If damaged sections cannot be isolated, use only necessary machinery which exhausts into the damaged section.

RUPTURE IN MAIN FEED PIPING

If damage occurs to main feed piping, secure the main feed pump. Then start the emergency feed pump and feed through the auxiliary feed system; secure the main feed stop and the check valve. When danger of low water in boiler exists, secure the boiler. Isolate sections of damaged piping and restore main feed service, if practicable; use main or emergency feed pumps as appropriate.

RUPTURE IN HIGH PRESSURE DRAIN PIPING

When damage occurs to sections of the high pressure drain system, the first corrective step is to close the bulkhead stops to isolate the damaged sections. If escaping vapor hinders operations in the space, close off the traps and crack open the funnel and bilge drains. To conserve water, crack open drains only at points in the piping where condensate will tend to form.

If a rupture occurs at a deaerating feed tank, the high pressure drain valves at the entrance to the deaerating feed tank should be closed. Whenever the high pressure drainage system cannot be used, drain various units to the low pressure drain system as often as needed. In some instances, all but the vital high pressure drain traps can be cut out and the high pressure drain system can be cross-connected.

RUPTURE IN FUEL OIL HEATER DRAIN PIPING

When battle damage causes a rupture in the fuel oil heater drain piping, isolate the damaged section from the drain system by securing the bulkhead stops. Let the isolated section drain to the bilges. Plug the drain piping and try to prevent excessive loss of water.

ELECTRICAL CASUALTIES

Since electrical casualties affect the normal operation of a ship, it is beneficial to have a general knowledge of electrical equipment installed on board to provide the maximum uninterrupted supply of electrical power and lighting. When all electric power, ventilation, and lights go out, it is too late to ask an Electrician's Mate what can be done to restore power. The Electrician's Mate will be too busy to stop and give any detailed information as to what happened, what can be done to restore electrical services, and how long it will take to get things back to normal conditions. Therefore, it is best to have a general knowledge of the purpose of electric generating plants and their operation under various conditions, and of the types of casualties that will interfere or disrupt the normal operation of an engineering plant.

THE ELECTRIC PLANT

The ship's power and lighting plant comprises the generators, switchboards, power panels, cables, circuit breakers, and other appurtenances necessary for the generation, distribution, and control of power supplies to electrically driven auxiliaries, lighting, interior communication, electronics equipment, and other electrically powered devices. In designing the electric plant, every effort has been made to obtain the greatest reliability and continuity of service practicable under casualty conditions.

The distribution system forms the vital connection between the generators and the equipment which uses electric power. The distribution of electrical power is through the ship's service or the emergency switchboards, and may be through a casualty power circuit rigged from either of these switchboards.

The general arrangement of the ship's service system is such that a faulty circuit will be cut out automatically, without interruption of power supply to other circuits, through the operation of protective devices. If the ship's service generators fail, the emergency generator is automatically placed in operation for battle functions. The emergency switchboard can supply power to the vital circuits of the ship.

Protection against loss of power on a ship with ship's service, emergency, and casualty power distribution systems can be summarized as follows:

1. **FAILURE OF ONE SHIP'S SERVICE GENERATING PLANT.** The load can be transferred, by the Electrician's Mate, to the other ship's service generating plant. Care must be taken to prevent overloading the generating plant that takes over the load.

2. **CIRCUIT OR SWITCHBOARD FAILURE.** Vital loads can be transferred to an alternate feeder and source of ship's service power by means of a manual or automatic bus transfer panel.

3. **FAILURE OF BOTH NORMAL AND ALTERNATE POWER SUPPLY.** In cases of this nature, certain vital equipment can be shifted to an emergency feeder which receives power from the emergency switchboard.

4. **FAILURE OF SHIP'S SERVICE AND EMERGENCY CIRCUITS.** Temporary circuits can be rigged with the casualty power cables from any live switchboard to supply power to vital circuits.

EMERGENCY POWER SYSTEM

The emergency power system is provided to furnish an immediate, automatic source of electric power to a limited number of selected vital circuits. It includes one or more Diesel-driven emergency generators, emergency switchboards, and a distribution system which is separate from the ship's service electric plant and distribution system. Emergency feeders run from the emergency switchboards to at least one and usually to two different ship's

service switchboards. Emergency power feeders for certain vital auxiliaries are also run to control panels. The emergency power system, with the use of transformers, is also used for furnishing emergency lighting.

Whenever practicable, emergency generators and switchboards are installed above the waterline, to minimize danger from flooding. Also, the emergency plant is installed as far away as possible from the ship's service plant, to avoid both plants being put out of action by battle damage.

On most ships, the emergency generators do not have the same capacity as the ship's service plants. Therefore, care must be taken to prevent overloading the emergency generator.

CASUALTY POWER SYSTEM

The scope of this system is limited to the bare minimum of facilities which are required, in the event of damage, to keep the ship afloat and to get it out of a danger area, so that temporary electrical repairs of a more extensive and time-consuming nature can be accomplished. Thus, the application of casualty power is limited to the most vital equipment on board ship. The casualty power system receives its electrical power from the following sources: the ship's service generating plant; the diesel-driven emergency power plant.

Additional information on casualty power systems can be obtained from chapter 9880 (88) of the Bureau of Ships Technical Manual.

EMERGENCY FIRE PUMPS

Most ships have electric-driven fire pumps located outside the engineering spaces. These pumps furnish water under pressure to their own piping system or to the ship's firemain. Provisions are made for different sources of electrical power to these pumps: Normal and alternate supply from the ship's service generators, emergency supply from the diesel-driven emergency generators, and the casualty power system.

Many ships, such as battleships, carriers, tankers, and tugs, have independent diesel-driven fire pumps. In case of damage to the ship's pumps and firemain, these diesel-driven pumps can furnish large amounts of water for fire-fighting purposes. Many of the tugs have

diesel-driven pumps and other facilities installed for fighting fire on other ships, piers, and docks.

LIGHTING SYSTEM

On ships using a-c generators, the ship's service and emergency lighting systems are energized from the generator and distribution switchboards through a bank of transformers. These transformers supply power to the lighting system through the lighting distribution panels.

Lighting throughout the machinery spaces is supplied from the normal switchboard for the compartments involved, with some lights in each space supplied from the alternate switchboard. A few lights in each compartment are supplied through automatic bus transfer equipment from

circuits originating at the emergency switchboards.

In the event of complete failure of the ship's service and emergency lighting systems, automatic type hand lanterns are provided to supply an instantaneous source of illumination. These relay-operated hand lanterns are installed at vital stations. In addition, nonautomatic type hand lanterns are installed at strategic locations. Although the Electrician's Mates have the responsibility for the maintenance of the hand battle lanterns, it is the duty of the petty officer in charge of the space to see that his men do not remove the lanterns or use them for unauthorized purposes. If the Electrician's Mates do not properly maintain the battle lanterns, the petty officer in charge should report the fact to the appropriate Electrician's Mate or take any other action that may be necessary.

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