SECTION 9.11

MARINE PUMPS

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Pumps used in marine shipboard applications, both commercial marine and Navy, can typically be divided into several groups. These groups include pumps associated with a vessel's propulsion, pumps used with the generators that produce electricity, pumps used in ship's service systems, pumps used to provide hotel services for crew and passengers, and pumps that are used in cargo or other specialized systems.

Because marine pumps must operate on a moving platform, they should be designed to withstand dynamic loads resulting from vessel motion (for example, pitch, roll, and so on). In addition, they must often operate in a hot, humid, and potentially corrosive environment. In addition, marine pumps must frequently be suitable to operate with a range of flow rates to accommodate anything from operation of the vessel at full speed to operation in port with the propulsion equipment secured. Furthermore, the minimization of size (especially the required deck space) and weight is always important when designing marine equipment. For this reason, many shipboard pumps are mounted vertically (Figures 1 and 2), and smaller units are frequently furnished in a close-coupled configuration (Figure 3) with the pump's rotating parts mounted directly on the driver's shaft. To enable them to stand freely under pitch and roll conditions, vertically mounted shipboard pumps often have larger bases than comparable shore-side units. Typical materials used in the construction of marine centrifugal pumps are listed in Table 1.

A description of the features typically incorporated into the designs of pumps used in selected shipboard applications follows. This information is general in nature, however, and may not apply in all cases based on the requirements for specific installations or the preferences of vessel owners and designers.

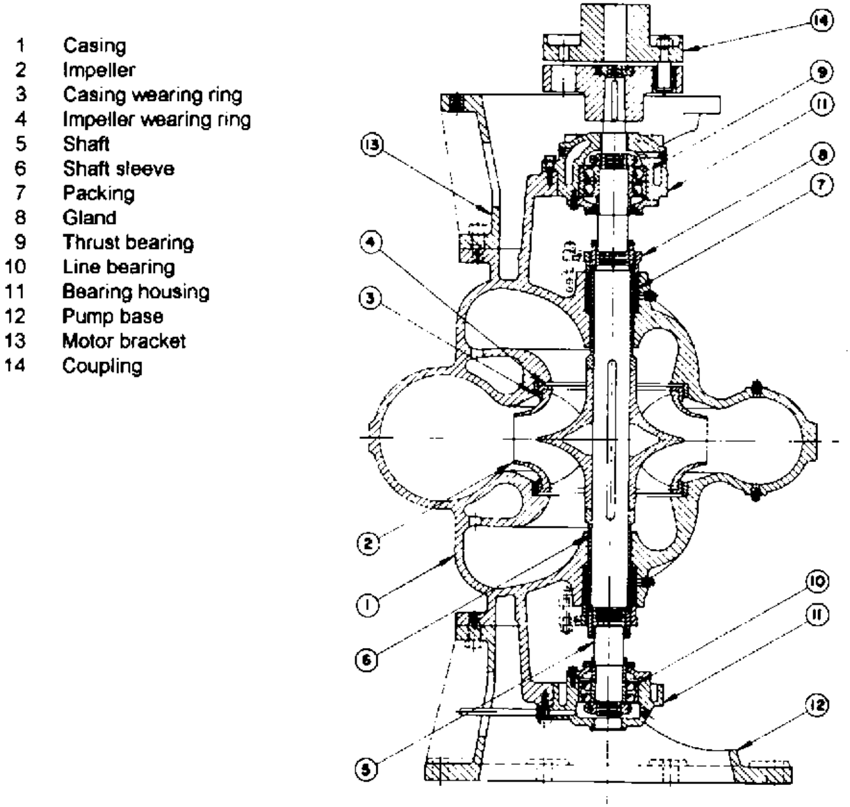

FIGURE 1 Vertical between-bearings centrifugal pump (Flowserve Corporation)

PROPULSION APPLICATIONS

Steam-Turbine-Propelled Vessels

FEED PUMPS A main feed pump is used to return water to a steam-powered vessel's boilers or steam generators. On a typical steam ship with fossil-fueled boilers, a main feed pump takes suction from a deaerating feed tank (DFT) and discharges feedwater to the steam drum in each of the vessel's boilers. In many cases, a main feed pump's discharge is connected to two separate lines that both lead to the boilers: a main feed line and an auxiliary feed line. In addition, the feedwater usually passes through one or more heaters before entering the steam drums. Although a single feed pump is frequently sized to handle a vessel's full-load requirements, some ships have multiple partial-capacity feed pumps that operate in parallel. Additional pumps are ordinarily provided for standby duty.

Typical feed pump configurations include single- and two-stage centrifugal pumps that are close-coupled to steam turbines (Figure 4) and multistage flexibly coupled pumps that are driven by steam turbines or electric motors. Although flexibly coupled feed pumps often have cast axially split volute-type casings (Figure 5), barrel pumps with diffusers and forged cylindrical casings are sometimes used. Turbine-driven feed pumps are usually mounted horizontally. Motor-driven feed pumps, however, have been used in both horizontal and vertical configurations.

7450	Coupling guard
3261	Bearing cover, driver side
3712	Bearing lock nut
4595	Lock washer
3132	Adapter
4542	Bearing-cover gasket
3262	Bearing cover, pump side
4300/2	Lip seal
6573	Gland stud
4120	Gland
4610/2	Inner O-ring
4113	Cooling cap
1222	Stuffing-box cover
4521	Casing gasket
6710	Impeller key
1111	Casing
4510	Impeller-lock-washer gasket
4552	Impeller-nut gasket
3170	Pump base
2912	Impeller nut
6543	Impeller lock washer
1500	Casing wearing ring
2200	Impeller
1521	Stuffing-box-cover wearing ring
2450	Shaft sleeve
4133	Throat bushing
4134	Lantern ring
4610/1	Outer O-ring
4130	Packing
6731	Shaft-sleeve key
2540	Slinger
3042	Line bearing
3853	Grease nipple
2100	Pump shaft
3133	Bearing housing
3041	Thrust bearing
3853	Grease nipple
6742/2	Pump coupling key
7112	Coupling
3160	Mounting frame
6742/1	Motor coupling key
8010	Motor

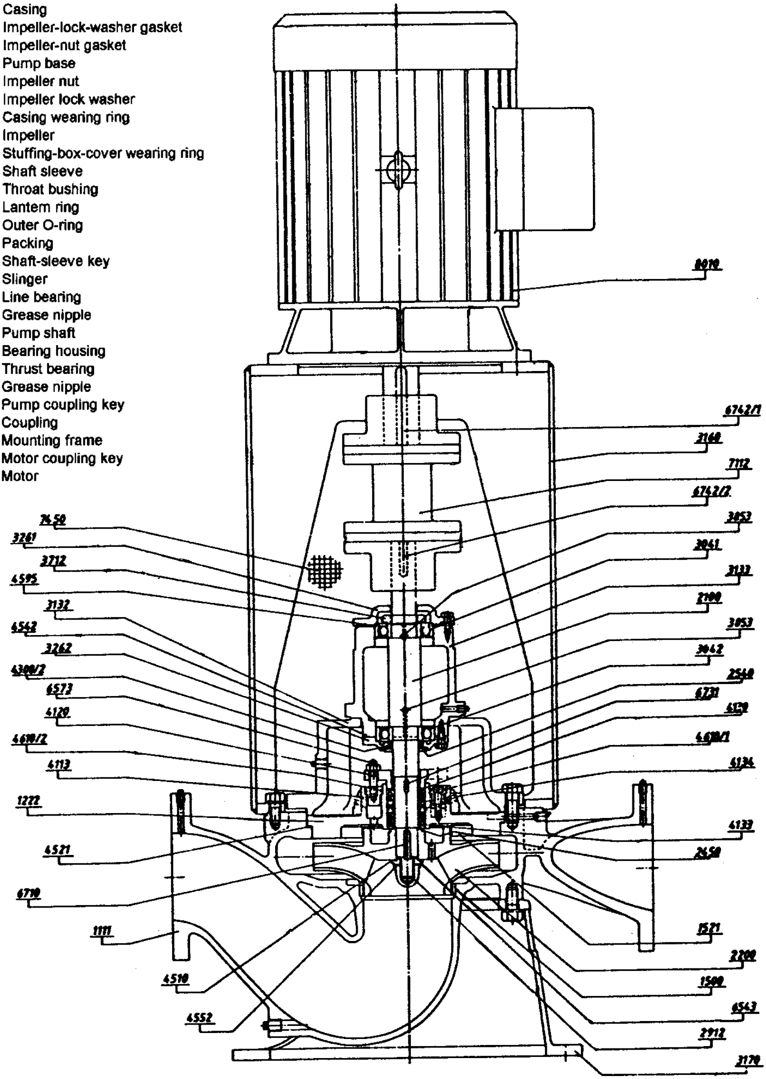

FIGURE 2 Vertical back-pull-out centrifugal pump (Flowserve Corporation)

1	Casing and suction head	7	Seal cage
2	Impeller	8	Shaft
3	Casing wearing ring	9	Slinger
4	Impeller nut	10	Shaft-sleeve seal ring
5	Shaft sleeve	11	Packing
6	Gland		

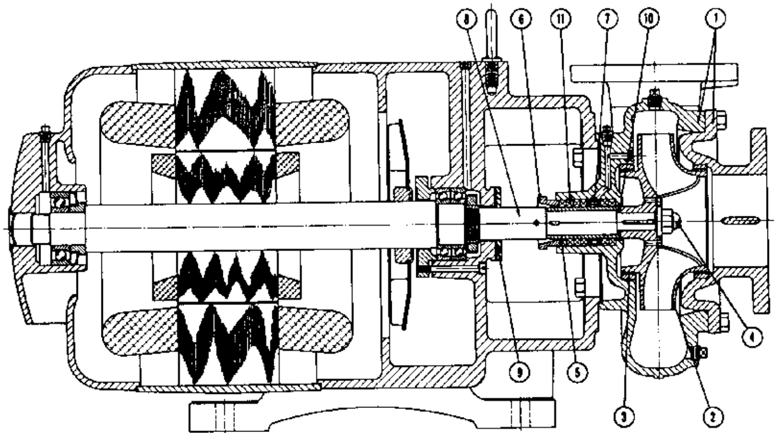

FIGURE 3 Horizontal close-coupled centrifugal pump (Flowserve Corporation)

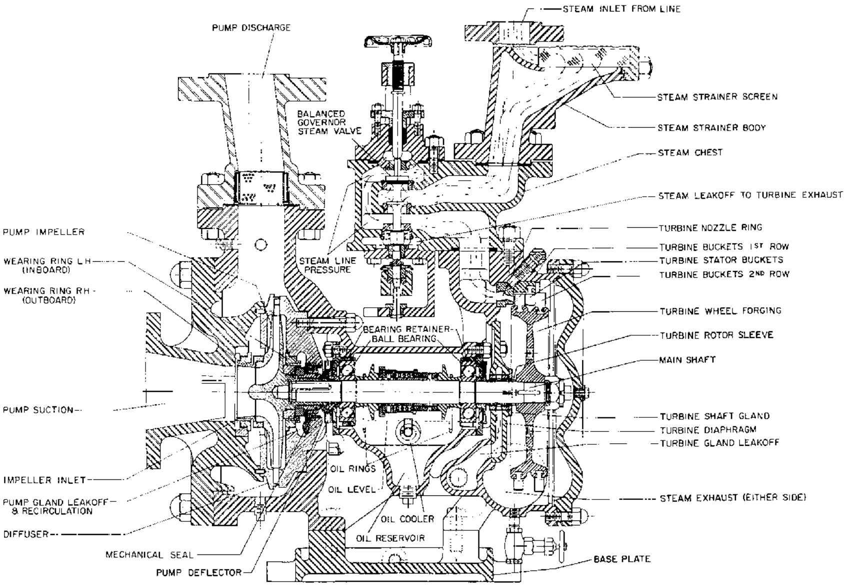

FIGURE 4 Close-coupled single-stage centrifugal main feed pump (Coffin Turbopump)

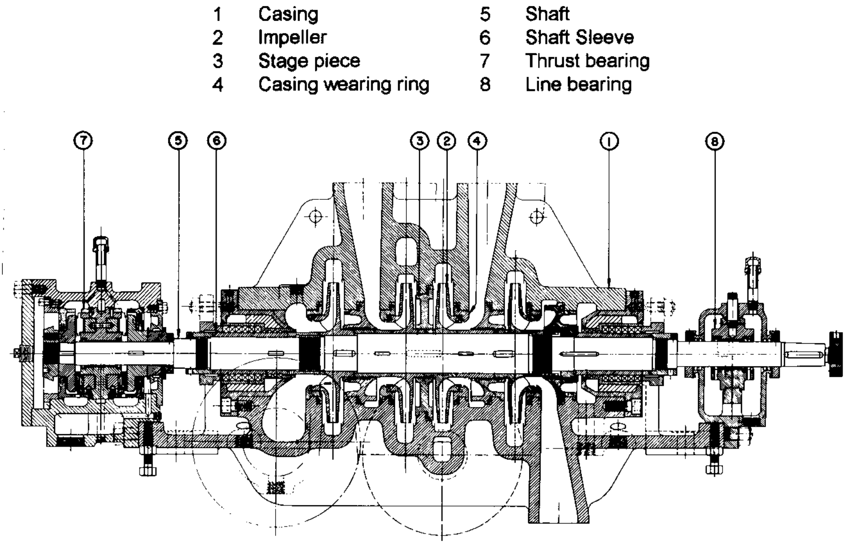

FIGURE 5 Flex-coupled multistage centrifugal main feed pump (Flowserve Corporation)

Motor-driven feed pumps may have grease-lubricated external bearings. Bearings in a turbine-driven feed pump, however, are usually lubricated with oil that is circulated by a shaft-driven rotary pump. Oil discharged by this pump also ordinarily lubricates the turbine's bearings and may be used in the pump's governor. A strainer, filter, and seawater-cooled heat exchanger are often installed in the lubricating-oil system. The lubricating oil used with the turbine-driven feed pumps on many steam-turbine-propelled vessels is the same grade of oil used in the main propulsion lubricating-oil system.

Although packed stuffing boxes are used to seal shaft penetrations in many marine feed pump casings, to reduce stuffing-box leakage, some feed pumps are fitted with mechanical seals. In addition, a condensate-injection shaft seal consisting either of a nonrotating labyrinth-type fixed breakdown bushing or a series of spring-loaded floating rings that are stacked axially is sometimes used. When a feed pump that has a condensate-injection shaft seal is operating, cool condensate is injected into the seal and fills the close radial clearance between the nonrotating seal parts and a rotating shaft sleeve. A small portion of this condensate may flow into the pump. The remainder, however, flows outward and enters a collection chamber that is usually piped back to the vessel's gland-exhaust condenser.

During constant-speed operation, the capacity of water delivered to a boiler by a main feed pump is typically controlled by the throttling action of an automatic feedwater-regulating valve. However, when steam is used to drive a feed pump, the amount that the regulating valve must be throttled is often reduced by controlling the amount of steam supplied to the pump's driver and, therefore, the pump's operating speed with either a constant-pressure or a constant-differential-pressure governor.

A constant-pressure governor automatically regulates a feed pump's operating speed to maintain a constant pressure at the pump discharge. If there is a reduction in the boiler load and the feedwater-regulating valve begins to close, the feed pump's discharge pressure will rise and the capacity of feedwater that the pump delivers to the boiler will be reduced. The constant-pressure governor, however, will sense the rise in discharge pressure and will reduce the pump's speed until this pressure returns to the desired value. As a result of the speed reduction, the amount that the regulating valve must close to limit the feedwater flow rate is reduced. An increase in boiler load has the opposite effect.

A constant-differential-pressure governor (sometimes referred to as an excess-pressure governor) regulates a steam-driven feed pump's operating speed to maintain a set difference between the pump discharge pressure and the pressure on the boiler-side of the feedwater-regulating valve. Because changes in the feed flow entering the boiler result, primarily, from variations in pump speed, the throttling action of the feedwater regulating valve is greatly reduced.

A relief valve is often installed on the discharge side of a main feed pump to protect the feed system from overpressurization. In addition, to prevent a feed pump from operating with too low a capacity, which could occur when the boiler load is low, a recirculation line is typically connected from the pump discharge to the DFT. An orifice is typically installed in the recirculation line to limit flow and to reduce the pressure of the water being recirculated to match the pressure in the DFT. A valve that can be closed during high-load operation is also frequently mounted in a feed-pump recirculation line.

Steam turbines that are used to drive feed pumps are generally protected with low-lubricating-oil-pressure, overspeed, and high-turbine-exhaust-pressure trips. In addition, a low-suction-pressure trip is sometimes provided to prevent a feed pump from operating with too low a suction pressure, which can result in cavitation, overheating, and a loss of load on the pump's driver.

In addition to the main feed pumps, a smaller capacity feed pump is also installed on some steam-powered vessels for use in port or during emergencies. Steam-driven direct-acting piston-type (Figure 6) and motor-driven plunger-type reciprocating pumps, either vertically or horizontally mounted, are often used for in-port feed service.

Because the feedwater removed from a DFT is normally at its vapor pressure, the net positive suction head (*NPSH*) available to a main feed pump is essentially equal to the elevation of the water level within the DFT above the feed pump, less losses in the feed-pump suction line. On a vessel where the elevation of the DFT is not sufficient to provide an adequate *NPSH* to the main feed pumps, separate electric-motor-driven centrifugal-type booster pumps are typically installed between the DFT and the main feed pumps. The booster pumps, which operate in series with but at a much lower speed than the main feed pumps, raise the pressure of the feed water entering the main pumps and, therefore, reduce the potential for cavitation.

MAIN CONDENSATE PUMPS A typical main condensate pump takes suction from the hotwell in a main condenser and discharges condensate, through various heat exchangers, to a deaerating feed tank (DFT). Vertically mounted centrifugal pumps with two or more stages are frequently used in this application. Although many of these pumps are driven by electric motors, some main condensate pumps are driven through reduction gears by steam turbines. Two condensate pumps are generally provided for each main condenser, with each pump sized to handle full-load requirements.

A typical two-stage condensate pump (Figure 7) is fitted with grease-lubricated ball bearings at the upper end of its shaft to absorb both axial and radial loads. In addition, an internal water-lubricated radial sleeve bearing is often installed between the two impellers. The first-stage impeller is usually mounted near the lower end of the shaft, which increases its submergence. In addition, its suction eye is directed upward, which enables the impeller to be self-venting. To help facilitate the removal of any air that may enter the pump, a vent line is ordinarily connected from the suction side of a condensate pump's casing to the upper portion of the condenser. The second-stage impeller is ordinarily mounted near the upper end of the condensate-pump shaft with its suction eye directed downward. With this orientation, the hydraulic axial thrust applied the second stage impeller opposes the axial thrust acting on the first-stage impeller, and the net axial load that must be absorbed by the pump's thrust bearing is reduced. In addition, condensate at the base of the shaft seal has already passed through both impellers and is, therefore, at an elevated pressure. This helps to prevent air from being drawn into the pump through the shaft seal. The effectiveness of the shaft seal, which can consist of a packed stuffing box or a mechanical seal, is also frequently increased by injecting pressurized condensate recirculated from the pump's discharge into the seal area.

The condensate removed from a condenser's hotwell is normally at or close to its vapor pressure. Consequently, the net positive suction head (*NPSH*) available to a condensate

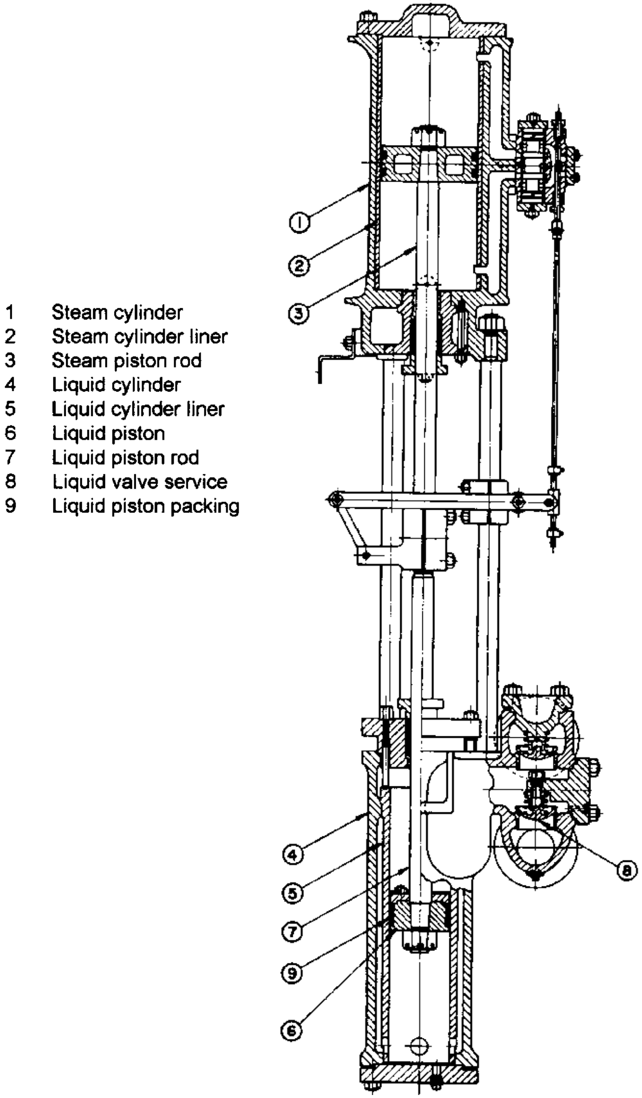

FIGURE 6 Simplex direct-acting reciprocating in-port feed pump (Flowserve Corporation)

pump is essentially equal to the height of the water level in the hotwell above the pump's first-stage impeller, which is seldom more than a few feet, less frictional losses in the suction piping. To help increase the *NPSH* available to main condensate pumps, they are ordinarily installed as low in a vessel as is practicable. They also frequently have special low-*NPSH* first-stage impellers.

If a condensate pump is driven by a steam turbine or by a variable-speed electric motor, its operating speed can be adjusted with plant load. This allows the capacity at which condensate is removed from the hotwell to match the rate at which steam is exhausted into

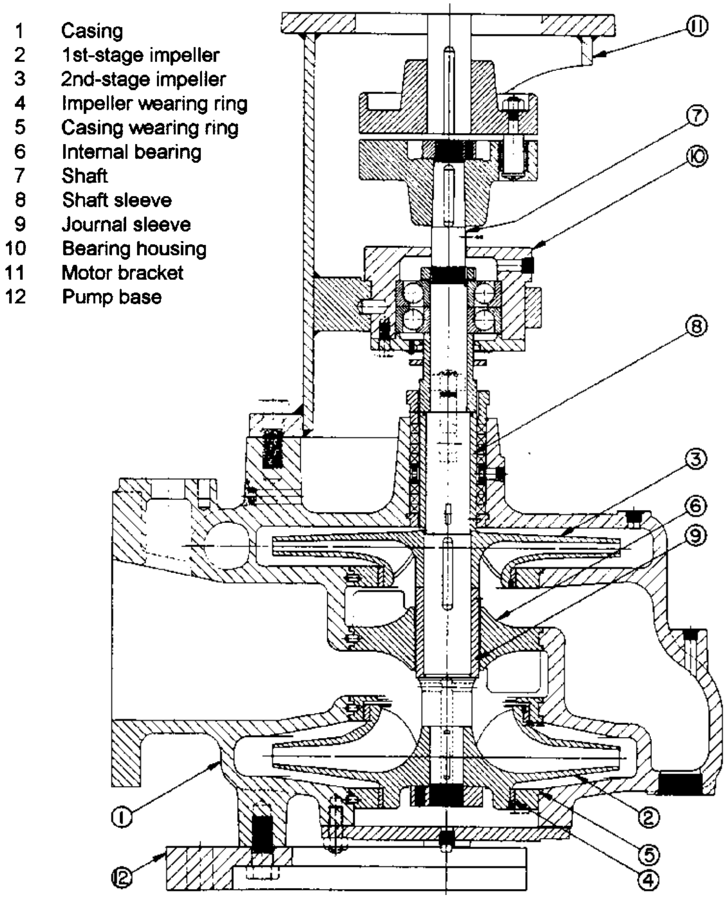

FIGURE 7 Two-stage centrifugal main condensate pump (Flowserve Corporation)

the condenser. This is usually accomplished by means of water level control. Alternatively, when a constant-speed driver is used, the capacity delivered by a main condensate pump is sometimes regulated by cavitation, which is referred to as submergence control. When submergence control is utilized, a reduction in plant load will typically result in a reduction in the main-condenser hotwell level and, therefore, in the *NPSH* available to the condensate pump. After the *NPSH* available drops below the condensate pump's *NPSH* requirement, the capacity being removed from the hotwell will be reduced by cavitation within the pump. As the hotwell level continues to drop, the amount of cavitation occurring will increase, and the pumped capacity will continue to be reduced until it eventually matches the rate at which steam is entering the condenser. When this occurs, the water level in the hotwell will stabilize at an elevation where the *NPSH* available to the condensate pump is equal to the pump's *NPSH* requirement at the new reduced capacity being pumped. Pumps designed to operate with submergence control need to be of robust construction and low energy level (per stage) to prevent damage from cavitation and cavitation-induced vibration.

To avoid operation with excessive cavitation, the capacity delivered by a constant-speed condensate pump can be regulated by throttling the pump's discharge valve as needed to maintain a constant condenser-hotwell level. However, when steam-jet air ejectors are used to deaerate a condenser, condensate-pump operation at too low a capacity can result in insufficient cooling in the ejector inter- and after-condensers. In addition, low-capacity operation can lead to surging caused by suction and discharge recirculation within a condensate pump. To prevent these problems from occurring and to reduce the need to throttle a condensate pump's discharge valve, a recirculation line back to the condenser is frequently used. This line is connected to a tee in the condensate-pump discharge piping, downstream from any air-ejector and gland-exhaust condensers. With this arrangement, if the hotwell level drops, a valve in the recirculation line can be opened, either manually or automatically, to permit a portion of the water discharged by the condensate pump to be returned to the condenser. The hotwell level can be maintained, therefore, at a value that is sufficient to suppress cavitation. In addition, because the condensate pump can always operate at or near its rated capacity, low-flow operation is avoided. Furthermore, an adequate flow of condensate through air-ejector condensers, when used, and a vessel's gland-exhaust condenser can be maintained during plant start-up and low-load operation. In some cases, the condensate-recirculation line may also be fitted with a thermostatically-controlled valve that opens and permits the condensate flow rate through the air-ejector condensers to increase when the temperature of the condensate leaving these heat exchangers exceeds a pre-set value.

CONDENSER-EXHAUSTING PUMPS Electric-motor-driven liquid-ring vacuum pumps are sometimes used instead of steam-jet air ejectors to deaerate a main condenser. The vacuum created by a liquid-ring vacuum pump is limited by the vapor pressure of the liquid compressant (water) within the pump's casing, which increases with temperature. Therefore, water separated from the gases discharged by a liquid-ring condenser-exhausting pump is generally cooled in a heat exchanger before being returned to the pump. Two pumps that are each capable of maintaining the required vacuum during full-load plant operation are frequently provided for each main condenser.

FRESHWATER-DRAIN-COLLECTING-TANK PUMPS A freshwater-drain-collecting-tank (FWDCT) pump (also sometimes referred to as an atmospheric-drain-tank pump) typically transfers condensate (collected from uncontaminated drains that are above atmospheric pressure) from a freshwater-drain-collecting tank to a deaerating feed tank (DFT). Electric-motor-driven single-stage centrifugal pumps are often used in this application. Two full capacity pumps are usually provided. With this arrangement, the on-line pump is often started and stopped automatically by a float control in the drain tank. The condensate removed from a freshwater-drain-collecting tank, which is ordinarily at a temperature of approximately 200 to 210°F (93 to 99°C), is close to its boiling point. To increase the net positive suction head (*NPSH*) available to a vessel's FWDCT pumps, they are frequently installed as far below the drain tank as practicable.

MAIN CIRCULATING PUMPS On a steam-powered vessel, a main circulating pump delivers seawater to a main condenser that receives steam exhausted from a propulsion turbine. In addition, a portion of the seawater discharged by a main circulating pump may be diverted to other seawater-cooled heat exchangers, such as the main lubricating-oil coolers. After passing through the main condenser or another cooler, the seawater is directed overboard. In addition to the main suction flange, which is connected to a sea chest, some main circulating pumps also have an auxiliary side-suction connection that can be used for emergency dewatering of the machinery space bilge.

Typically, one or two main circulating pumps are provided for each of a vessel's main condensers. Single-stage axial-flow propeller pumps (Figure 8) that deliver high flow rates at relatively low discharge pressures are often used in this application. In many cases, the pump is not furnished with a thrust bearing. Instead, the pump shaft is rigidly coupled to the driver's shaft, and axial loads are absorbed by the driver's thrust bearing. Radial loads applied to the pump shaft, however, are generally absorbed by a journal bearing that is located above the overhung propeller. During operation in harbors and inland waterways, the water delivered by a main circulating pump will often contain silt, sand, and other abrasives. Consequently, internal journal bearings that are lubricated by water discharged

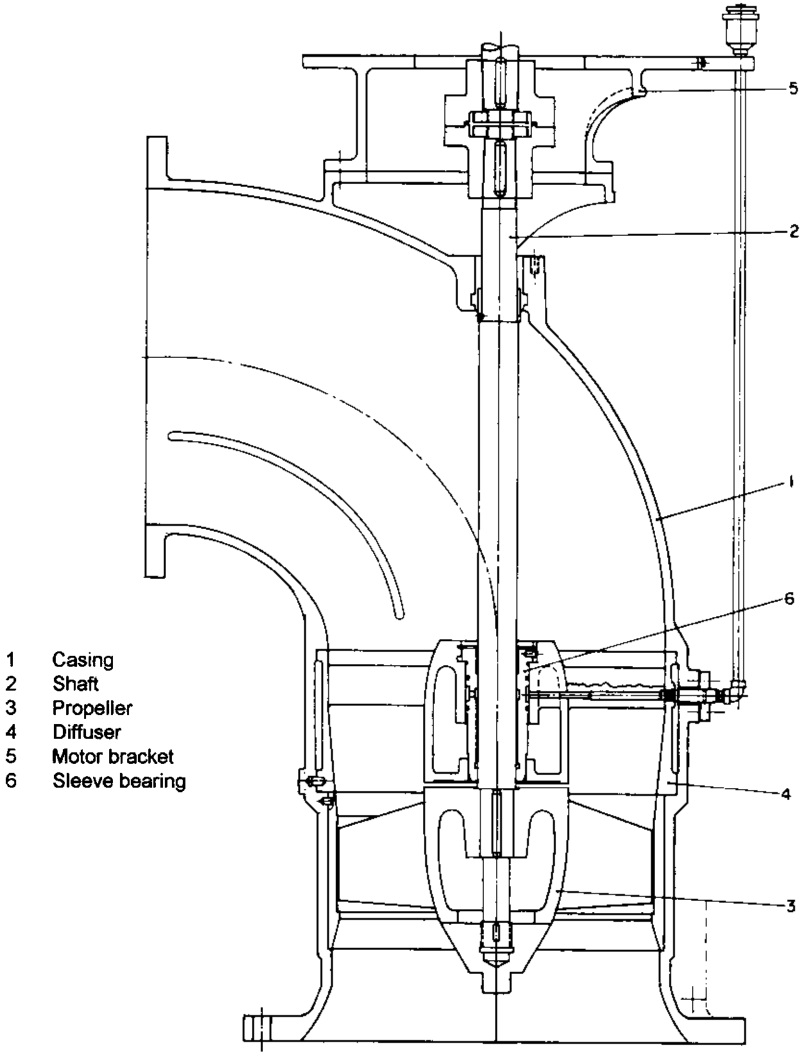

FIGURE 8 Axial-flow main circulating pump (Flowserve Corporation)

from the propeller are sometimes furnished in abrasion-resistant grades of rubber or composite materials. Alternatively, some main-circulating pump internal bearings are lubricated by grease or clean water supplied through an external connection in the pump's casing.

When higher discharge pressures are required, single-stage mixed-flow pumps with overhung end-suction impellers or single-stage radial-flow pumps with double-suction impellers mounted between bearings are sometimes used as main circulating pumps.

Main circulating pumps are generally driven either by steam turbines with reduction gears or by two-speed electric motors. This permits the capacity of seawater discharged through the condenser to be reduced during system startup and shutdown and other periods of low-plant-load operation by reducing the speed of the circulating pump's driver. Many steam ships are fitted with a scoop-injection system that permits seawater to be forced through the main condensers by the forward momentum of the vessel. With this arrangement, the main circulating pumps are usually stopped whenever the vessel is operating above a certain speed.

FUEL-OIL SERVICE PUMPS A fuel-oil (FO) service pump typically takes suction through either high- or low-suction ports in the FO service or settling tanks and supplies fuel oil to the burners in a steam ship's oil-fired boilers. At least two service pumps each capable of delivering the vessel's full-power fuel-oil requirement are generally provided. FO service pump suction and discharge lines are generally fitted with duplex strainers. In addition, one or more flow meters and heaters are frequently installed in a FO service system.

Horizontally and vertically mounted multiple-screw rotary pumps that are driven by either steam turbines or two-speed electric motors are often used in this application. In addition, some older ships have steam-driven reciprocating FO service pumps. When a vessel normally burns heavy (residual) fuel oil, which must be heated before being delivered to a boiler's burners, a separate electric-motor-driven rotary pump is also usually provided to supply unheated distillate fuel oil to the boilers during plant start-up.

The steam flow to a turbine-driven rotary or a direct-acting reciprocating FO service pump is often regulated with a constant-pressure governor that acts to maintain a constant FO-service-pump discharge pressure. With this arrangement, changes in the flow rate passing through the FO service pump result from variations in the pump's operating speed. When a two-speed electric motor is used to drive a FO service pump, the motor is ordinarily operated at low speed during low-plant-load periods (for example, in port) and at high speed during high-plant-load periods. However, during operation at either speed, a motor-driven FO service pump typically discharges more oil than the amount required by the burners. The excess oil is usually returned to the suction side of the FO service system through a recirculation line. The flow rate through this recirculation line is often regulated by an automatic valve that maintains a constant FO-service-pump discharge pressure. An additional recirculation line with a hand-operated valve is frequently provided to permit fuel oil to be circulated through a FO-service-system heater and a boiler's burner manifold prior to lighting-off the boiler. To prevent FO-service-system overpressurization, a relief valve should always be installed on the discharge side of each FO service pump.

Remote controls are typically provided that enable a vessel's FO service pumps to be stopped in an emergency from outside of the machinery space. In addition, flanged FO-service-pump discharge connections are ordinarily fitted with wrap-around shields to deflect spray in case of a leak. In addition, a drip pan or similar device is usually installed under a FO service pump to prevent oil that may leak out of the pump from draining into a vessel's bilge.

LUBRICATING-OIL SERVICE PUMPS A lubricating-oil service (LOS) pump removes lubricating oil from the propulsion-reduction-gear sump and discharges it to the propulsion-turbine bearings, the reduction gears and their bearings, and the main thrust bearing for each propulsion shaft. This oil is also usually directed to the inlet side of a speed-limiting governor pump mounted on the forward end of each propulsion turbine's shaft and to the propulsion-turbine throttle- or nozzle-valve controls. In addition, a portion of the pumped oil may be sent to an overhead gravity tank that holds enough oil to lubricate the propulsion machinery for several minutes following a loss of LOS-pump discharge pressure.

Most steam-powered vessels have two or three LOS pumps. Horizontally and vertically mounted multiple-screw pumps are frequently used. When mounted vertically, the pumps may be submerged directly within the lubricating-oil (LO) sump. In most cases, at least one rotary LOS pump is electric-motor-driven. Remaining units may also be motor driven, or they may be driven by steam turbines or off the propulsion shafting. In addition, steam-driven reciprocating-piston pumps are sometimes used as standby LOS pumps. In addition, some vessels have a battery-operated emergency LOS pump.

LOS pumps are typically installed low in a vessel and close to the LO sump. Suction and discharge lines are often fitted with duplex strainers. In addition, a relief valve and coolers are generally installed in pump discharge lines. Also, one or more orifices are typically installed in a LOS system to reduce the pump's full discharge pressure, which is usually based on the requirements of the propulsion-turbine governors and controls, down to the pressure required by the bearings and gears. A pressure-controlled switch or valve that automatically starts a standby pump if the oil pressure at the discharge of the operating LOS pump drops below a preset value is often provided. Most steam-turbine-propelled vessels also have a device that stops the supply of steam to the ahead propulsion turbines in case of a LOS-system failure.

DIESEL-PROPELLED VESSELS

A propulsion diesel engine that operates below approximately 300 rpm and is directly connected to a propulsion shaft is usually classified as a slow-speed engine. Diesel engines that are connected to propulsion shafts through reduction gears and have maximum operating speeds below 900 to 1200 rpm are typically classified as medium-speed engines, and engines that operate above 900 to 1200 rpm and are used with reduction gears are generally classified as high-speed engines.

ENGINE FRESHWATER COOLING PUMPS A pump is ordinarily used to circulate freshwater through jackets in a propulsion diesel engine's cylinders and cylinder heads, the engine's turbocharger, and, on some vessels, an evaporator where the jacket water provides heat to produce fresh water. The jacket water may also pass through the engine's lubricating-oil and charge-air coolers. In addition, a heat exchanger in which the jacket water is cooled by either freshwater or seawater is frequently included in the system. Alternatively, this heat exchanger is sometimes eliminated when a vessel has a central freshwater cooling system. Instead, some freshwater from a separate low-temperature loop is admitted into the high-temperature jacket-water loop where it mixes with and cools the hot jacket water. An additional heat exchanger that can be used to preheat the jacket water prior to engine start-up is often provided as part of a main engine's jacket-water system.

The pumps that circulate cooling water through a propulsion diesel engine are frequently called jacket-water circulating pumps. Alternatively, however, they may be referred to as high-temperature freshwater cooling pumps on a vessel that has a central freshwater cooling system. Two vertically or horizontally mounted single-stage centrifugal pumps that are each sized to meet normal full-load requirements are often provided for each propulsion engine. Although each pump may be driven by an electric motor, when used with a high- or medium-speed propulsion engine, one of the pumps is often mounted on and driven off the engine. An elevated tank is ordinarily included in the system to allow for any thermal expansion of the water and to maintain a positive pressure at the pump suction.

Separate electric-motor-driven pumps may be used to circulate fresh water through a propulsion engine's pistons when they are water-cooled. Although single-stage centrifugal pumps are often used in this application, vertical turbine pumps that are submerged in the piston-cooling-water drain tank are used on some vessels. When required by the engine design, an additional pair of electric-motor-driven centrifugal pumps is provided to circulate fresh water through an independent loop that cools the main-engine fuel valves or injectors.

ENGINE SEAWATER COOLING PUMPS On some vessels, single-stage centrifugal pumps are used to supply seawater to diesel-engine charge-air, lubricating-oil, and jacket-water coolers. Two pumps that are each sized to meet normal full-load requirements are often provided for each propulsion engine. Although both seawater-cooling pumps may be driven by electric motors, when a medium- and high-speed diesel engine is used, one pump is sometimes attached to and driven by the engine.

FUEL-OIL SUPPLY AND BOOSTER PUMPS Fuel-oil (FO) pumps used for diesel engines should be suitable to handle any of the various grades of fuel that may be burned in a vessel's engines, which can often include both light distillates that are used during maneuvering and heavy residual oils that are used while underway at sea. When heavy fuel oil is supplied to an engine, it must generally be heated to reduce its viscosity.

A FO booster pump typically takes suction either directly from a diesel-propelled vessel's daily service tanks or from a separate mixing tank and supplies fuel oil to the main-engine injector pumps. Two multiple-screw- or gear-type fuel-oil booster pumps that are each capable of meeting full-power requirements are often provided for each propulsion engine. Both FO booster pumps may be electric motor driven. Alternatively, however, when a medium- and high-speed diesel engine is used, one FO booster pump is sometimes attached to and driven by the engine. Also, in some high-temperature heavy-fuel-oil systems, a pair of electric-motor-driven screw- or gear-type FO supply pumps that operate upstream of and in series with the FO booster pumps are located between the service tanks and the mixing tank. More oil is typically delivered to an engine than the amount required for combustion, and the excess oil is ordinarily returned to the service or mixing tank through a recirculation line. Strainers, filters, flow meters, and heaters are also frequently installed in the FO service system.

LUBRICATING-OIL PUMPS The main-engine lubricating-oil (LO) pump typically removes lubricating oil from a sump located below a propulsion engine and discharges the oil to the engine's bearings, governor controls, turbochargers, and, when they are cooled by oil, the engine's pistons. Strainers, filters, and a cooler are also usually included in a LO system. Two main LO pumps that are each capable of delivering the oil required during normal full-load engine operation are usually provided for a propulsion engine. Vertically or horizontally mounted multiple-screw and gear pumps are frequently used in this application. Although both pumps may be driven by electric motors, one pump is sometimes attached to and driven off a medium- or high-speed engine. Alternatively, some vessels have electric-motor-driven vertical turbine pumps that are submerged within the LO sump installed. A device that sounds an alarm following a failure of the LO system is normally provided.

When a vessel is propelled by a crosshead-type diesel engine, some of the oil discharged by the main LO pump is often directed to the suction-side of a lower-capacity rotary-type booster pump that supplies oil to lubricate the engine's crosshead bearings. In addition, a separate low-capacity rotary pump is frequently required to fill a head tank that supplies a different grade of oil to lubricators that inject the oil into each of a crosshead engine's cylinders. Also, with some designs, a separate pair of rotary pumps is required to supply lubricating oil to the engine's camshaft bearings.

In addition to the pumps that supply lubricating oil to propulsion engines, separate rotary pumps are generally used to supply lubricating oil to reduction gears and their bearings on vessels propelled by medium- or high-speed engines.

GAS-TURBINE-PROPELLED VESSELS

FUEL-OIL SERVICE PUMPS Typically, fuel oil is delivered to a propulsion gas turbine's combustion-chamber nozzles by a gear pump that is mounted on and driven by the gas turbine. In addition, a pair of two-speed electric-motor-driven rotary pumps that operate upstream of and in series with the attached pump are usually provided. Duplex strainers, filters, and heaters are also ordinarily included in a gas turbine's fuel-oil service system.

LUBRICATING-OIL PUMPS A typical gas turbine is furnished with an attached gear- or centrifugal-type lubricating-oil (LO) pump that is driven off the gas turbine. This pump takes suction from a LO reservoir and discharges synthetic oil to the bearings for the gas turbine and to control devices. Filters are also included in the LO system. In addition, electric-motor-driven gear, vane, or centrifugal pumps are ordinarily used to circulate lubricating oil through the system during start-up and cool-down periods and to serve as a backup to the attached pump. Excess oil delivered by a gas turbine's LO pump is frequently returned through a pressure regulating valve to the LO reservoir. A device is normally provided that sounds an alarm and, in some cases, automatically stops the flow of fuel to a gas turbine following a failure of the LO system.

Separate rotary scavenge pumps may be used to return oil that drains from a gas turbine's bearings to the LO reservoir. In addition, multiple-screw pumps are frequently used to circulate mineral oil through an independent lubrication system for a gas-turbine-propelled vessel's reduction gears and their bearings. Although one of these screw pumps may be driven off the reduction gears, the remaining reduction-gear LO pumps are usually electric motor driven. Some of the mineral oil in the reduction-gear LO system frequently passes through a heat exchanger in which it absorbs heat from the synthetic oil that lubricates the gas turbine's bearings. The reduction-gear lubricating oil also usually passes through a second heat exchanger in which it is cooled either by freshwater or seawater.

GENERATOR APPLICATIONS

Steam-Turbine-Driven Turbogenerators

AUXILIARY CONDENSATE PUMPS When the steam leaving a steam ship's turbogenerator exhausts into an auxiliary condenser, an auxiliary condensate pump is ordinarily used to remove condensate from the auxiliary condenser's hotwell and return it to the DFT. A typical auxiliary condensate pump is a vertical two-stage centrifugal pump that is similar in configuration to a main condensate pump but is smaller in size. One auxiliary condensate pump is typically furnished for each auxiliary condenser. Crossover lines are, however, often provided so each auxiliary condensate pump on a vessel can remove condensate from any of the vessel's auxiliary condensers.

AUXILIARY CIRCULATING PUMPS A single-stage centrifugal pump is often used to circulate seawater through the tubes of an auxiliary condenser that receives steam exhausted from a vessel's turbogenerator. Seawater discharged by this pump may also be directed to the generator's lubricating-oil and air coolers. One auxiliary circulating pump is typically furnished for each auxiliary condenser. Crossover lines, however, are often provided so one generator's auxiliary circulating pump can supply seawater to any of the vessel's auxiliary condensers. In addition, a line is often installed that permits seawater discharged from a vessel's auxiliary circulating pumps to be directed, in case of a main circulating pump failure, to a main condenser.

LUBRICATING-OIL PUMPS A typical turbogenerator is fitted with an internal or external gear-type lubricating-oil (LO) pump that is geared to and driven by the turbine. The pump ordinarily takes its suction from a sump located below the turbine's reduction gears and discharges lubricating oil to bearings, the turbine's reduction gears, and the governor that controls the flow of steam to the turbine. A separate hand-operated or electric-motor-driven gear pump may also be provided to enable lubricating oil to be circulated through the LO system during generator start-up and shutdown periods.

A duplex strainer, a cooler, and one or more relief valves are often included in a turbogenerator's LO system. In addition to protecting the system from overpressurization, the relief valves act as backpressure valves that maintain the desired LO pressure in various parts of the system. This arrangement permits lubricating oil sent to the governor to be at a higher pressure than the oil directed to bearings and reduction gears. A turbogenerator is ordinarily fitted with a trip that stops the flow of steam to the turbine if the LO pressure drops below a preset value.

DIESEL-DRIVEN GENERATORS

JACKET-WATER CIRCULATING PUMPS A diesel engine that drives a generator is often furnished with an attached centrifugal-type jacket-water circulating pump that circulates freshwater through passages in the engine's cylinders and cylinder heads, the engine's turbocharger, and the engine's lubricating-oil cooler. In addition, the jacket-water system may include a preheater that is used to warm-up the water prior to engine start-up. When the jacket water is air cooled, it will also pass through a radiator. Alternatively, the jacket water may be cooled by seawater or freshwater in a heat exchanger. When seawater is used as the cooling medium in a jacket-water cooler, the seawater may be circulated by a centrifugal pump that is attached to and driven by the diesel engine or by a separate electric-motor-driven centrifugal pump.

FUEL-OIL PUMPS A diesel engine that drives a generator frequently has an attached rotary gear-type fuel-oil (FO) pump that is mounted on and driven by the engine. The pump typically takes suction from a daily service tank and delivers fuel oil to the engine's injector pumps. Excess oil delivered to the engine is ordinarily returned through a recirculation line to the service tank. A filter is typically included in the system. A separate hand-operated FO pump that can be used to prime the engine-driven FO pump (for example, following maintenance performed on the FO system, such as filter replacement) may also be provided. A diesel engine's FO supply line is often fitted with a valve that can be closed from outside the machinery space to stop the engine in case of a fire or other emergency.

LUBRICATING-OIL PUMPS A diesel engine that drives a generator is usually fitted with an attached rotary gear-type lubricating-oil (LO) pump that is mounted on and driven by the engine. The pump typically takes suction from a sump located below the engine and discharges oil to the engine's bearings. A filter and cooler are also ordinarily included in an engine's LO system. In addition, a hand-operated or air-motor-driven rotary-type LO pump is often provided to permit the engine's bearings to be prelubricated prior to startup. A diesel engine that drives a generator is often protected by a trip that stops the engine if the pressure in the LO system drops below a preset value.

AUXILIARY APPLICATIONS

Ship's Service Pumps

FUEL-OIL TRANSFER PUMPS A fuel-oil (FO) transfer pump is used to remove fuel oil from one or more of a vessel's FO storage tanks and to transfer the oil to settling tanks, to other storage tanks (that is, to adjust the list, trim, or stability of the vessel), or to an above-deck connection through which the oil can be directed ashore or to another vessel. Most vessels have at least two pumps that can be used to transfer fuel oil. Although horizontally and vertically mounted multiple-screw rotary pumps are frequently used in this application, steam-driven reciprocating-piston pumps are sometimes used to transfer fuel oil. FO transfer pumps are often installed low in a vessel to improve suction conditions.

Some rotary FO transfer pumps are driven by two-speed electric motors or steam turbines. When this is the case, the capacity of fuel transferred can be changed by altering the speed of the transfer pump's driver. The capacity delivered by a FO transfer pump during constant-speed operation can often be reduced by opening a valve in a bypass line through which a portion of the oil discharged by the pump is recirculated back to the suction line. A FO transfer pump is usually protected with a suction strainer and a discharge relief valve and is often fitted with remote controls that enable the pump to be stopped from outside of a vessel's machinery spaces.

On a steam-propelled vessel with oil-fired boilers, a FO service pump typically takes suction directly from the fuel-oil settlers and discharges oil to burners in the vessel's boilers. On a diesel-propelled vessel, however, fuel oil in the settlers is ordinarily passed through one or more purifiers as it is transferred to separate daily service tanks from which the engine FO supply or booster pumps take suction. The rotary gear-type pump that frequently delivers fuel oil to a purifier is often mounted on and driven by the purifier. In some cases, a second attached rotary pump is used to boost the pressure of the clean oil leaving a purifier. Alternatively, independent electric-motor-driven pumps are sometimes used with FO purifiers.

FRESHWATER COOLING PUMPS To reduce corrosion from seawater, some vessels are fitted with a central freshwater cooling system. When this is the case, single-stage centrifugal pumps are generally provided to circulate freshwater through two separate cooling loops: a low-temperature loop and a high-temperature loop. Two centrifugal pumps that are each capable of delivering the full-load capacity are frequently installed in each freshwater loop. Smaller pumps may also be provided for startup and in-port use.

A low-temperature freshwater cooling pump ordinarily circulates freshwater through a vessel's various condensers, oil coolers, and air coolers. Jacket-water coolers for a vessel's auxiliary diesel engines may also be included in the low-temperature loop. In addition, freshwater in the low-temperature loop typically passes through a seawater-cooled heat exchanger. On a diesel-propelled vessel, the high-temperature freshwater cooling pump serves as the jacket-water-circulating pump and typically circulates fresh water through the propulsion-engine jackets, turbochargers, and a freshwater generator (evaporator). On some vessels, freshwater in the high-temperature loop also passes through a heat exchanger in which it is cooled by freshwater in the low-temperature loop. Alternatively, however, the need for this heat exchanger is eliminated in some central freshwater cooling systems with a control valve that allows some of the freshwater in the low-temperature loop to enter, mix with, and cool the hotter water in the high-temperature loop.

SEAWATER SERVICE PUMPS A seawater service pump takes suction from a sea chest and supplies seawater to heat exchangers in which this water serves as the cooling medium. This can sometimes include refrigeration and air-conditioning condensers, various lubricating-oil coolers, and air-compressor coolers. On newer vessels that have a central freshwater cooling system, however, the seawater cooling pumps supply seawater only to large freshwater coolers. With either arrangement, after leaving the heat exchangers that it passes through, the seawater is ordinarily directed overboard.

Two or more horizontally or vertically mounted electric-motor-driven single-stage centrifugal seawater service pumps (these pumps are also sometimes referred to as seawater cooling pumps or auxiliary seawater pumps) are usually installed on a vessel. A seawater pump is typically located low in a vessel so it can operate with a flooded suction. In some cases, the pump's suction line may be connected to both a lower sea chest and an upper sea chest. The use of the lower sea chest, which often receives seawater through an opening in the bottom of a vessel's hull, reduces the potential for air to enter a seawater pump's suction line (especially when the vessel is rolling in rough seas). However, when the vessel is in shallow water, using the upper sea chest, which is typically connected to an opening in the side of a vessel's hull, can reduce the amount of silt, mud, and other contaminants entering the seawater-pump suction. In addition to the sea-chest connections, on a diesel-propelled vessel, the largest seawater-cooling pump may also have an emergency bilge suction line through which the machinery space can be dewatered in case of flooding.

To help protect a seawater pump from foreign material that may enter a sea chest, a strainer is frequently installed in a seawater pump's suction line. In addition, when a mechanical-seal flushing line is used with a seawater pump, it is sometimes fitted with a cyclone abrasive separator. In a typical installation, a recirculation line from the discharge side of the pump's casing is connected to the inlet on the side of the separator. Clean water leaving the top of the separator is directed to the mechanical seal's flushing connection, which is usually in the seal's gland. Dirty water discharged from the bottom of the separator is returned to the suction side of the pump's casing.

LUBRICATING-OIL TRANSFER PUMPS Rotary gear pumps are frequently used to transfer lubricating oil from a vessel's lubricating-oil (LO) storage tanks to tanks in various locations throughout the vessel where the oil is stored for use in auxiliary machinery. In addition, a rotary pump may be used to add lubricating oil directly to oil-lubricated machinery.

Most vessels have one or more LO purifiers that can be used to remove water and other contaminants from the lubricating oil contained in machinery LO sumps (for example, LO sumps for diesel engines, turbogenerators, and main-propulsion-turbines). A LO purifier may also be used to transfer lubricating oil from a vessel's LO storage tanks to separate LO settling tanks. A rotary gear pump is often used to deliver lubricating oil to a LO purifier. In many cases, the pump is mounted on and driven by the purifier. A second attached rotary pump may also be used to boost the pressure of the clean oil leaving a purifier. Alternatively, independent electric-motor-driven pumps are sometimes used with LO purifiers.

STERN-TUBE LUBRICATING-OIL PUMPS An electric motor-driven rotary screw, gear, or vane pump is required to circulate lubricating oil through a vessel's stern-lube bearings and seals when these components are oil lubricated. One pump is typically provided for each propulsion shaft. The pressure on the discharge side of a stern-tube lubricating-oil (LO) pump is ordinarily established by the elevation of a head tank that is connected to the system. (Stern-tube LO pumps are not required on vessels that have seawater-lubricated stern-tube bearings and seals.)

AUXILIARY AND EXHAUST-GAS (WASTE-HEAT) BOILER PUMPS Diesel-propelled vessels are frequently fitted with exhaust-gas boilers in which heat contained in the engine exhaust-gas is utilized to generate steam for various purposes, such as heating fuel, liquid cargo, and water. On some vessels, a portion of the steam produced may even be superheated and supplied to turbine-driven equipment, such as turbogenerators. To permit steam to be generated during periods of low engine load or when an engine is secured (for example, in port), most of these vessels are also fitted with auxiliary oil-fired boilers that can operate alone or parallel to the exhaust-gas boilers.

In a typical installation, a feed pump is used to return condensate from a drank tank to the boilers. In addition, a separate pump is generally required to circulate water through the boiler generating tubes. Furthermore, when condensing turbines are installed in an auxiliary steam system, a condensate pump is used to transfer condensate from the condenser's hotwell to the drain tank. Electric-motor-driven single and multistage centrifugal and regenerative turbine pumps are typically used in these applications.

A fuel oil (FO) service pump is usually required to supply fuel oil to an oil-fired auxiliary boiler. Electric-motor-driven gear pumps are often used in this application.

HYDRAULIC-SYSTEM PUMPS Positive-displacement pumps are ordinarily used to pressurize and circulate the hydraulic fluid in a vessel's hydraulic systems. Typical examples of shipboard hydraulically powered machinery include steering gear, anchor windlasses, cranes, hatch covers, and valves. The hydraulic pumps, which can be installed in a self-contained system that is an integral part of the hydraulically powered component or in a larger central system that provides fluid to all of the hydraulic equipment on a vessel, are usually driven by electric motors or diesel engines.

In a constant-pressure hydraulic system, one or more variable-displacement rotating-piston pumps are often used to supply hydraulic liquid at essentially a constant pressure to the components that are powered by the system. If the capacity delivered by a pump exceeds the system's demand, the pump discharge pressure will include and an automatic controller will reduce the pump's stroke and the capacity pumped until the discharge pressure returns to the set point. If the system demand increases and the pump discharge pressure drops, the pump's stroke and the capacity delivered will be increased. The pump stroke and the pumped capacity are, therefore, automatically adjusted to match the demand on the hydraulic system. In some systems, hydraulic pumps may also be automatically started and stopped as needed.

The hydraulic fluid in a constant-flow variable-pressure hydraulic system is typically circulated by gear, vane, multiple-screw, or fixed-displacement rotating-piston pumps. These pumps, which often operate continuously, take suction from a sump or tank and deliver pressurized oil to the components powered by the system. If the capacity delivered by a system's pumps exceeds the system requirement, excess oil is recirculated through an unloading valve back to the sump.

FIRE PUMPS A fire pump takes suction from a vessel's sea chest and discharges seawater through a fixed fire main to hydrants located throughout the vessel. Most vessels have at least two fire pumps that are each capable of delivering a minimum capacity of seawater simultaneously to a specified number of the most remote hydrants at a specified pressure. Although fire pumps are sometimes used for other purposes, at least one fire pump on a vessel should always be available to provide water to the fire main. In addition, some of a vessel's fire pumps, together with their sea connections and sources of power, are ordinarily installed in separate spaces and arranged so a fire in any one location cannot incapacitate all of the vessel's fire pumps. Also, controls are sometimes provided that enable a fire pump's suction and discharge valves to be opened and the pump to be started from outside of the machinery space. A pressure gage and a relief valve are usually installed in a fire pump's discharge line. (See Section 9.4.)

Single-stage and, in some cases, two-stage centrifugal pumps may be used in fire service. Vertically mounted centrifugal fire pumps are generally driven by electric motors. Horizontal fire pumps, however, can be driven by electric motors, steam turbines, or diesel engines. In addition, smaller centrifugal fire pumps and the electric motors that typically drive them are sometimes furnished in a close-coupled configuration. A centrifugal fire pump is ordinarily installed low in a vessel so it operates with a flooded suction. Alternatively, a vertical turbine pump is sometimes used in this application, which enables the fire-pump impellers to be submerged within a tank.

Some vessels also carry portable fire pumps that can be moved throughout the vessel by the crew. A typical portable unit consists of a single-stage end-suction centrifugal pump that is close-coupled to a gasoline engine. An integral vacuum priming pump is often included with a portable unit to enable the fire pump to be used in areas of the vessel that are above the waterline.

BILGE PUMPS Bilge pumps remove liquid from machinery-space bilges, tank tops, the shaft alley, and watertight compartments located throughout a vessel. Fluid discharged from a bilge pump is typically directed, depending on its content and applicable regulations, to an oily-waste holding tank or overboard. Most vessels have more than one bilge pump. In addition to a common suction main that is connected to branches that lead to suction wells (sometimes referred to as rose boxes) located throughout a vessel, one or more independent bilge-pump suction lines are generally provided in machinery spaces. In addition, a vessel's bilge pumps, together with their sources of power, may be installed in various watertight compartments throughout a vessel so the flooding of one compartment will not incapacitate all of the vessel's bilge pumps. Alternatively, some vessels have an emergency bilge pump that is suitable for use even when the pump is submerged. The submersible bilge pump, which is normally powered through the vessel's emergency switchboard, can normally be operated remotely from outside of the vessel's machinery spaces.

Horizontally and vertically mounted centrifugal pumps are frequently used for bilge service. Centrifugal bilge pumps are frequently driven by electric motors. Some bilge pumps, however, are driven off a vessel's propulsion machinery. Because bilge pumps frequently operate with a suction lift, a non-self-priming centrifugal bilge pump is usually connected to a vacuum-priming pump. The vacuum pump can be part of a central system that is used to prime multiple pumps on a vessel (Figure 9), or it may be a dedicated unit that is used only with the bilge pump. When a dedicated vacuum pump is provided, it is sometimes electric-motor-driven and mounted on the same baseplate as the bilge pump that it primes. Alternatively, a dedicated vacuum pump may be mounted on and driven directly off the bilge pump.

To eliminate the need for a separate priming pump, self-priming centrifugal pumps are sometimes used in bilge service. A typical self-priming centrifugal pump (Figure 10) has a casing with an enlarged suction chamber that retains liquid whenever the unit is stopped. When the pump is started with air in its suction line, the liquid in the suction chamber is pumped through the impeller and enters a discharge chamber installed at the top of the casing. The evacuation of the suction chamber creates a vacuum that draws air from the suction line into the pump. The liquid in the discharge chamber is returned to the pump's impeller through either an internal port or an external recirculation line and mixes with this air. The liquid-and-air mixture is then pumped through the impeller and into the discharge chamber where the air is vented from the pump. The liquid is again returned to the impeller, and the cycle is repeated. Each time the stored liquid is recirculated through the pump, an additional amount of air is removed from the suction line.

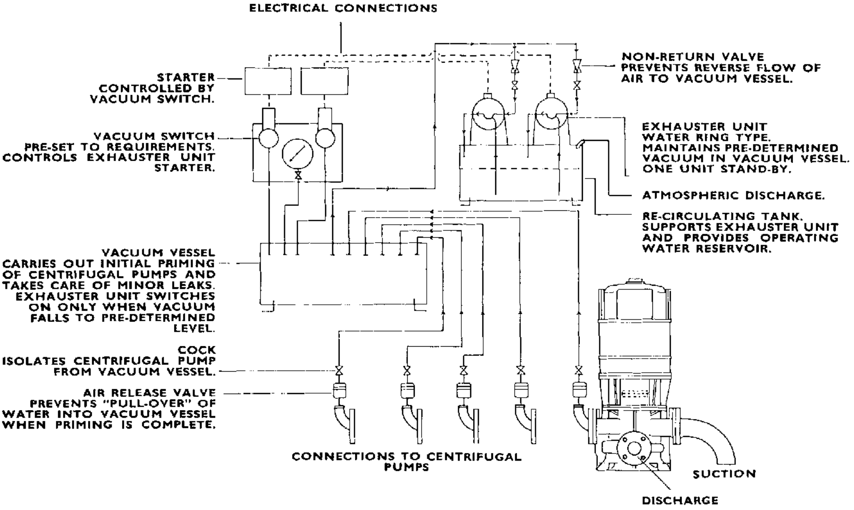

FIGURE 9 Central priming system (Flowserve Corporation)

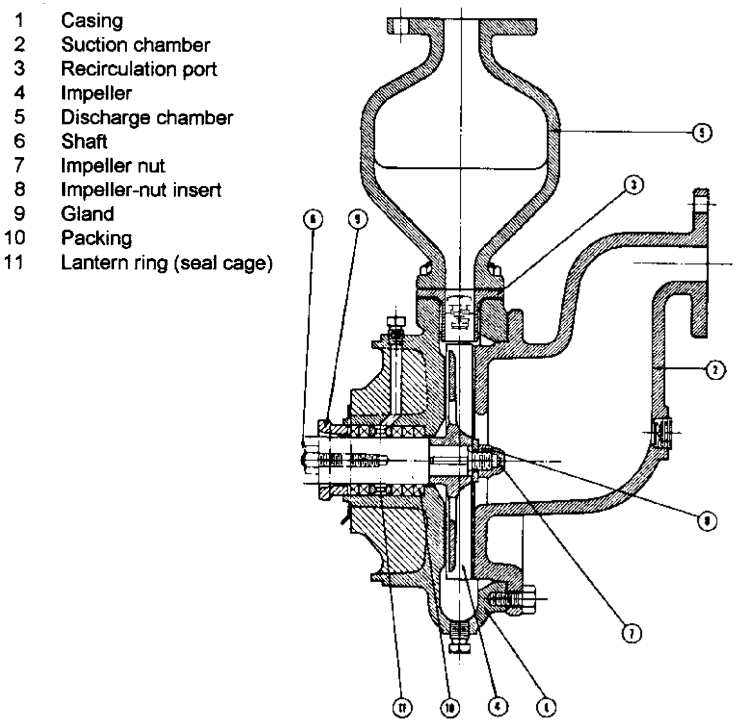

FIGURE 10 Self-priming centrifugal pump (Flowserve Corporation)

After this occurs, the pump will discharge liquid in a normal fashion. However, priming times can be excessive when large amounts of air must be removed from a suction line; consequently, self-priming centrifugal pumps are usually only used for bilge service when the length of the bilge suction piping is relatively short.

Additional types of bilge pumps that do not require priming pumps include motor-driven sump pumps that are submerged within the bilge drain wells; rotary-type vane pumps; air-operated diaphragm pumps; and motor-, steam-, or air-driven piston-type reciprocating pumps.

An oily-water separator (OWS) is used to remove oil from bilge water so the water can be discharged overboard. A typical OWS is fitted with one or more dedicated pumps that take suction either from an oily-water holding tank or directly from bilge suction wells and circulate the oily water through the separator, discharge clean water overboard, and transfer separated oil to a waste-oil tank. Electric-motor-driven progressing-cavity pumps are often used with an OWS.

BALLAST PUMPS A ballast pump is used to transfer seawater into and out of a vessel's ballast tanks to adjust list, trim, draft, and stability. Ballast pumps may also be used during a voyage to exchange water contained within ballast tanks to prevent the introduction of nonindigenous aquatic species into coastal and inland waterways. A ballast pump must, therefore, have the capability to take suction either from a sea chest or from ballast tanks that are being emptied. In addition, it must be possible to direct seawater discharged by a ballast pump either to ballast tanks that are being filled or overboard. Furthermore, the seawater discharged by a ballast pump may be used as the motive fluid in eductors that are provided to strip ballast tanks. On some vessels, pumps used for ballasting and deballasting may also be used for other purposes, such as bilge dewatering (that is, a bilge and ballast pump) or fire fighting. Vessels with large segregated ballast tanks, such as many tankers, however, frequently have dedicated ballast pumps.

Horizontally and vertically mounted single-stage centrifugal pumps that are installed in a vessel's machinery space are often used for ballast service. Although many of these pumps are driven by electric motors, larger ballast pumps are sometimes driven by steam turbines. A centrifugal ballast pump is normally located low in a vessel so it will operate with a flooded suction when it is lined up to the sea chest or begins to empty a ballast tank that is full. As the water level in a ballast tank being emptied drops, however, the submergence of the pump's impeller is continuously reduced. To enable it to be reprimed if suction is lost prematurely during operation with a suction lift, a centrifugal ballast pump may be connected to a priming system.

As an alternative to centrifugal ballast pumps installed in a machinery space, hydraulic-motor-driven centrifugal ballast pumps that are submerged directly in the ballast tanks are used on some vessels. In addition, some vessels have vertical line-shaft deep-well ballast pumps. So the pump can take suction from multiple locations, a deep-well ballast pump is frequently installed in a suction can that is connected to the ballast-system suction piping. To enable air and vapor to be removed from the can and suction piping, a deep-well ballast pump is often fitted with self-priming valves.

HOTEL SERVICE PUMPS

FLASH-DISTILLING-PLANT PUMPS Many steam ships have multistage flash distilling plants that are used to generate freshwater from seawater. Several electric-motor-driven single-stage centrifugal pumps are used with a typical flash unit. Smaller pumps are often provided in a close-coupled configuration.

A distiller-feed pump takes suction from a sea chest and supplies seawater to the distilling plant's first-stage flash chamber. This water often passes through various heat exchangers, such as a distillate cooler, distillate condensers, air-ejector condenser, and seawater heater before it enters the flash chamber. The distiller-feed pump is usually located sufficiently below the vessel's waterline so it operates with a flooded suction.

The hot high-salinity brine remaining in a flash distilling plant's last stage is typically removed by a brine pump that discharges it overboard. A line is often provided to permit a brine pump's shaft seals to be flushed with seawater discharged from the distiller-feed pump. In addition, a vent line is typically connected from a brine pump's suction to the last-stage flash chamber.

The freshwater or distillate produced by a flash distilling plant is removed from the last-stage distillate condenser by a distillate pump. During normal operation, water discharged from this pump ordinarily passes through a cooler and is then directed to a vessel's distilled-water (reserve-feedwater) or potable-water tanks. A salinity cell in the pump discharge line, however, will typically trip a three-way valve that dumps the distillate to the bilge if salinity of this water is excessive. A vent line may be connected from a distillate pump's suction to the last-stage distillate condenser.

An additional pump is sometimes provided to remove condensate from the hotwell of a flash distilling plant's seawater heater and transfer it to a freshwater drain tank. Alternatively, however, this condensate may be returned directly to a main or auxiliary condenser through a vacuum-drag line. With this latter arrangement, the feed-heater condensate pump is not required.

Because the distillate, brine, and feed-heater condensate pumps each take their suction from a chamber in which the pumped liquid is at or near its vapor pressure, pumps used in these applications should have low *NPSH* requirements. In addition, to increase the submergence of their impellers, these pumps are often located as far below the distilling plant assembly as practicable.

HEAT-RECOVERY DISTILLING-PLANT PUMPS It is common for a diesel-propelled vessel to be fitted with one or more heat-recovery distilling plants in which jacket water from the vessel's diesel engines serves as the heating medium. In a typical heat-recovery distilling plant, this jacket water is pumped through either a plate or a submerged-tube evaporator.

Seawater is often delivered to a heat-recovery distilling-plant by a dedicated distiller-feed pump (sometimes referred to as an eductor or ejector feed pump) that takes its suction from a sea chest. In some units, this seawater initially passes through the distilling plant's condenser where it absorbs heat from the distilled vapor generated in the evaporator. A portion of this seawater then enters the evaporator section of the shell as feed. The remaining portion of the seawater frequently serves as the motive fluid for an eductor that removes brine from the evaporator and air from the condenser portion of the distilling plant's shell. After leaving the eductors, this seawater is directed overboard with the brine and air. (In some units, the mixture of seawater, brine, and air passes through the distilling plant's condenser before being discharged overboard.) The feed pump is typically located low in a vessel to enable it to operate with a flooded suction.

A distillate pump is used to remove the freshwater collected in a heat-recovery distilling plant's condenser and discharge it either to the vessel's freshwater tanks or, when the salinity is high, to the bilge. Both the eductor-feed pump and the distillate pump are generally electric-motor-driven single-stage centrifugal-type pumps. In addition, they are often furnished in a close-coupled configuration.

POTABLE-WATER PUMPS A potable-water pump typically takes suction from a vessel's potable-water or domestic tanks and discharges freshwater either directly to sinks, showers, and other potable-water fixtures located throughout the vessel or to an air-charged pressure tank, sometimes referred to as a hydrophore or a hydropneumatic tank, that is frequently included in a potable water system. Most vessels have at least two full-capacity potable-water pumps. Electric-motor-driven single-stage centrifugal pumps are often used in this application. In addition, regenerative turbine pumps are sometimes used. Smaller pumps are often furnished in a close-coupled configuration. To improve suction conditions, a potable-water pump may be installed as far as practicable below a vessel's potable water tanks.

In a typical potable-water system in which a hydrophore is connected to the pump discharge line, a potable-water pump may be cycled on and off automatically by a pressure switch installed on the hydrophore. During periods when the pump is not running, any potable-water usage will result in a drop of the water level within the hydrophore, the expansion of the compressed air located in the upper portion of this tank, and a reduction in the hydrophore pressure. However, the force exerted by the compressed air ordinarily prevents the potable-water system pressure from dropping too suddenly. If the potable-water usage continues, the pressure exerted by the compressed air within the hydrophore will continue to drop until it reaches the cut-in pressure for the potable-water pump's motor. At this point, the pump will be started and the water level and pressure within the hydrophore will normally increase. This will continue until the pressure switch's cut-out pressure is reached and the potable-water pump is stopped.

Although it is less common, on a vessel with a high potable-water demand, a potable-water pump may be operated continuously. When a potable-water pump operates continuously, however, a recirculation line is typically provided to prevent the pump from overheating during periods of low water usage.

HOT-WATER CIRCULATION PUMPS Some of the freshwater discharged from a vessel's portable-water pumps is circulated through a heater and is then directed to sinks, showers, and other hot-water fixtures located throughout a vessel. One or more hot-water circulation pumps are ordinarily used to recirculate unused water contained in the hot-water distribution piping through the heater so the water will remain hot. Electric-motor-driven single-stage centrifugal pumps are typically used in this application. In addition, most hot-water circulating pumps, which generally operate continuously, are furnished in a close-coupled configuration.

SANITARY PUMPS Seawater is sometimes used as the flushing medium in bathrooms on a vessel. When this is the case, a sanitary or flushing-water pump may be provided to take suction from a sea chest and discharge seawater to the vessel's flushometer valves. Two electric-motor-driven single-stage centrifugal pumps are frequently used in this application. When each pump is sized to meet peak-demand requirements, one pump can be cycled on and off automatically by a discharge-pressure switch while the second pump serves as a standby unit. To reduce the number of sanitary-pump starts and stops, an air-charged pressure tank similar to the potable-water-system hydrophore described previously is often included in a sanitary system. A sanitary pump is frequently located low in a vessel so it can operate with a flooded suction.

SEWAGE PUMPS When a vessel has a sewage holding tank, a sewage pump typically takes suction from the holding tank and discharges the sewage and waste water, based on applicable regulations, overboard or to an above-deck connection for transfer ashore. Electric-motor-driven single-stage centrifugal pumps are frequently used in this application. Some of these pumps have casings with large waterways and are fitted with special non-clog impellers. Alternatively, some vessels have sump-type centrifugal pumps that are submerged within the sewage tank and are driven by submersible motors or through vertical line shafting by above-tank motors. With either arrangement, two pumps are often provided for each holding tank.

Instead of a sewage holding tank, many vessels now have an onboard sewage treatment plant, referred to as a marine sanitation device (MSD). At least two pumps are ordinarily provided with each MSD to discharge the treated effluent overboard. Standard electric-motor-driven single-stage centrifugal pumps are frequently suitable for this purpose.

Some vessels also have one or more lift stations in which sewage and wastewater is collected before being transferred to an MSD or a larger sewage holding tank. Macerator pumps are frequently used to transfer a lift station's contents to the MSD or holding tank. A macerator grinds the sewage and breaks up solids into small particles that are more easily treated. Lift-station transfer pumps are usually started and stopped automatically by a float switch in the lift station. Two pumps are often provided for each lift station.

AIR-CONDITIONING CHILLED-WATER PUMPS Some vessels utilize freshwater as a secondary refrigerant for air conditioning. With this arrangement, a chilled-water pump circulates the fresh water through a chiller where it is cooled by the system's primary refrigerant. The water then passes through duct-mounted cooling coils, where it absorbs heat from air being supplied to temperature-controlled spaces located throughout the vessel. The chilled water may also be used to cool electronic components. Electric-motor-driven single-stage centrifugal pumps are frequently used in this application. A pressurized or elevated expansion tank that is typically installed on the suction side of the system maintains a minimum pressure at the inlet to the pumps.

CARGO PUMPS AND ASSOCIATED PUMPS

Cargo pumps are used to discharge the liquid cargo transported in a vessel's tanks. The types of vessels that carry liquid bulk cargo include ultra-large and very-large crude carriers (ULCC's and VLCC's), multi-petroleum product and chemical carriers, and liquefied natural gas (LNG) and liquefied petroleum gas (LPG) carriers. In addition, some freighters and supply vessels have tanks in which they can carry a limited amount of liquid cargo.

As liquid cargo is discharged from a vessel, the level in a cargo tank being emptied and, therefore, the suction head to the cargo pump are continuously reduced. This, as well as the fact that many cargoes have relatively high vapor pressures, means cargo pumps must often operate with relatively low values of available net positive suction head (*NPSH*). In addition, as a cargo tank is being emptied, vortices can form on the surface of the liquid in the tank, and air or inert gas (the space in a cargo tank above a flammable liquid is typically filled with inert gas) from the tank's atmosphere can be drawn through a vortex and into the cargo pump's suction. To reduce the potential for cavitation and vortex formation, the flow rate discharged by a cargo pump is frequently reduced by the use of either manually controlled or motorized remote-operated discharge valves during the latter stages of a pump-out cycle.

The materials used in the construction of a cargo pump's wetted components must be compatible with all of the fluids that the pump will discharge. In addition to the cargoes that the vessel will carry, this can also include seawater if the cargo pumps will be used to remove slops during tank washing. In addition, if fluids that are flammable or explosive will be pumped, components with contacting surfaces should be constructed from nonsparking materials.

A description of some of the different types of pumps used in marine cargo service follows.

CENTRIFUGAL CARGO PUMPS Single-stage centrifugal pumps are used to discharge liquid cargo on many crude-oil carriers. In addition, they are used on some large product carriers that transport a limited number of different liquid cargoes. Typically, three or four centrifugal cargo pumps are installed in one or more pump rooms located low in a vessel. Each pump can frequently remove cargo from multiple tanks through interconnected suction piping.

A centrifugal cargo pump may be furnished with a double-suction impeller mounted in a between-bearings configuration (Figure 11). Pumps of this type, which must be fitted with two shaft seals, are installed in both horizontal and vertical configurations. Alternatively, a vertically mounted centrifugal cargo pump design with an impeller that is overhung on the end of a shaft (Figure 12) is used on some vessels. This latter configuration enables both of the pump's external bearings and the single shaft seal to be located above the impeller, which facilitates maintenance. A centrifugal pump's bearing housings are often fitted with explosion-proof intrinsically safe resistance temperature detectors (RTDs) that permit the operator to detect a hot bearing before it leads to a serious casualty. In addition to the suction and discharge connections, one or more vents are often provided in the suction area of a centrifugal cargo pump's casing so vapor and gas mixed with the liquid entering the pump during a pump-out can be removed from the casing.

Although centrifugal cargo pumps are frequently driven by steam turbines, they are also sometimes driven by diesel engines or electric motors. To isolate it from the explosive vapor that is often present in a pump room, a centrifugal cargo pump's driver is usually installed in a separate machinery space located adjacent to the pump room. With this arrangement, each driver is typically flexibly coupled to the cargo pump that it drives through an intermediate jackshaft. The opening in the pump-room bulkhead (for a horizontal pump, Figure 13a) or overhead (for a vertical pump, Figure 13b) through which the jackshaft passes is ordinarily sealed with a gas-tight stuffing box to prevent explosive

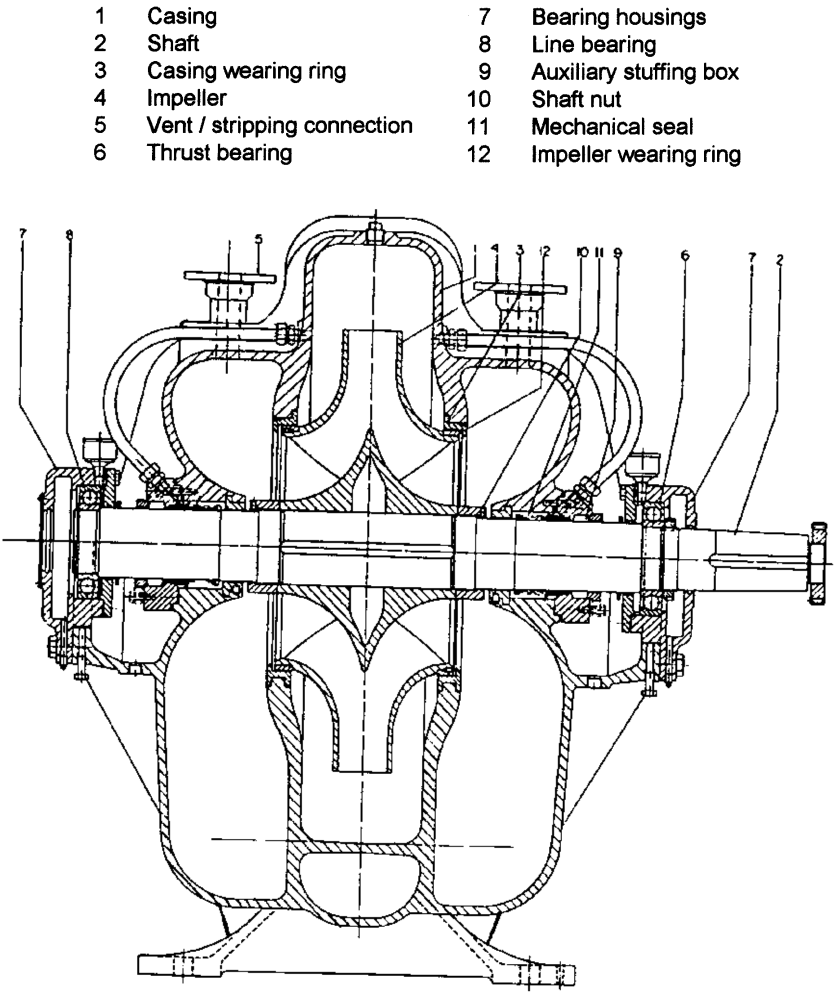

FIGURE 11 Between bearings centrifugal cargo pump (Flowserve Corporation)

vapor in the pump room from entering the machinery space. A thrust bearing is also frequently provided in the driver to support the weight of a jackshaft used with a vertically mounted cargo pump.

As the liquid level in a cargo tank being emptied approaches the inlet to the suction tailpipe (referred to as a suction strum), air or inert gas from the tank's atmosphere can be drawn into the cargo pump through vortices that form on the surface of the liquid. This entrained gas can cause a centrifugal cargo pump to lose suction before the cargo tank has been emptied. Although a separate stripping pump may then be used to remove the liquid remaining in the cargo tank, stripping pumps typically deliver much lower capacities than large centrifugal cargo pumps. Therefore, self-priming/stripping systems are sometimes employed to increase the amount of cargo that can be discharged by a centrifugal cargo pump. A recirculation-priming system and an automated-vacuum-stripping system are two types of systems that are used.

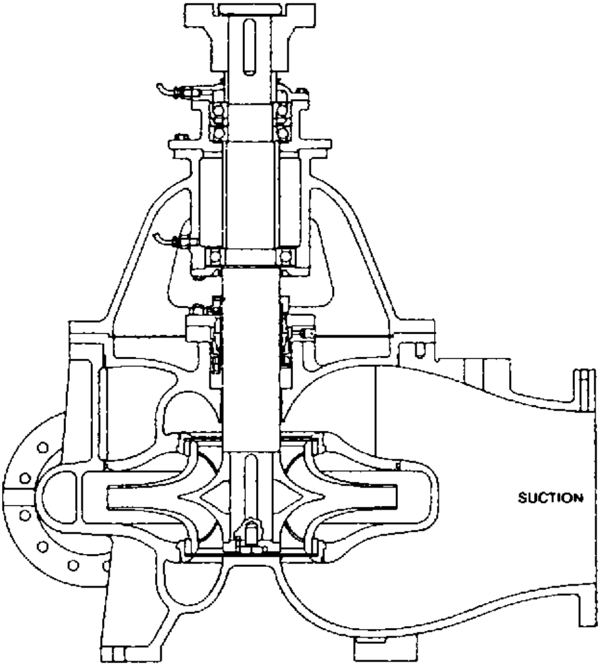

FIGURE 12 Vertical overhung centrifugal cargo pump (Flowserve Corporation)

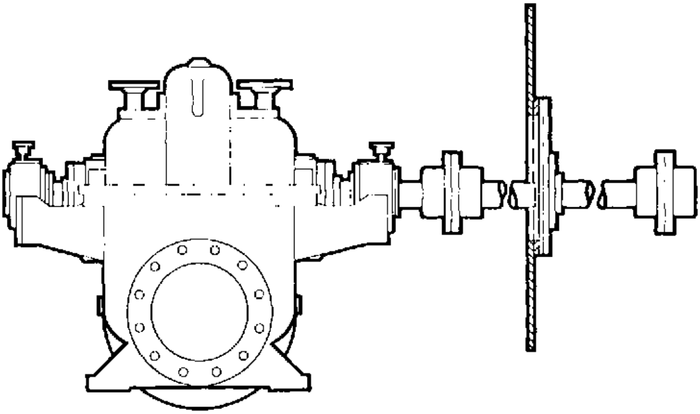

FIGURE 13A Horizontal centrifugal cargo pump with jackshaft (Flowserve Corporation)

In a typical recirculation-priming system, a recirculation tank is mounted between the cargo-system suction piping and the inlet to the cargo pump. In addition, one or more priming valves are mounted in the cargo discharge line near the outlet from the pump. Also, a recirculation line is connected from these valves back to the recirculation tank at the pump's inlet, a check valve is installed in the cargo-pump discharge piping above and

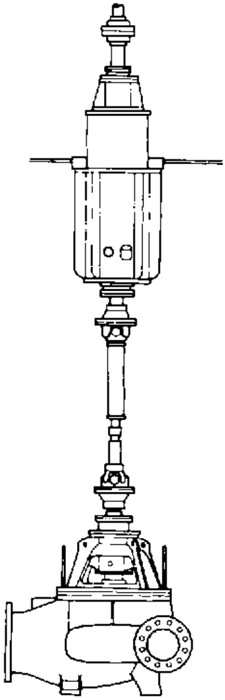

FIGURE 13B Vertical centrifugal cargo pump with jackshaft (Flowserve Corporation)

downstream from the priming valves, and a vent line with a second check valve is connected from the top of the recirculation tank to the cargo-pump discharge line just upstream of the discharge check valve. A branch from the recirculation tank's vent line is ordinarily piped to the vent/stripping connections in the cargo pump's casing.

At the beginning of a pump-out, the recirculation tank is filled with liquid cargo and the priming valves are closed. However, if, as the level in the cargo tank being emptied is reduced, the percentage of gas in the liquid being transferred increases sufficiently for the cargo pump to lose suction, the priming valves in the discharge line will open. This permits the cargo contained in the discharge line between these priming valves and the discharge check valve, which closes when the flow through it stops, to be returned through the recirculation line to the recirculation tank. As this liquid drains through the open priming valves, a vacuum is created in the discharge line. The gas contained in the recirculation tank is displaced by the returning liquid and is drawn by the discharge-line vacuum through the vent line and into the portion of the discharge piping that has been evacuated.

As the recirculated liquid cargo enters the recirculation tank, the liquid level within the tank rises until the submergence of the cargo pump's impeller is sufficient for the pump to regain suction. After this occurs, the flow of liquid through the pump will resume, the priming valves and the check valve in the vent line will close, and the gases that have accumulated in the discharge line will be forced through the discharge check valve. The priming cycles will continue until enough gas has been removed from the cargo suction line for the cargo pump to operate normally. As the level in the cargo tank being emptied continues to be reduced, the amount of gas entering the suction strum will increase, and the cargo pump will lose suction more frequently. When the amount of liquid remaining in the cargo tank is not sufficient for the cargo pump to be reprimed, the pump should be stopped.

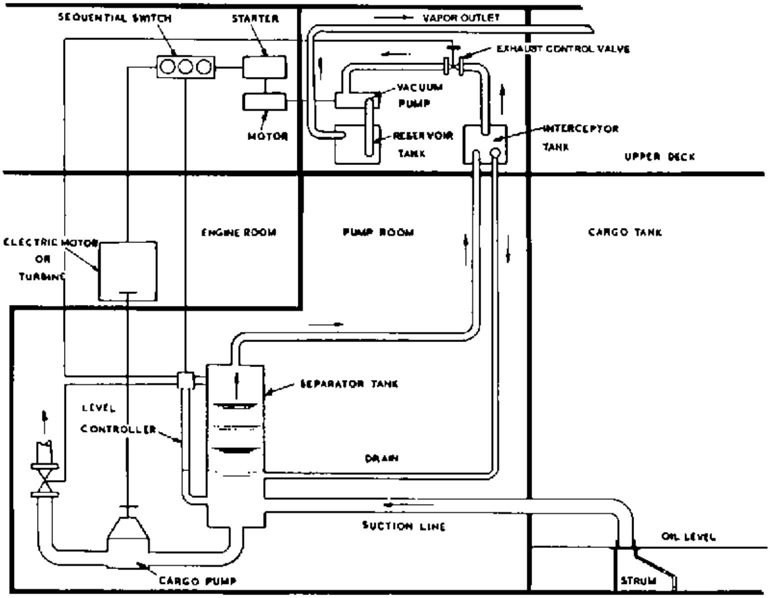

FIGURE 14 Automated-vacuum-stripping system (Flowserve Corporation)

The key components used in a typical automated-vacuum-stripping system (Figure 14) include a separator tank located at the cargo pump's inlet, a vent line connected to the top of the separator tank, an automatic exhaust control valve mounted in the vent line, one or more electric-motor-driven vacuum pumps, a cargo-pump discharge valve with actuator, and associated controls. As with the recirculation system, a branch from the separator tank's vent line is ordinarily piped to the vent connections in the cargo-pump casing.

At the beginning of a pump-out, the separator tank is ordinarily filled with liquid cargo. However, as the pump-out progresses, the liquid level in the cargo tank being emptied and the cargo-pump's suction pressure will both be reduced. Eventually, cargo vapor will typically begin to accumulate in the top of the separator tank and the liquid level in the separator tank will drop. At a specified point, the exhaust control valve in the vent line opens to permit vapor in the separator tank to pass through the vent line before it can enter the cargo pump. If the venting process is not sufficient, the vacuum pump will start and draw vapor out of the separator tank. After the vapor has been removed from the separator tank, the separator-tank liquid level may rise sufficiently for the vacuum pump to stop and the exhaust control valve to close. The exhaust control valve will, however, reopen and the vacuum pump will restart automatically if, because of the reaccumulation of vapor in the top of the separator tank, the separator tank level again drops. The exhaust control valve will continue to open and close and the vacuum pump will continue to cycle on and off automatically, as needed, based on the level in the separator tank.

With further reductions in the cargo-tank liquid level, the amount of cargo that vaporizes in the cargo-pump suction line and separator tank will increase. In addition, as the cargo-tank liquid level approaches the suction strum, vortices will typically form on the surface of the liquid in the cargo tank and draw gas from the tank's atmosphere into the suction line. As the percentage of vapor and entrained gas in the liquid cargo being unloaded increases, the frequency of the exhaust-control-valve/vacuum-pump cycles described above will increase. Eventually, near the end of the pump-out, it will usually become necessary for the exhaust control valve to remain open and for the vacuum pump to operate continuously.

In addition to operating the exhaust control valve and the vacuum pump, the automated-vacuum-stripping system will normally automatically throttle the cargo pump's discharge valve whenever the vacuum pump is started. In addition, when permitted by the type of driver used, the cargo pump's operating speed may be reduced. Controls may also be included in the system to automatically shut down the cargo pump driver when the pump-out has been completed.

DEEP-WELL CARGO PUMPS Vertical line-shaft deep-well pumps are used to discharge liquid cargo on some multi-product and chemical carriers. Therefore, a deep-well cargo pump must frequently be suitable to transfer a wide range of liquids having different specific gravities, vapor pressures, viscosities, and temperatures. Some cargoes, such as lubricating oils, waxes, and other viscous cargoes, may be heated to improve pumpability. With certain cargoes, such as molten sulfur, steam, or a heated liquid may even be circulated through jackets that surround the deep-well pump to prevent the cargo from solidifying within the pump. In addition, deep-well pumps are sometimes used to discharge cryogenic cargoes, such as liquefied petroleum gas (LPG).

A deep-well cargo pump can be driven by a vertical electric or hydraulic motor mounted on top of the pump's discharge head. Alternatively, a deep-well cargo pump may be driven through a right-angle gear mounted on the discharge head by a horizontal motor, steam turbine, or diesel engine. Although a deep-well cargo pump's discharge head is often mounted on a vessel's main deck, on some vessels, the deep-well-cargo-pump discharge heads are located below deck in a pump room. In addition, in some cases, a deep-well cargo pump's horizontal driver is located in an adjacent space and is coupled to the pump's right-angle gear with a jackshaft that passes through a bulkhead separating the pump's discharge head from the driver. The opening for the jackshaft in the bulkhead is ordinarily sealed with a gas-tight stuffing box so the driver can be isolated from any explosive vapor that may be emitted from the pup. Some designs are also available with submersible motors that allow the entire pump-driver assembly to be located at the bottom of the cargo tank.

Many deep-well cargo pumps are furnished with a multistage bowl assembly that has single-suction impellers. When high-vapor-pressure or high-viscosity cargo will be pumped, an inducer is sometimes mounted on the lower end of the bowl assembly's impeller shaft to reduce the pump's net positive suction head requirements. Alternatively, a deepwell pump may be fitted with a special low-*NPSH* first-stage impeller, or, in some cases, a double-suction first-stage impeller. A spool piece is sometimes installed between the top of a deep-well pump's bowl assembly and the lower end of its column assembly so the bowls can be removed for maintenance while the column and discharge head are still in place.

Hydraulic axial unbalance resulting from the use of single-suction impellers can result in the generation of a high axial thrust. Some deep-well pumps are fitted with a balancing device, such as a balancing drum or front and back impeller wear rings, to reduce this thrust. Alternatively, a thrust bearing is frequently used to absorb the axial thrust acting on a deep-well pump's shaft. This bearing is sometimes installed in a housing that is an integral part of the pump's discharge head. In many cases, however, the thrust bearing is in the vertical driver or right-angle gear (when a horizontal driver is used) that is mounted on top of the pump's discharge head. With this latter arrangement, the deep-well pump's top shaft is typically secured to the vertical driver or gear either with a rigid coupling when the driver or gear has a solid shaft or with an adjusting nut when a hollow-shaft driver or gear is used. It is always important that the pump shaft be raised the proper amount during assembly to prevent contact between the pump's rotating and stationary parts during operation.

Mating sections of a deep-well pump's line shaft are typically connected with threaded or keyed couplings. Radial bearings that support the line shaft are frequently mounted in brackets, sometimes referred to as spiders, that are sandwiched between mating sections of column pipe. Impeller- and line-shaft bearings are often lubricated by the pumped cargo. Consequently, bearing materials must typically be compatible with all of the fluids that will be pumped. The bearings should also be able to tolerate operation with loss of suction if the deep-well pump will be used for stripping or during tank cleaning. Although bronze bearings are common, bearings constructed from carbon, polytetrafluoroethylene (PTFE) compounds, and various composites and plastics have also been used.

The use of a single shaft seal at the location where a deep-well pump's top shaft penetrates the discharge head is sometimes suitable. A multiple sealing arrangement consisting of two packed stuffing boxes or a double mechanical seal may be utilized, however, when a deep-well pump will discharge a volatile cargo. In addition, if a deep-well pump is fitted with a double mechanical seal, a static seal may also be provided to prevent vapor from escaping around the pump's shaft during periods when the mechanical seals are being replaced. A reservoir tank that stores liquid for seal lubrication is often mounted on the side of the discharge head of a deep-well pump that has one or more mechanical seals.

On some multi-product and chemical carriers, a separate deep-well pump is installed in each cargo tank. This arrangement eliminates the need for suction piping, and it can result in a high degree of cargo segregation. On a double-bottom vessel, the deep-well pump's suction opening is frequently submerged in a suction well located in the bottom of the cargo tank. In-tank supports are often provided to stabilize the pump during periods of pitch and roll. However, to prevent these supports from restricting thermal expansion and distorting a pump's column or line shaft as a vessel flexes, they are generally not rigidly attached to the pump.

To prevent fluid in a deep-well pump's discharge head, column pipe, and bowl assembly from draining back into a cargo tank after the pump is stopped, a deep-well cargo pump's inlet opening is sometimes fitted with a nonreturn suction valve (Figure 15). During normal operation, the valve is open. However, after the discharge cycle has been completed, the suction valve closes automatically. The deep-well pump's driver is then stopped, the pump's above-deck discharge valve is closed, and compressed air or inert gas is injected into the pump through a connection in the discharge head. The gas forces the cargo contained within the deep-well pump out through a bypass line connected to the lower portion of the bowl assembly and into the vessel's piping.

On some vessels, such as those that carry either a limited number of different cargoes or cargoes that are not sensitive to contamination, each deep-well pump may be used to discharge cargo from several of the vessel's tanks. When this arrangement is used, each deep-well pump is generally mounted in a suction tank or can that is connected to multiple cargo tanks via suction piping.

A deep-well cargo pump that is installed in a suction can is frequently fitted with automatic priming valves that enable the pump to remove gas and vapor from the can and from the attached suction piping. The operation of these priming valves and their associated components is often similar to the operation of the recirculation system used to reprime centrifugal cargo pumps. A typical self-priming deep-well pump is fitted with two or three priming valves that are mounted in the pump's column pipe just above the bowl assembly (Figure 16). When the pump is discharging fluid, these valves are closed. However, when the deep-well pump loses suction, the priming valves open and permit the liquid contained within the pump's column and discharge head to drain into the suction can. As this liquid drains through the open priming valves, a vacuum is created in the discharge head and column pipe. The gas in the bottom of the can, which is displaced by the returning liquid, is drawn by the vacuum through a vent line that is connected from the top of the suction can to the pump's discharge head and into the evacuated portion of the discharge head and column. When the liquid level in the suction tank rises sufficiently for the deep-well pump to regain suction, the flow of liquid through the pump resumes, the priming valves and a check valve in the vent line close, and the gases that have been drawn into the column and discharge head are forced out through a check valve installed at the pump's discharge connection. The priming cycles will continue until enough gas has been removed from the cargo suction line for the deep-well pump to operate normally. As the level in the cargo tank being emptied continues to be reduced, the amount of gas entering the suction can will increase, and the deep-well pump will lose suction more frequently. When the amount of liquid remaining in the cargo tank is not sufficient for the deep-well pump to be reprimed, the pump should be stopped.

HYDRAULIC-MOTOR-DRIVEN SUBMERSIBLE CARGO PUMPS Hydraulic-motor-driven submersible pumps are used to discharge cargo on many chemical and multi-petroleum-product carriers. In addition, they are used for cargo discharge on some crude carriers. A separate

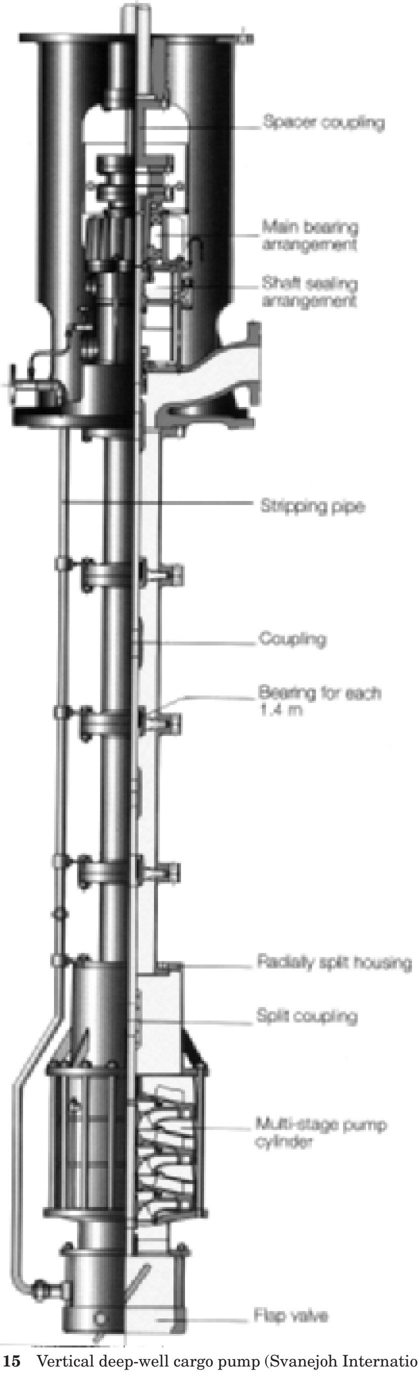

FIGURE 15 Vertical deep-well cargo pump (Svanejoh International A/S)

600	Discharge Head
604	Adjusting nut
608	Head or top shaft
616	Stuffing box
617	Stuffing-box bushing
618	Gland
620	Packing
624	Bypass pipe
641	Top column pipe
644	Bottom column pipe
646	Line shaft
649	Line-shaft coupling
652	Bearing retainer or bracket
653	Line-shaft bearing
655	Impeller-shaft coupling
660	Pump or impeller shaft
666	Top bowl
670	Intermediate bowl
672	Bowl bearing
673	Impeller
674	First-stage (priming-stage) impeller
677	Impeller taper lock
685	Adapter case
689	Suction bell
690	Suction-bell bearing
702	Autoprime (self-priming) valve housing
704	Autoprime (self-priming) valve spring
705	Autoprime (self-priming) valve
706	Air-release (vent) check valve
707	Air-release (vent) line
708	First-stage (priming-stage) impeller
762	Column-flange bolt
764	Bowl cap screw
779	Stuffing-box gasket

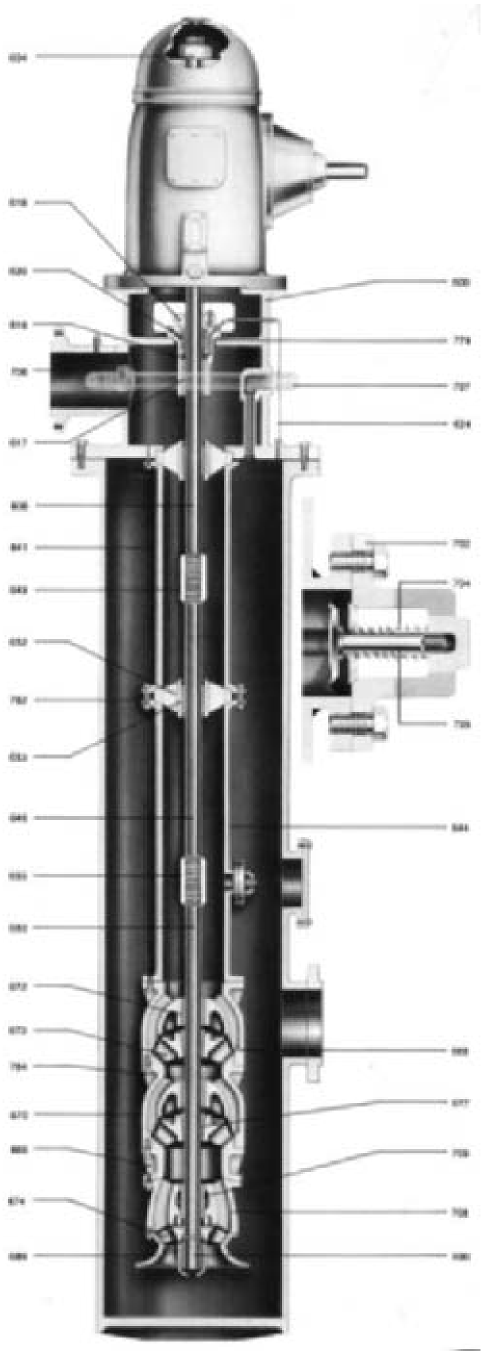

FIGURE 16 Self-priming vertical deep-well cargo pump (ITT/Gould Pumps, Inc.)

pump is usually installed in each cargo tank, which eliminates the need for suction piping. In addition, to prevent different cargoes carried by a vessel from mixing, each pump may be connected to an independent above-deck discharge line. Although the pressurized oil required to drive the hydraulic motors for all of the cargo pumps on a vessel is frequently supplied by a central hydraulic system, a self-contained hydraulic power pack is furnished for each cargo pump on some vessels.

Each submersible unit usually consists of a single-stage end-suction centrifugal pump with a short shaft that is driven, often through either a splined connection or a coupling, by a hydraulic motor (Figure 17). The pump's shaft is typically supported by antifriction ball or roller bearings that are submerged in and lubricated by the hydraulic oil that drains from the motor. The pump is mounted on the lower end of a vertical support pipe that is suspended from a top plate installed on the vessel's main deck. The hydraulic-oil supply and return lines are ordinarily enclosed within this support pipe. Fluid discharged from the pump's volute-type casing typically passes through a second vertical pipe that terminates at an above-deck discharge connection. A control valve that can be used to vary the flow of hydraulic oil to the motor and, therefore, the pump's operating speed valve is usually mounted on the above-deck top plate.

Mechanical or lip-type seals are generally used at the shaft penetrations in a submersible pump-and-hydraulic-motor assembly to prevent hydraulic oil from leaking into a cargo tank and to prevent cargo from mixing with hydraulic oil. Air or inert gas can usually be circulated through a void space or cofferdam that runs through the vertical support pipe that surrounds the hydraulic supply and return lines, the housing that surrounds the hydraulic motor, and a chamber between the pump's seals. After leaving the cofferdam, this gas frequently passes through an above-deck trap in which liquid is separated so a hydraulic-oil or cargo-seal leak can be detected. Compressed air or inert gas is also frequently injected into a submersible pump's above-deck discharge connection after a pump-out has been completed to force cargo contained within the vertical discharge pipe out through a small bypass line connected to the base of the pump. However, because a submersible pump's inlet is generally not fitted with a nonreturn valve, this operation must be performed before the driver is stopped.

It is often possible to disassemble a submersible pump and remove it from a cargo tank for maintenance without disturbing the vertical support pipe or top plate. In most cases, vessels fitted with hydraulic-motor-driven submersible cargo pumps carry one or more portable hydraulically driven submersible pumps that can be lowered into a cargo tank with a winch and used to discharge cargo if the main pump in the tank is inoperable.

In addition to being used for cargo discharge, a submersible cargo pump is sometimes operated while a vessel is underway to circulate cargo through a diffuser so sediment in the liquid does not settle in the cargo tank or through an above-deck heater to prevent the cargo from cooling. Also, to eliminate the need for separate drop lines, on some vessels, liquid is loaded into small cargo tanks by allowing it to flow backwards through a vessel's submersible cargo pumps. When this is done, a nonreverse brake is generally mounted on the submersible pump's shaft to prevent reverse rotation during loading. However, because of the resistance created by the pump's impeller, loading through a submersible cargo pump can increase loading times.

ELECTRIC-MOTOR-DRIVEN SUBMERSIBLE CARGO PUMPS Electric-motor-driven submersible pumps are often used to discharge cargo from liquefied natural gas (LNG) and liquefied petroleum gas (LPG) carriers. Each submersible unit typically consists of a vertical centrifugal pump with either one or two impellers that are mounted on the lower end of an electric motor's shaft. In addition, an inducer is often installed at the inlet to the first-stage impeller (the only impeller in a single-stage pump) to reduce the pump's net positive suction head requirements.

Pumps used for cargo unloading are frequently installed directly within a vessel's cargo tanks. Cargo typically enters an electric-motor-driven submersible pump through an opening in the bottom of the pump. After being discharged by the pump's impellers, the cargo often enters an annular passage formed between the motor frame and an outer casing that surrounds the motor. A portion of this liquid usually passes through openings in the motor frame and flows through the motor. In addition to cooling the motor, this bypass

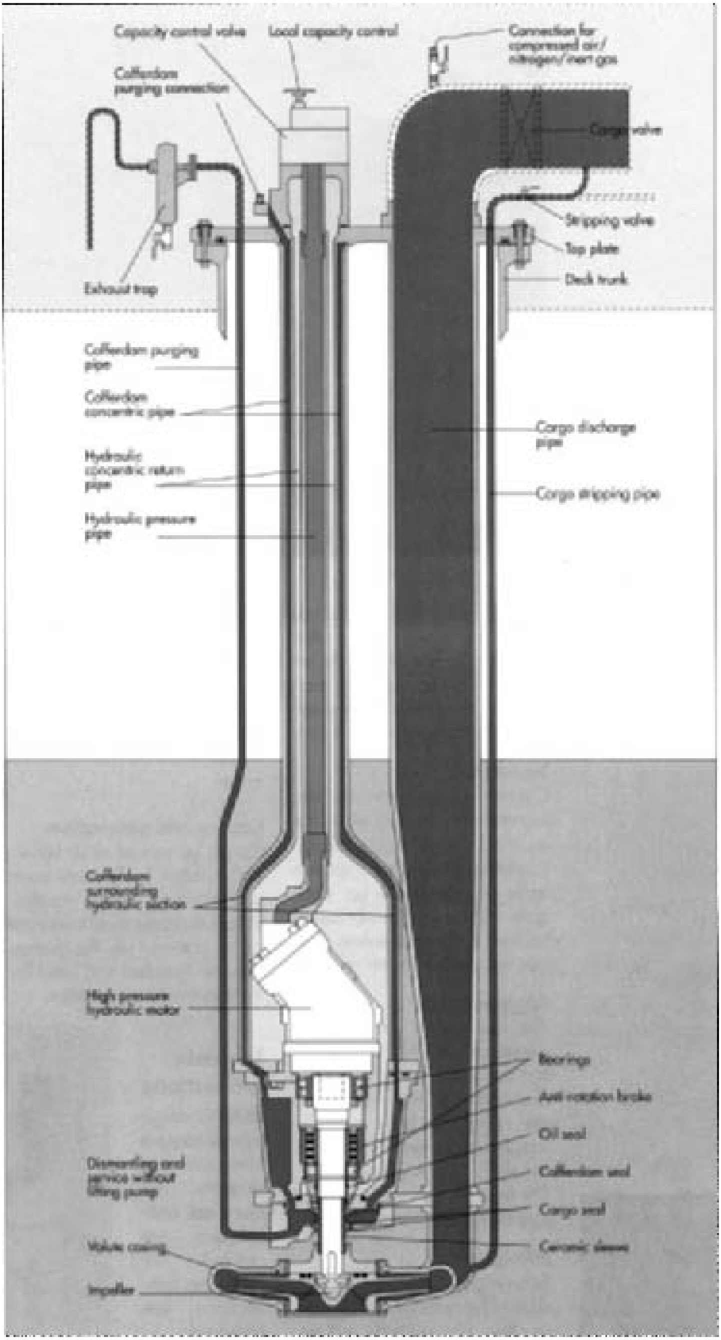

FIGURE 17 Hydraulic-motor-driven submersible cargo pump (Frank Mohn AS)

flow lubricates the ball bearings that support the common pump and motor shaft. After leaving the top of the annular passage, the cargo that has been discharged by the pump passes through a connection located above the motor and enters a vertical pipe that leads to the main deck.

In addition to the main cargo unloading pumps, smaller spray or cool-down pumps are often installed on an LNG carrier. When an LNG carrier is unloaded, some cargo is typically left in each tank. During the voyage back to the loading terminal, the spray pumps circulate this LNG through a cool-down header and spray nozzles in each tank. The LNG vaporizes as it passes through the spray nozzles and absorbs heat from the cargo tanks. This enables the tanks to be kept cold until the vessel is reloaded with additional cargo.

ROTARY CARGO PUMPS Some vessels that carry high-viscosity cargoes have multiple-screw- or lobe-type rotary main cargo unloading pumps. In addition, vessels that have centrifugal-type main cargo pumps sometimes also have lower-capacity screw, lobe, or sliding-vane pumps that are used to strip cargo tanks.

A rotary main cargo or stripping pump may be installed in a pump room located in the lower part of a vessel. With this arrangement, the pump can typically take its suction from multiple cargo tanks through interconnected suction piping. So the driver can be isolated from explosive vapor in the pump room, it is frequently installed in an adjacent space and is coupled to the pump with a jackshaft that passes through a bulkhead stuffing box. A typical rotary cargo pump is driven either by a variable-speed driver or by a constant-speed driver through a fluid coupling, which enables the pump speed and, therefore, the capacity delivered to be changed during a pump-out.

Some multiple-screw rotary cargo pumps are furnished in a deep-well configuration (Figure 18), which can eliminate much of the suction piping in a cargo system. Although a vertical driver can be used to drive a deep-well rotary pump, many deep-well rotary pumps are driven through right-angle gears by horizontal motors or engines to facilitate maintenance and reduce vertical height requirements. Typically, the output shaft of the above-deck vertical driver or right-angle gear is connected to the power rotor in the pump through a line shaft that is enclosed within a vertical column pipe. Cargo discharged by a deep-well rotary pump may pass through the column, or it may pass through a separate vertical pipe mounted adjacent to the column. Bearings that support the line shaft, together with the pump's bearings and timing gears, when used, are sometimes lubricated by the pumped fluid. Alternatively, a deep-well rotary pump may be furnished with a pressurized forced-feed lubrication system.

RECIPROCATING CARGO PUMPS Direct-acting reciprocating pumps are used to strip cargo tanks on some vessels. These units typically have double-acting pistons in both the liquid- and the drive-endcylinders. Some reciprocating stripping pumps are mounted in a pump room and are connected to the vessel's cargo tanks through suction piping. With this arrangement, one pump can be used to strip multiple tanks. Pumps installed in this fashion are frequently duplex units (that is, two liquid cylinders) that are mounted vertically and are driven by steam (Figure 19).

When used on multi-product carriers, a separate reciprocating stripping pump may be used for each cargo tank. These stripping pumps are frequently driven by compressed air or inert gas. On some vessels, a horizontal duplex reciprocating pump is mounted in the bottom of each cargo tank. Alternatively, a vertical simplex (that is, one liquid cylinder) pump with a liquid cylinder that is submerged within a cargo tank and a drive cylinder that is mounted on deck is sometimes used. With this latter configuration, the liquid-end piston is coupled to the piston in the drive cylinder through a long intermediate shaft.

INERT-GAS SYSTEM PUMPS To reduce the risk of explosion and fire, the space in a cargo tank above a flammable liquid must typically be kept filled with an inert gas. Some vessels use flue gas from either a fossil-fueled steam boiler or a dedicated oil-fired inert-gas generator to inert cargo tanks. A pump is usually required to deliver seawater to a scrubber where the water is used to cool, clean, and desulfurize the inert gas. A separate pump is also frequently required to supply seawater to a wet-type deck seal that is used to pre-

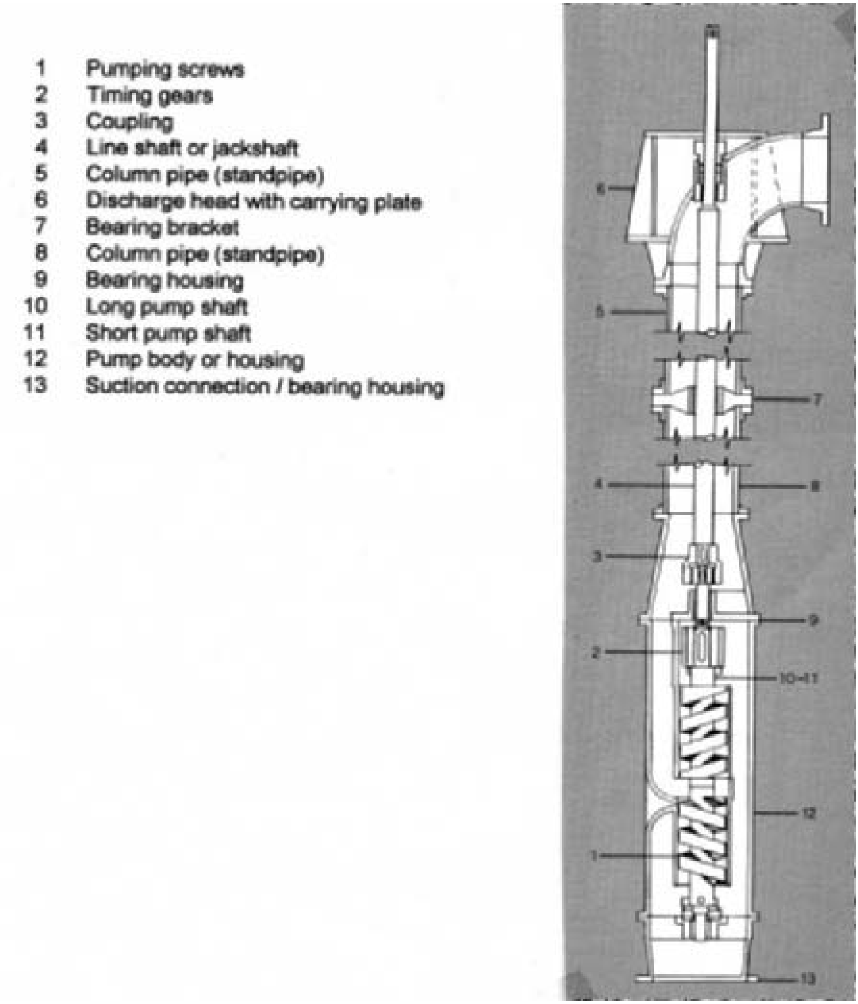

FIGURE 18 Deep-well screw pump (IMO-Warren Pump)

vent vapor in the vessel's cargo tanks from flowing backwards through the inert-gas supply piping and into the machinery spaces. It is common to use single-stage electric-motor-driven centrifugal pumps for both of these applications.

TANK-CLEANING PUMPS On some vessels, hot seawater is used to clean cargo tanks of residue that remains in the tanks after the liquid cargo has been discharged. A typical tank-cleaning or tank-washing pump takes suction from a sea chest and discharges seawater through a heater in which it is often heated to a temperature of approximately 200°F (93°C). The hot seawater then passes through nozzles in tank washing machines and is sprayed onto the sides of the cargo tanks being cleaned. Single- and two-stage centrifugal pumps that are driven by steam turbines, electric motors, or hydraulic motors are frequently used in this application. A tank-washing pump may also be used for other purposes, such as fire fighting.

1 Steam cylinder
2 Steam piston rod
3 Liquid cylinder
4 Liquid-cylinder liner
5 Liquid piston rod
6 Liquid piston
7 Liquid piston packing
8 Liquid valve service
9 Air chamber (pulsation dampener)

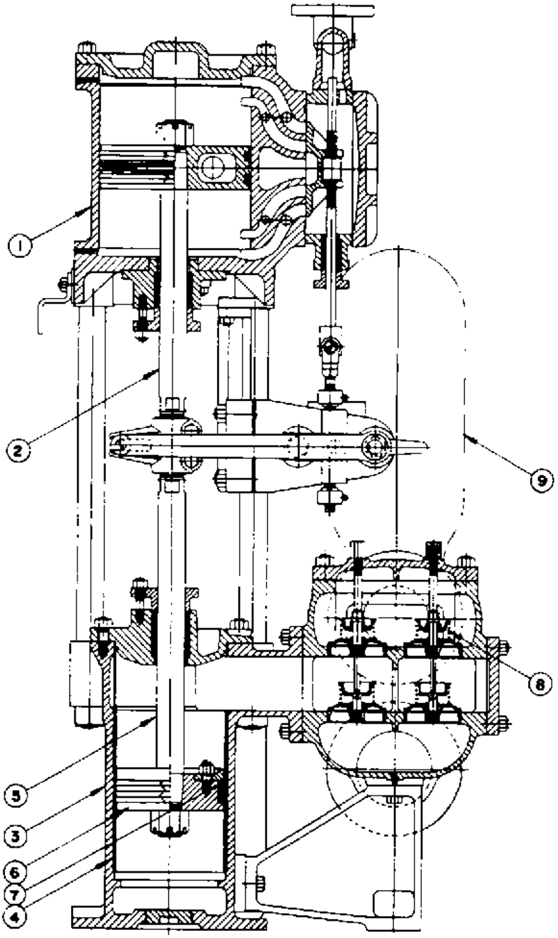

FIGURE 19 Duplex direct-acting reciprocating pump (Flowserve Corporation)

As an alternative to washing cargo tanks with seawater, crude carriers frequently clean tanks with crude oil, referred to as crude-oil washing (COW). A general-service pump is often used on a crude carrier to deliver pressurized crude oil to the vessel's tank-washing machines. The pump may receive this oil from a holding or slop tank on the vessel. The general service pump may also be used to deliver cargo to an eductor that strips cargo tanks during the final stages of unloading or during crude-oil washing. This cargo, which serves as the motive fluid in the eductor, mixes with the fluid being removed from the cargo tank and is then usually discharged by the eductor into one of the vessel's slop tanks. On a typical crude carrier, the general-service pump is similar in configuration to the vessel's main cargo pumps but is smaller.

FURTHER READING

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