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INSTALLATION, OPERATION AND MAINTENANCE

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The information contained in this chapter is general and should be supplemented by the specific instructions prepared by the manufacturer of the pump in question.

INSTALLATION

INSTRUCTION BOOKS Instruction books are intended to help keep the pumps in an efficient and reliable condition at all times. It is necessary, therefore, that instruction books be available to all personnel involved in this function.

Preparation for Shipment After a pump is assembled in the manufacturer's shop, it should be suitably prepared for the type of shipment the purchaser has specified. This can include blocking of the rotor, when necessary. If the rotor is blocked, this should be identified by weather-resistant tags. As shipped, the equipment should be suitable for at least six months of outdoor, uncovered storage from the time of shipment, with no disassembly required at the time of installation and operation except for possible inspection of bearings and seals. If storage for a longer time is required and specified, the manufacturer and purchaser should agree on the preparation and storage procedures and requirements prior to shipment.

The pump and driver should be prepared for shipment only after all testing and inspection processes have been completed and the equipment has been released for shipment by the purchaser. If packing was used for testing, it should be removed before shipment. Usually pumps are not disassembled after performance testing. The pump must be completely drained and dried, and all internal parts should be coated with a suitable rust preventative within four hours of testing. Alternatively, within four hours of testing, the pump and seal chamber should be drained to the extent practical, filled with a water-displacing inhibitor, and redrained before shipment.

Flanged openings should be provided with covers, usually metal, at least $\frac{3}{16}$ in (5 mm) thick and sealed with an elastomeric gasket. Threaded openings should be closed with steel caps or plugs. Any openings that have been prepared for welding in the field should be provided with closures designed to protect against damage to the welding surface as well as the entrance of foreign materials into the equipment.

Exposed shafts and shaft couplings should be wrapped with waterproof cloth or paper and sealed with oil-proof adhesive tape. Bearing assemblies should be protected from moisture and dirt (dust). If vapor phase inhibitor crystals in bags are installed to absorb moisture, the location of the bags should be tagged so they will be removed before installation of the equipment in the field.

Usually a copy of the manufacturer's standard installation instructions is packed inside the equipment prior to shipment.

Care of Equipment in the Field The manufacturer should provide the purchaser with the instructions necessary to preserve the integrity of the original storage preparation when the equipment is received at the job site and prior to start-up. All equipment and materials should be stored free from direct ground contact and away from areas subject to collecting water. Indoor storage should be used whenever possible.

All carbon and low alloy steel surfaces should be protected from any contact with corrosive environments to prevent rust formation. All items with machined surfaces should be stored to facilitate periodic examination for damage or rust. Storage areas should be kept clean and free from such contaminants as concrete chipping, sanding, and painting.

Periodic rotation of equipment shafts should be performed in accordance with the equipment manufacturer's instructions for the specific equipment type and preservation methods used. When rotation is performed, determine first that all shipping blocks on rotating components have been removed and that there is adequate lubrication before rotation.

Certain preservatives and storage lubricants can affect safety and operating life of the equipment, especially if they react with the process fluid or operating lubricant. The installer should ensure that all preservative and storage lubricants are suitable for the specific application. Preservatives should not be used on surfaces where prohibited by the process or application.

Pump Location Working space must be checked to assure adequate accessibility for maintenance. Axially split casing horizontal pumps require sufficient headroom to lift the upper half of the casing free of the rotor. The inner assembly of radially split multistage centrifugal pumps is removed axially (Subsection 2.2.1, Figure 23). Space must be provided so the assembly can be pulled out without canting it. For large pumps with heavy casings and rotors, a traveling crane or other facility for attaching a hoist should be provided over the pump location.

Pumps should be located as close as practicable to the source of liquid supply. Whenever possible, the pump centerline should be placed below the level of the liquid in the suction reservoir.

Foundations Foundations may consist of any structure heavy enough to afford permanent rigid support to the full area of the baseplate and to absorb any normal strains or shocks. Reinforced concrete foundations built up from solid ground are the most satisfactory. Although most pumping units are mounted on baseplates, very large equipment may be mounted directly on the foundations by using soleplates under the pump and driver feet. Misalignment is corrected with shims.

The space required by the pumping unit and the location of the foundation bolts are determined from the drawings supplied by the manufacturer. Each foundation bolt (Figure 1) should be surrounded by a pipe sleeve three or four diameters larger than the bolt. After the concrete foundations are poured, the pipe is held solidly in place but the bolt may be moved to conform to the corresponding hole in the baseplate.

When a unit is mounted on steelwork or some other structure, it should be placed directly over or as near as possible to the main members, beams, or walls and should be supported so the baseplate cannot be distorted or the alignment disturbed by any yielding or springing of the structure or of the baseplate.

Mounting of Vertical Wet-Pit Pumps A curb ring or soleplate must be used as a bearing surface for the support flange of a vertical wet-pit pump. The mounting face must be machined because the curb ring or soleplate will be used in aligning the pump.

If the discharge pipe is located below the support flange of the pump (belowground discharge), the curb ring or soleplate must be large enough to pass the discharge elbow during assembly. A rectangular ring should be used (Figure 2). If the discharge pipe is located above the support flange (aboveground discharge), a round curb ring or soleplate should be provided with clearance on its inner diameter to pass all sections of the pump below the support flange (Figure 3). A typical method of arranging a grouted soleplate for vertical pumps is shown in Figure 4.

If the discharge is belowground and an expansion joint is used, it is necessary to determine the moment that may be imposed on the structure. The pump casing should be attached securely to some rigid structural members with tie rods. If vertical wet-pit pumps are very long, some steadying device is required irrespective of the location of the discharge or of the type of pipe connection. Tie rods can be used to connect the unit to a wall, or a small clearance around a flange can be used to prevent excessive displacement of the pump in the horizontal plane.

Alignment When a complete unit is assembled at the factory, the baseplate is placed on a flat, even surface; the pump and driver are mounted on the baseplate; and the coupling halves are accurately aligned, using shims under the driver mounting surfaces where necessary. The pump is usually doweled to the baseplate at the factory, but the driver is left to be doweled after installation at the site.

The unit should be supported over the foundation by short strips of steel plate or shim stock close to the foundation bolts, allowing a space of $\frac{3}{4}$ to 2 in (2 to 5 cm) between the bottom of the baseplate and the top of the foundation for grouting. The shim stock should extend fully across the supporting edge of the baseplate. The coupling bolts should be

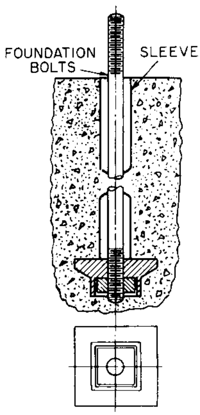


FIGURE 1 Foundation bolt

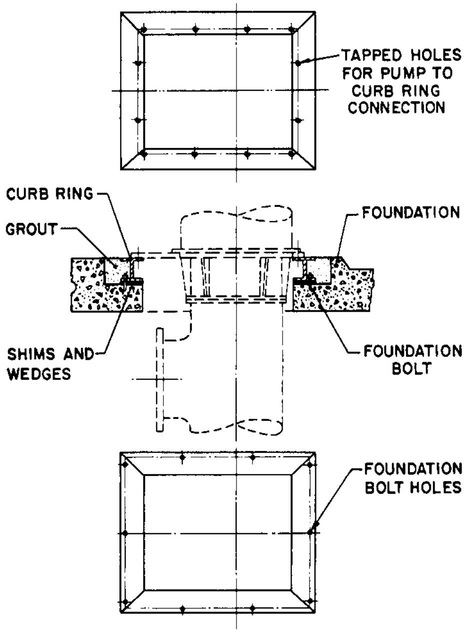


FIGURE 2 Rectangular curb ring for belowground discharge vertical pump

removed before the unit is leveled and the coupling halves are aligned. Where possible, it is preferable to place the level on some exposed part of the pump shaft, sleeve, or planed surface of the pump casing. The steel supporting strips or shim stock under the baseplate should be adjusted until the pump shaft is level, the suction and discharge flanges are vertical or horizontal as required, and the pump is at the specified height and location. When the baseplate has been leveled, the nuts on the foundation bolts should be made handtight.

During this leveling operation, accurate alignment of the unbolted coupling halves must be maintained. A straightedge should be placed across the top and sides of the coupling, and at the same time the faces of the coupling halves should be checked with a tapered thickness gage or with feeler gages (Figure 5) to see that they are parallel. For all alignment checks, including parallelism of coupling faces, both shafts should be pressed hard over to one side when taking readings.

When the peripheries of the coupling halves are true circles of equal diameter and the faces are flat and perpendicular to the shaft axes, exact alignment exists when the distance between the faces is the same at all points and when a straightedge lies squarely across the rims at any point. If the faces are not parallel, the thickness gage or feelers will show variation at different points. If one coupling is higher than the other, the amount may be determined by the straightedge and feeler gages.

Sometimes coupling halves are not true circles or are not of identical diameter because of manufacturing tolerances. To check the trueness of either coupling half, rotate it while holding the other coupling half stationary and check the alignment at each quarter turn of the half being rotated. Then the half previously held stationary should be revolved and the alignment checked. A variation within manufacturing limits may be found in either of the half-couplings, and proper allowance for this must be made when aligning the unit.

A more exact method for checking alignment that is recommended requires the use of a dial indicator. With the indicator bolted to the pump half of the coupling, both radial and

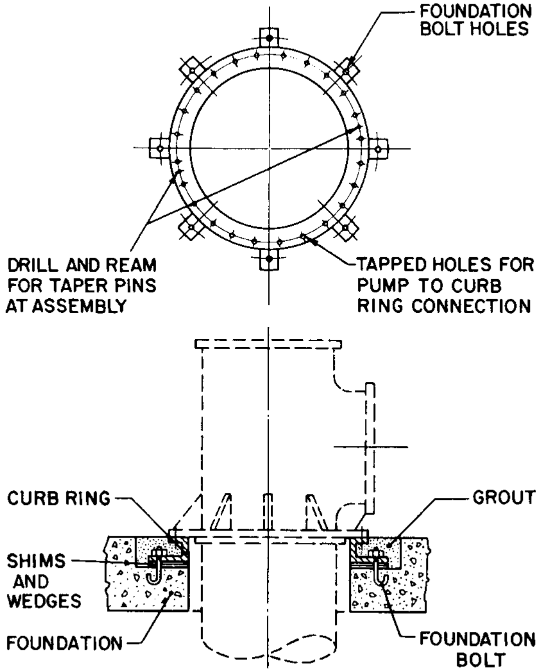


FIGURE 3 Round curb ring for aboveground discharge vertical pump

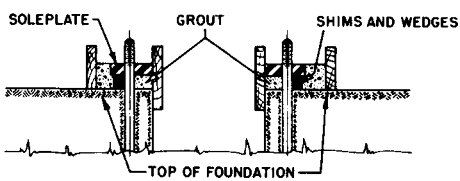


FIGURE 4 Grouting form for vertical pump soleplate (ANSI B-58.1 [AWWAE 101-61])

axial alignment can be checked, as illustrated in Figure 6. This method is called face-and-rim alignment. With the button resting on the periphery of the other coupling half, the dial should be set at zero and a mark chalked on the coupling half at the point where the button rests. For any check (top, bottom, or sides), both shafts should be rotated the same amount, that is, all readings on the dial should be made with the button on the chalk mark. The dial readings will indicate whether the driver must be raised, lowered, or moved to either side. After any movement, it is necessary to check that the coupling faces remain parallel to one another.

For example, if the dial reading at the starting point is set to zero and the diametrically opposite reading at the bottom or sides shows ±0.020 in (±0.508 mm), the driver must be raised or lowered by shimming or moved to one side or the other by half of this reading. The same procedure is used to align gear couplings, but the coupling covers must first be moved back out of the way and all measurements should be made on the coupling hubs.

When a spacer-type coupling connects the pump to its driver, a dial indicator should be used to check the alignment (Figure 7). The spacer between the coupling halves should be removed to expose the coupling hubs. The coupling nut on the end of the shaft may be used

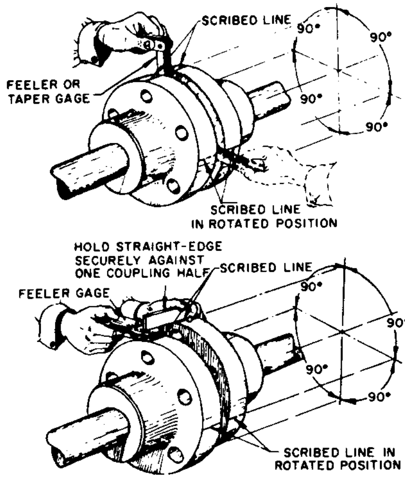


FIGURE 5 Coupling alignment using feeler gages

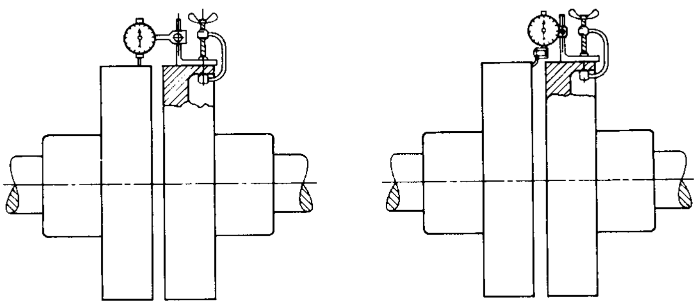


FIGURE 6 Use of dial indicator for face-and-rim alignment of standard coupling

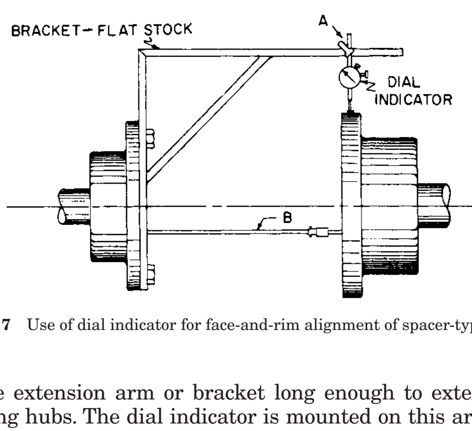


FIGURE 7 Use of dial indicator for face-and-rim alignment of spacer-type coupling

to clamp a suitable extension arm or bracket long enough to extend across the space between the coupling hubs. The dial indicator is mounted on this arm, and alignment is checked for both concentricity of the hub diameters and parallelism of the hub faces.

Changing the arm from one hub to the other provides an additional check. The dial extension bracket must be checked for sag, and readings must be corrected accordingly.

The clearance between the faces of the coupling hubs and the ends of the shafts should be such that they cannot touch, rub, or exert a pull on either pump or driver. The amount of this clearance may vary with the size and type of coupling used. Sufficient clearance will allow unhampered endwise movement of the shaft of the driving element to the limit of its bearing clearance. On motor-driven units, the magnetic center of the motor will determine the running position of the motor half-coupling. This position should be checked by running the motor uncoupled. This will also permit checking the direction of rotation of the motor. If current is not available at the time of installation, move the motor shaft in both directions as far as the bearings will permit and adjust the shaft centrally between these limits. The unit should then be assembled with the correct gap between the coupling halves.

Large horizontal sleeve-bearing motors are not generally equipped with thrust bearings. The motor rotor is permitted to float, and as it will seek its magnetic center, an axial force of rather small magnitude can cause it to move off this center. Sometimes it will move enough to cause the shaft collar to contact and possibly damage the bearing. To avoid this, a limited-end-float coupling is used between the pump and the motor on all large units to restrict the motor rotor (Subsection 6.3.1). The setting of axial clearances for such units should be given by the manufacturer in the instruction books and elevation drawings.

When the pump handles a liquid at other than ambient temperature or when it is driven by a steam turbine, the expansion of the pump or turbine at operating temperature will alter the vertical alignment. Alignment should be made at ambient temperature with suitable allowances for the changes in pump and driver centerlines after expansion. The final alignment must be made with the pump and driver at their normal temperatures and adjusted as required before the pump is placed into permanent service.

For large installations, particularly with steam-turbine-driven pumps, more sophisticated alignment methods are sometimes employed, using proximity probes and optical instruments. Such procedures permit checking the effect of temperature changes and machine strains caused by piping stresses while the unit is in operation. When such procedures are recommended, they are included with the manufacturer's instructions.

When the unit has been accurately leveled and aligned, the hold-down bolts should be gently and evenly tightened before grouting. The alignment must be rechecked after the suction and discharge piping has been bolted to the pump to test the effect of piping strains. This can be done by loosening the bolts and reading the movement of the pump, if any, with dial indicators.

The pump and driver alignment should be occasionally rechecked because misalignment may develop from piping strains after a unit has been operating for some time. This is especially true when the pump handles hot liquids because there may be a growth or change in the shape of the piping. Pipe flanges at the pump should be disconnected after a period of operation to check the effect of the expansion of the piping, and adjustments should be made to compensate for this.

For a further discussion of hot and cold alignment, face-and-rim versus reverse dial methods measurement of dial bracket sag, and graphical alignment plotting procedure, refer to Subsection 2.3.3.

Grouting Ordinarily, the baseplate is grouted before the piping connections are made and before the alignment of the coupling halves is finally rechecked. The purpose of grouting is to prevent lateral shifting of the baseplate, to increase the mass to reduce vibration, and to fill in irregularities in the foundation. Generally, it is recommended that all permanently installed pumping equipment be supported by a reinforced concrete foundation. Some pumps that require an elevated installation may be supported on structural steel structures, but care must be taken to ensure that such structures are of adequate stiffness and strength.

Foundation dimensions must consider the size and arrangement of the pump and driver, the piping arrangement and anticipated piping loads, anchor bolt placement, and minimum dimensions required for servicing the equipment. Vertically suspended canned pump foundations should be designed so the pump can is directly attached to a mounting plate and is removable without disturbing the grout.

Foundation materials must be properly resistant to chemicals and oils. If the environment is aggressive, protective coatings or covers should be considered to protect the foundation and reinforcing steel. Two types of grout are commonly used: epoxy and cement-based. Epoxy grout, although usually more expensive, has significant advantages in higher bond strength and nonporous finished surface characteristics that generally make it the material of choice for most pump installations.

When the foundation has been prepared, the grout material has been selected, and the baseplate has been properly positioned on the foundation, a preliminary coupling alignment is made to ensure that final alignment is possible after the baseplate is finally grouted. After this alignment check is successfully accomplished, the grout is added through the holes in the baseplate. To retain the grout in place, a leak-tight form is built around the outside of the baseplate. Grout is added until the entire space under the baseplate is filled to the top of the underside (Figure 8). The grout holes and vent holes in the baseplate allow air to escape as the grout fills the cavity. A stiff wire may be used through the grout holes to work the grout and release any air pockets. It is usually best to start at one end and force the air out as the grout proceeds toward the other end of the baseplate. Leveling shims and wedges used to level the baseplate should be left in place after grouting.

When the grout has properly cured, voids have been filled and forms have been removed, the exposed surfaces of the grout and foundation can be properly finished. The foundation anchor/hold-down bolts should be finally torqued to the proper values and the coupling halves can be rechecked for alignment.

The pump and driver alignment must be rechecked thoroughly after the grout has hardened permanently, and at reasonable intervals thereafter.

Doweling of Pump and Driver When the pump handles hot liquids, doweling of both the pump and its driver should be delayed until the unit has been operated. A final recheck of alignment with the coupling bolts removed and with the pump and driver at operating temperature is advisable before doweling.

Large pumps handling hot liquids are usually doweled near the coupling end, allowing the pump to expand from that end out. Sometimes the other end is provided with a key and a keyway in the casing foot and the baseplate.

PIPING

Suction Piping The suction piping should be as direct and short as possible. If a long suction line is required, the pipe size should be increased to reduce frictional losses. (The exception to this recommendation is in the case of boiler-feed pumps, where difficulties may arise during transient conditions of load change if the suction piping volume is excessive. This is a special and complex subject, and the manufacturer should be consulted.) Where the pump must lift the liquid from a lower level, the suction piping should be laid out with a continual rise toward the pump, avoiding high spots in the line to prevent the formation of air pockets. Where a static suction head will exist, the pump suction piping should slope continuously downward to the pump.

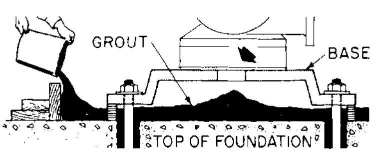


FIGURE 8 Application of grouting. Grout is added until the entire space under the base is filled. Holes in the base (arrow) allow air to escape and permit working of the grout to release air pockets.

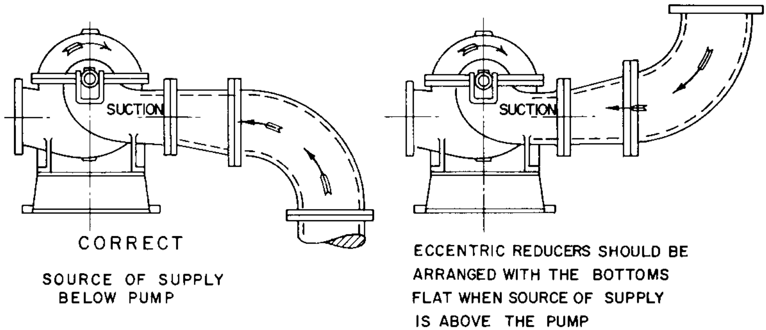


FIGURE 9 Recommended installation of reducers at pump suction

Generally, the suction line is larger than the pump suction nozzle and eccentric reducers should be used. If the source of supply is above the pump centerline, the reducer should be installed straight side up. If the source of supply is above the pump, the straight side of the reducer should be at the bottom (Figure 9). Installing eccentric reducers with a change in diameters greater than 4 in (10 cm) could disturb the suction flow. If such a change is necessary, it is advisable to use properly vented concentric reducers.

Elbows and other fittings next to the pump suction should be carefully arranged, or the flow into the pump impeller will be disturbed. Long-radius elbows are preferred for suction lines because they create less friction and provide a more uniform flow distribution than standard elbows.

It is extremely important to avoid the formation of vortices at the suction of both wet-pit and dry-pit pump installations. For a discussion of this and other suction conditions recommendations, see Sections 10.1 and 10.2.

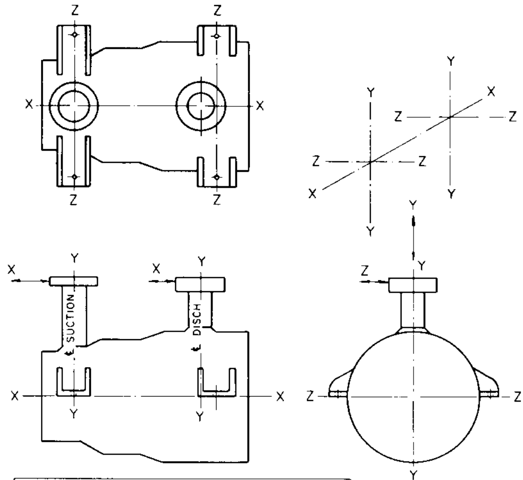
Discharge Piping Generally both a check valve and a gate valve are installed in the discharge line. The check valve is placed between the pump and the gate valve and protects the pump from reverse flow in the event of unexpected driver failure or from reverse flow from another operating pump. The gate valve is used when priming the pump or when shutting it down for inspection and repairs. Manually operated valves that are difficult to reach should be fitted with a sprocket rim wheel and chain. In many cases, discharge gate valves are motorized and can be operated by remote control.

Piping Strains Cast iron pumps are never provided with raised face flanges. If steel suction or discharge piping is used, the pipe flanges should be of the flat-face and not the raised-face type. Full-face gaskets must be used with cast iron pumps.

Piping should not impose excessive forces and moments on the pump to which it is connected because these might spring the pump or pull it out of position. Piping flanges must be brought squarely together before the bolts are tightened. The suction and discharge piping and all associated valves, strainers, and so on should be supported and anchored near to but independent of the pump, so no strain will be transmitted to the pump casing.

There are four factors to be considered in determining the effect of nozzle loads: material stress in pump nozzles resulting from forces and bending moments, distortion of internal moving parts affecting critical clearances, stresses in pump hold-down bolts, and distortion in pump supports and baseplates resulting in driver coupling misalignment. API Standard 610 (Centrifugal Pumps for Refinery, Heavy Duty Chemical, and Gas Industry Services) provides guidelines for limiting the magnitude of nozzle loads and moments on pumps with suction nozzles 16 in (41 cm) and smaller and with casings constructed of steel or alloy steel.

With large pumps or when major temperature changes are expected, the pump manufacturer generally indicates to the user the maximum moments and forces that can be



ALLOWABLE FORCES, LB			
	X	Y	Z
SUCTION	15,800	15,800	11,200
DISCHARGE	19,300	15,800	11,200
TOTAL	19,300	15,800	11,200

ALLOWABLE MOMENTS, FT-LB			
	X-X AXIS	Y-Y AXIS	Z-Z AXIS
SUCTION	22,900	45,400	22,900
DISCHARGE	21,600	43,200	21,600
TOTAL	22,900	45,400	22,900

FIGURE 10 Diagram of typical permissible pipe stresses and moments for a radially split double-casing multistage pump with top suction and discharge (1 N = 0.225 lb; 1 N · m = 0.737 ft · lb).

imposed on the pump by the piping. A typical diagram is illustrated in Figure 10 for a radially split double-casing multistage pump with top suction and discharge.

Expansion Joints Expansion joints are sometimes used in the discharge and suction piping to avoid transmitting any piping strains caused by misalignment or by expansion when hot liquids are handled. On occasion, expansion joints are formed by looping the pipe. More often, they are of the slip-joint or corrugated-diaphragm type. However, they transmit to the pump a force equal to the area of the expansion joint times the pressure in the pipe. These forces can be of very significant magnitude, and it is impractical to design the pump casings, baseplates, and so on to withstand them. Consequently, when expansion joints are used, a suitable pipe anchor must be installed between them and the pump proper. Alternately, tie rods can be used to prevent the forces from being transmitted to the pump.

Suction Strainers Except for certain special designs, pumps are not intended to handle liquid containing foreign matter. If the particles are sufficiently large, such foreign matter can clog the pump, reduce its capacity, or even render it altogether incapable of pumping. Small particles of foreign matter may cause damage by lodging between close running clearances. Therefore, proper suction strainers may be required in the suction lines of pumps not specially designed to handle foreign matter.

In such an installation, the piping must first be thoroughly cleaned and flushed. The recommended practice is to flush all piping to waste before connecting it to the pump. Then a temporary strainer of appropriate size should be installed in the suction line as close to the pump as possible. This temporary strainer may have a finer mesh than the permanent strainer installed after the piping has been thoroughly cleaned of all possible mill scale or other foreign matter. The size of the mesh is generally recommended by the pump manufacturer. For further details on strainers, see Sections 8.1 and 10.1.

Venting and Draining Vent valves are generally installed at one or more high points of the pump casing waterways to provide a means of escape for air or vapor trapped in the casing. These valves are used during the priming of the pump or during operation if the pump should become air- or vapor-bound. In most cases, these valves need not be piped up away from the pump because their use is infrequent, and the vented air or vapors can be allowed to escape into the surrounding atmosphere. On the other hand, vents from pumps handling flammable, toxic, or corrosive fluids must be connected in such a way that they endanger neither the operating personnel nor the installation. The suction vents of pumps taking liquids from closed vessels under vacuum must be piped to the source of the pump suction above the liquid level.

All drain and drip connections should be piped to a point where the leakage can be disposed of or collected for reuse if worth reclaiming.

Warm-Up Piping When it is necessary for a pump to come up to operating temperature before it is started up or to keep it ready to start at rated temperature, provision should be made for a warm-up flow to pass through the pump. There are a number of arrangements used to accomplish this. If the pump operates under positive pressure on the suction, the pumped liquid can be permitted to drain out through the pump casing drain connection to some point at a pressure lower than the suction pressure (Figure 11). Alternately, some liquid can be made to flow back from the discharge header through a jumper line around the check valve into the pump and out into the suction header (Figure 12). An orifice is provided in this jumper line to regulate the amount of warm-up flow. Care must be exercised in such an installation to maintain the suction valve open (unless the warm-up line valve is closed, as when the pump is to be dismantled) lest the entire pump, suction valve, and suction piping be subjected to full discharge pressure.

The manufacturer's recommendations should be sought in all cases as to the best means of providing an adequate warm-up procedure. Care must be taken to ensure that the pump is warmed uniformly. Stratification of the warm-up flow, or inadequate warm-up flow volume, can result in casing distortion or rotor bowing, or both.[4]

RELIEF VALVES Positive displacement pumps, such as rotary and reciprocating pumps, can develop discharge pressures much in excess of their maximum design pressures. To protect these pumps against excessive pressures when the discharge is throttled or shut off, a pressure relief valve might be used. Some pumps are provided with internal integral relief valves, but unless operation against a closed discharge is both infrequent and of very

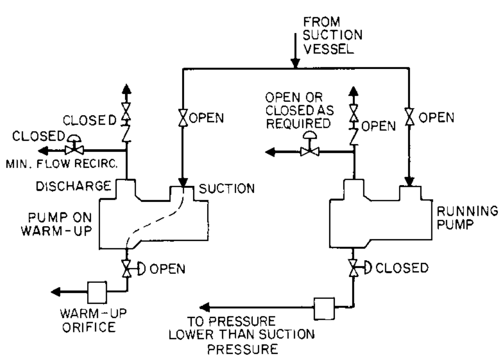


FIGURE 11 Arrangement for warm-up through pump casing drain connection

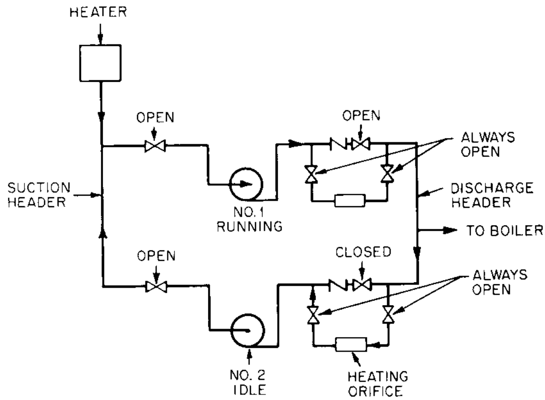


FIGURE 12 Arrangement for warm-up through jumper line around discharge check valve

short duration, a relief valve with an external return connection must be used and the liquid from the relief valve must be piped back to the source of supply.

Surge Chambers Generally, centrifugal pumps do not require surge chambers in their suction or discharge piping. Reciprocating pumps may have a suction and discharge piping layout that does not require compensation for variations in the flow velocity in the piping system. In many cases, however, reciprocating pump installations require surge chambers when the suction or discharge lines are of considerable length, when there is an appreciable static head on the discharge, when the liquid pumped is hot, or when it is desirable to smooth out variations in the discharge flow. The type, size, and arrangement of the surge chamber should be chosen on the basis of the manufacturer's recommendations. For more details, see Section 3.4.

Instrumentation There are a number of instruments that are essential to maintaining a close check on the performance and condition of a pump. A compound pressure gage should be connected to the suction of the pump, and a pressure gage should be connected to its discharge at the pressure taps that may be provided in the suction and discharge flanges. The gages should be mounted in a convenient location so they can be easily observed.

In addition, it is advisable to provide a flow-metering device. Depending upon the importance of the installation, indicating meters may be supplemented by recording attachments.

Whenever pumps incorporate various leakoff arrangements, such as a balancing device or pressure-reducing labyrinths, a check should be maintained on the quantity of these leakoffs by measuring orifices and differential gages installed in the leakoff lines.

Pumps operating in important or complex services or operating completely unattended by remote control may have additional instrumentation, such as speed indicators, vibration monitors, and bearing or casing temperature indicators. For more detail, see Subsections 2.3.2, 2.3.3, and Section 3.4.

OPERATION

Pumps are generally selected for a given capacity and total head when operating at rated speed. These characteristics are referred to as "rated conditions of service" and, with few exceptions, represent those conditions at or near which the pump will operate the greatest part of the time. Positive displacement pumps cannot operate at any greater flows than rated except by increasing their speed, nor can they operate at lower flows except by reducing their operating speed or bypassing some of the flow back to the source of supply. (See Section 3.5.)

On the other hand, centrifugal pumps can operate over a wide range of capacities, from near zero flow to well beyond the rated capacity. Because a centrifugal pump will always operate at the intersection of its head-capacity and system-head curves, the pump operating capacity may be altered either by throttling the pump discharge (hence altering the system-head curve) or by varying the pump speed (changing the pump head-capacity curve). This makes the centrifugal pump very flexible in a wide range of services and applications that require the pump to operate at capacities and heads differing considerably from the rated conditions. There are, however, some limitations imposed upon such operation by hydraulic, mechanical, or thermodynamic considerations (Subsection 2.3.1).

Operation of Centrifugal Pumps at Reduced Flows There are certain minimum operating flows that must be imposed on centrifugal pumps for either hydraulic or mechanical reasons. Four limiting factors must be considered: radial thrust, temperature rise, internal recirculation, and shape of the brake horsepower curve.

Radial thrust is discussed in Subsections 2.2.1 and 2.3.1. For sustained operation, it is imperative to adhere to the minimum flow limits recommended by the pump manufacturer, which depend on the specific design of the pump casing and impeller.

The thermodynamic problem that arises when a centrifugal pump is operated at extremely reduced flows is caused by the heating up of the liquid handled. The difference between the brake horsepower consumed and the water horsepower developed represents the power losses in the pump, except for a small amount lost in the pump bearings. These power losses are converted to heat and transferred to the liquid passing through the pump.

If the pump were to operate against a completely closed valve, the power losses would be equal to the shutoff brake horsepower, and because there would be no flow through the pump, all this power would go into heating the small quantity of liquid contained in the pump casing. The pump casing would heat up, and a certain amount of heat would be dissipated by radiation and convection to the atmosphere. However, because the temperature rise in the liquid pumped could be quite rapid, it is generally safer to ignore the dissipation of heat through radiation and the absorption of heat by the casing. Calculations for determining the temperature rise in the pumped liquid are given in Subsection 2.3.1. The maximum permissible temperature rise in a centrifugal pump varies over a wide range, depending on the type of service and installation. For hot-water pumps, as on boiler-feed service, it is generally advisable to limit the temperature rise to about 15°F (8°C). As a general rule, the minimum permissible flow to hold the temperature rise in boiler-feed pumps to this value is 30 gpm for each 100 bhp (9.13 m^3/h per 100 kW) at shutoff. When the pump handles cold water, the temperature rise may be permitted to reach 50 or even 100°F (28 or 56°C). The minimum capacity based on thermodynamic considerations is then established as the capacity at which the temperature rise is the maximum permitted. Means and controls used to provide the necessary minimum flows are described in Subsection 2.3.4.

There are also hydraulic considerations that may affect the minimum flow at which a centrifugal pump can operate. In recent years, correlation has been developed between operation at low flows and the appearance of hydraulic pulsations both in the suction and in the discharge of centrifugal impellers. It has been proved that these pulsations are caused by the development of an internal recirculation at the inlet and discharge of an impeller at certain flows below the best-efficiency capacity. This subject is treated in Subsections 2.3.1 and 2.3.2. The pump manufacturer's recommendations on minimum flows dictated by these considerations must be followed.

Priming With very few exceptions, no centrifugal pump should ever be started until it is fully primed; that is, until it has been filled with the liquid pumped and all the air contained in the pump has been allowed to escape. The exceptions involve self-priming pumps and some special large-capacity, low-head, and low-speed installations where it is not practical to prime the pump prior to starting; the priming takes place almost simultaneously with the starting in these cases. For further details, see Section 2.4.

Reciprocating pumps of the piston or plunger type are in principle self-priming. However, if quick starting is required, priming connections should be piped to a supply above the pump.

Positive displacement pumps of the rotating type, such as rotary or screw pumps, have clearances that allow the liquid in the pump to drain back to the suction. When pumping low-viscosity liquids, the pump may completely dry out when it is idle. In such cases a foot valve may be used to help keep the pump primed. Alternately, a vacuum device may be used to prime the pump. When handling liquids of higher viscosity, foot valves are usually not required because liquid is retained in the clearances and acts as a seal when the pump is restarted. However, before the initial start of a rotating positive displacement pump, some of the liquid to be pumped should be introduced through the discharge side of the pump to wet the rotating element.

The various methods and arrangements used for priming pumps are described in Section 2.4.

Final Checks Before Start-Up A few final checks are recommended before a pump is placed into service for its initial start. For pumps with journal bearings, the bearing covers should be removed, and the bearings should be flushed and thoroughly cleaned. They should then be filled with new lubricant in accordance with the manufacturer's recommendations.

With the coupling disconnected, the driver should be tested again for correct direction of rotation. Generally an arrow on the pump casing indicates the correct rotation.

It must be possible to rotate the rotor of a centrifugal pump by hand, and in the case of a pump handling hot liquids, the rotor must be free to rotate with the pump cold or hot. If the rotor is bound or even drags slightly, do not operate the pump until the cause of the trouble is determined or corrected.

Starting and Stopping Procedures The steps necessary to start a centrifugal pump depend upon its type and upon the service on which it is installed. For example, standby pumps are generally held ready for immediate starting. The suction and discharge gate valves are held open, and reverse flow through the pump is prevented by the check valve in the discharge line.

The methods followed in starting are greatly influenced by the shape of the power-capacity curve of the pump. High- and medium-head pumps (low and medium specific speeds) have power curves that rise from zero flow to the normal capacity condition. Such pumps should be started against a closed discharge valve to reduce the starting load on the driver. A check valve is equivalent to a closed valve for this purpose, as long as another pump is already on the line. The check valve will not lift until the pump being started comes up to a speed sufficient to generate a head high enough to lift the check valve from its seat. If a pump is started with a closed discharge valve, the recirculation bypass line must be open to prevent overheating.

Low-head pumps (high specific speed) of the mixed-flow and propeller type have power curves that rise sharply with a reduction in capacity; they should be started with the discharge valve wide open against a check valve, if required, to prevent backflow.

Assuming that the pump in question is motor-driven, that its shutoff power does not exceed the safe motor power, and that it is to be started against a closed gate valve, the starting procedure is as follows:

1. Prime the pump, opening the suction valve, closing the drains, and so on, to prepare the pump for operation.
2. Open the valve in the cooling supply to the bearings, where applicable.
3. Open the valve in the cooling supply if the seal chambers are liquid-cooled.
4. Open the valve in the sealing liquid supply if the pump is so fitted.

5. Open the warm-up valve of a pump handling hot liquids if the pump is not normally kept at operating temperature. When the pump is warmed up, close the valve.
6. Open the valve in the recirculating line if the pump should not be operated against dead shutoff.
7. Start the motor.
8. Open the discharge valve slowly.
9. For pumps equipped with mechanical seals, check for seal leakage: there should be none.
10. For pump with shelf packing, observe the leakage from the stuffing boxes and adjust the sealing liquid valve for proper flow to ensure the lubrication of the packing. If the packing is new, do not tighten up on the gland immediately, but let the packing run in before reducing the leakage through the stuffing boxes.
11. Check the general mechanical operation of the pump and motor.
12. Close the valve in the recirculating line when there is sufficient flow through the pump to prevent overheating.

If the pump is to be started against a closed check valve with the discharge gate valve open, the steps are the same, except that the discharge gate valve is opened some time before the motor is started.

In certain cases, cooling to the bearings and flush liquid to the mechanical seals or to the packing seal cages is provided by the pump. This, of course, eliminates the need for the steps listed for the cooling and sealing supply.

Just as in starting a pump, the stopping procedure depends upon the type and service of the pump. Generally, the steps followed to stop a pump that can operate against a closed gate valve are

1. Open the valve in the recirculating line.
2. Close the gate valve.
3. Stop the motor.
4. Open the warm-up valve if the pump is to be kept at operating temperature.
5. Close the valve in the cooling supply to the bearings and seal chambers.
6. If the sealing liquid supply is not required while the pump is idle, close the valve in this supply line.
7. Close the suction valve, open the drain valves, and so on, as required by the particular installation or if the pump is to be opened up for inspection.

If the pump is of a type that does not permit operation against a closed gate valve, steps 2 and 3 are reversed.

In general, the starting and stopping of steam-turbine-driven pumps require the same steps and sequence prescribed for a motor-driven pump. As a rule, steam turbines have various drains and seals that must be opened or closed before and after operation. Similarly, many turbines require warming up before starting. Finally, some turbines require turning gear operation if they are kept on the line ready to start up. The operator should therefore follow the steps outlined by the turbine manufacturer in starting and stopping the turbine.

Most of the steps listed for starting and stopping centrifugal pumps are equally applicable to positive displacement pumps. There are, however, two notable exceptions:

1. Never operate a positive displacement pump against a closed discharge. If the gate valve on the discharge must be closed, always start the pump with the recirculation bypass valve open.
2. Always open the steam cylinder drain cocks of a steam reciprocating pump before starting, to allow condensate to escape and to prevent damage to the cylinder heads.

Auxiliary Services on Standby Pumps Standby pumps are frequently started up from a remote location, and several methods of operation are available for the auxiliary services, such as the cooling supply to bearings or seal chambers:

1. A constant flow may be kept through jackets or oil coolers and through stuffing box lantern rings or seal chambers whether the pump is running or on standby service.
2. The service connections may be opened automatically whenever the pump is started up.
3. The service connections may be kept closed while the pump is idle, and the operator may be instructed to open them shortly after the pump has been put on the line automatically.

The choice among these methods must be dictated by the specific circumstances surrounding each case. There are, however, certain cases where sealing liquid supply to the pump seal chambers must be maintained whether the pump is running or not. This is the case when the pump handles a liquid that is corrosive or that may crystallize and deposit on the sealing components. It is also the case when the sealing supply is used to prevent air infiltration into a pump when it is operating under a vacuum.

Restarting Motor-Driven Pumps After Power Failure Assuming that power failure will not cause the pump to go into reverse rotation; that is, that a check valve will protect the pump against reverse flow, there is generally no reason why the pump should not be permitted to restart after current has been re-established. Whether the pump will start again automatically when power is restored will depend on the type of motor control used. (Subsection 2.3.1 and Section 8.1 give reasons why some pumps should not be started in reverse.)

Because pumps operating on a suction lift may lose their prime during the time that power is off, it is preferable to use starters with low load protection for such installations to prevent an automatic restart. This does not apply, of course, if the pumps are automatically primed or if some protection device is incorporated so the pump cannot run unless it is primed.

MAINTENANCE

Because of the wide variation in pump types, sizes, designs, and materials of construction, these comments on maintenance are restricted to those types of pumps most commonly encountered. The manufacturer's instruction books must be carefully studied before any attempt is made to service a particular pump.

Daily Observation of Pump Operation When operators are on constant duty, hourly and daily inspections should be made and any irregularities in the operation of a pump should be recorded and reported immediately. This applies particularly to changes in sound of a running pump, abrupt changes in bearing temperatures, and seal chamber leakage. A check of pressure gages and of flowmeters, if installed, and vibration should be made routinely during the day. If recording instruments are provided, a daily check should be made to determine whether the current capacity, pressure, power consumption or vibration level indicates that further inspection is required. If these readings are taken electronically, trending charts should be produced to allow observation of changes as a function of time. Certain trends may allow for scheduled outages to address deterioration of specific performance values.

Semiannual Inspection The following should be done at least every six months:

1. For pumps equipped with shaft packing, the free movement of stuffing box glands should be checked, gland bolts should be cleaned and lubricated, and the packing should be inspected to determine whether it requires replacement.
2. The pump and driver alignment should be checked and corrected if necessary.
3. Housings for oil-lubricated bearings should be drained, flushed, and refilled with fresh oil.
4. Grease-lubricated bearings should be checked to see that they contain the correct amount of grease and that it is still of suitable consistency.

Annual Inspection A very thorough inspection should be performed once a year. In addition to the semiannual procedure, the following items should be considered:

1. Vibration trends should be reviewed. If the pump is trending toward unacceptable vibration levels,
   - **a.** The bearings should be removed, cleaned, and examined for flaws and wear.
   - **b.** The bearing housings should be carefully cleaned.
   - **c.** Rolling element bearings should be examined for scratches and wear.
   - **d.** Immediately after cleaning, rolling element bearings that are considered acceptable for reinstallation should be coated with oil or grease. *Note:* If there is any sign of damage, or if the bearings were damaged during removal, they should be replaced with new bearings of the correct size and type per the manufacturer's instruction book.
   - **e.** The assembled rotor—or major rotor components if the rotor is not assembled of shrink-fit components—should be checked for balance prior to reassembly in the pump.
2. For pumps equipped with shaft packing, the packing should be removed and the shaft sleeves—or shaft, if no sleeves are used—should be examined for wear.
3. For pumps equipped with mechanical seals, if the seals were indicating signs of leaking, they should be removed and returned to the seal manufacturer for inspection, possible bench testing, and refurbishment.
4. When coupling halves are disconnected for an alignment check, the vertical shaft movement of a pump with sleeve (journal) bearings should be checked at both ends with packing or seals removed. Any movement exceeding 150% of the original design clearance should be investigated to determine the cause. Endplay allowed by the bearings should also be checked. If it exceeds that recommended by the manufacturer, the cause should be determined and corrected.
5. All auxiliary piping, such as drains, sealing water piping, and cooling water piping, should be checked and flushed, as necessary. Auxiliary coolers should also be flushed and cleaned.
6. Pump equipped with stuffing boxes should be repacked, and the pump and driver should be realigned and reconnected.
7. All instruments and flow-metering devices should be recalibrated, whenever feasible, and—whenever possible—the pump should be tested to determine whether proper performance is being obtained. If internal repairs are made, the pump should again be tested after completion of the repairs.

Complete Overhaul It is difficult to make general rules about the frequency of complete pump overhauls as it depends on the pump service, the pump construction and materials, the liquid handled, and the economic evaluation of overhaul costs versus the cost of power losses resulting from increased clearances or of unscheduled downtime. Some pumps on very severe service may need a complete overhaul monthly, whereas other applications require overhauls only every two to four years or even less frequently.

A pump should not be opened for inspection unless either factual or circumstantial evidence indicates that overhaul is necessary. Factual evidence implies that the pump performance has fallen off significantly or that the noise or driver load indicates trouble. Circumstantial evidence refers to past experience with the pump in question or with similar equipment on similar service.

In order to ensure rapid restoration to service in the event of an unexpected overhaul, an adequate store of spare parts should be maintained at all times.

The relative complexity of the repairs, the facilities available at the site, and many other factors enter into the decision whether the necessary repairs will be carried out at the installation site or at the pump manufacturer's plant.

Spare and Repair Parts The severity of the service in which the pump is used will determine, to a great extent, the minimum number of spare parts that should be carried in stock at the installation site. Unless prior experience is available, the pump manufacturer should be consulted on this subject. As an insurance against delays, spare parts should be purchased when the pump is purchased. Depending on the contemplated method of overhaul, certain replacement parts may have to be supplied either oversized or undersized instead of the size used in the original unit.

API Standard 610, 8th edition, shows recommended spare parts as a function of the number of identical pumps installed at a site. It also lists parts usually associated with start-up and with normal maintenance. A form based on the recommendations of API Standard 610 is shown in Table 1.

When ordering spare parts after a pump has been in service, the manufacturer should always be given the pump serial number and size (stamped on the nameplate). This information is essential in identifying the pump exactly and in furnishing repair parts of correct size and material.

Records of Inspections and Repairs The working schedule of the semiannual and annual inspections should be entered into a log that tracks individual pump maintenance history. This log should then contain a complete record of all the items requiring attention. This log, usually electronic, should also contain comments and observations on the conditions of the parts to be repaired or replaced, on the rate and appearance of wear, and on the repair methods followed. In many cases, it is advisable to photograph badly worn parts before they are repaired.

In all cases, complete records of the cost of maintenance and repairs should be kept for each pump, together with a record of its operating hours. A study of these records will generally reveal whether a change in materials or even construction may be the most economical course of action to improve pump performance, reliability, and life.

Diagnosis of Pump Problems Pump operating problems may be either hydraulic or mechanical. In the first category, a pump may fail to deliver liquid, it may deliver an insufficient capacity or develop insufficient pressure, or it may lose its prime after starting. In the second category, it may consume excessive power, or symptoms of mechanical difficulties may develop at the seal chambers or at the bearings, or vibration, noise, or breakage of some pump parts may occur.

There is a definite interdependence between some difficulties of both categories. For example, increased wear at the running clearances must be classified as a mechanical trouble, but it will result in a reduction of the net pump capacity—a hydraulic symptom—without necessarily causing a mechanical breakdown or even excessive vibration. As a result, it is most useful to classify symptoms and causes separately and to list for each symptom a schedule of potential contributory causes. Such a diagnostic analysis is presented in Tables 2 through 5. Additionally, the following parts of this handbook should also be referred to for assistance in diagnosing pump hydraulic and mechanical problems and possible solutions: Subsections 2.2.2, 2.2.3, 2.3.2, and 2.3.3 and Sections 3.4 and 8.4.

TABLE 1 Recommended spare parts

Spares Recommended								
Part	See Note	Start-up			Normal Maintenance			
Number of identical pumps		1–3	4–6	7+	1–3	4–6	7–9	10+
Cartridge	(2) (5)				1	1	1	1
Element	(2) (6)				1	1	1	1
Rotor	(3) (7)				1	1	1	1
Case	(1)							1
Head (case cover and seal chamber)								1
Bearing bracket	(1)							1
Shaft (w/key)					1	1	2	N/3
Impeller					1	1	2	N/3
Wear rings (set)	(8)	1	1	1	1	1	2	N/3
Bearings complete (rolling element, radial)	(1) (9)	1	1	2	1	2	N/3	N/3
Bearings complete (rolling element, thrust)	(1) (9)	1	1	2	1	2	N/3	N/3
Bearings complete (hydrodynamic, radial)	(1) (9)	1	1	2	1	2	N/3	N/3
Bearing pads only (hydrodynamic, radial)	(1) (9)	1	1	2	1	2	N/3	N/3
Bearing complete (hydrodynamic, thrust)	(1) (9)	1	1	2	1	2	N/3	N/3
Bearing pads only (hydrodynamic, thrust)	(1) (9)	1	1	2	1	2	N/3	N/3
Mechanical seal/packing	(4) (8) (9)	1	2	N/3	1	2	N/3	N/3
Shaft sleeve	(8)	1	2	N/3	1	2	N/3	N/3
Gaskets, shims, O-rings (set)	(8)	1	2	N/3	1	2	N/3	N/3
Add for vertical pump								
Bowls							N/3	N/3
Spiders (set)				1	1	1	N/3	N/3
Bearings, bushings (set)		1	1	2	1	1	N/3	N/3
Add for high speed integral gear								
Gear box			1	1	1	1	1	N/3
Diffuser and cover		1	1	1	1	1	1	N/3
Splined shaft		1	1	1	1	1	1	N/3
Gear box housing					1	1	1	N/3
Oil pump, internal			1	1	1	1	1	N/3
Oil pump, external			1	1	1	1	1	N/3
Oil filter		1	2	N/3	1	2	3	N/3

Notes:
N = Number of identical pumps
(1) Horizontal pumps only
(2) Vital service pumps are generally unspared, partially spared, or multistage. When a vital machine is down, production loss or violation of environmental permits results.
(3) Essential service pumps are required for operation and have an installed spare. A production loss will occur only if main and spare fail simultaneously.
(4) Cartridge type mechanical seals shall include sleeve and gland.
(5) Cartridge consists of assembled element plus discharge head, seal(s), and bearing housing(s).
(6) Element consists of assembled rotor plus stationary hydraulic parts (diffuser(s) or volute(s)).
(7) Rotor consists of all rotating parts attached to the shaft.
(8) Normal wear parts
(9) Per pump set

Source (Reference 1)

TABLE 2A Check chart for centrifugal pump problems

Symptoms	Possible cause of trouble (each number is defined in Table 2B)
1. Pump does not deliver liquid	1, 2, 3, 5, 10, 12, 13, 14, 16, 21, 22, 25, 30, 32, 38, 40
2. Insufficient capacity delivered	2, 3, 4, 5, 6, 7, 7a, 10, 11, 12, 13, 14, 15, 16, 17, 18, 21, 22, 23, 24, 25, 31, 32, 40, 41, 44, 63, 64
3. Insufficient pressure developed	4, 6, 7, 7a, 10, 11, 12, 13, 14, 15, 16, 18, 21, 22, 23, 24, 25, 34, 39, 40, 41, 63, 64
4. Pump loses prime after starting	2, 4, 6, 7, 7a, 8, 9, 10, 11
5. Pump requires excessive power	20, 22, 23, 24, 26, 32, 33, 34, 35, 39, 40, 41, 44, 45, 61, 69, 70, 71
6. Pump vibrates or is noisy at all flows	2, 16, 37, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 67, 78, 79, 80, 81, 82, 83, 84, 85
7. Pump vibrates or is noisy at low flows	2, 3, 17, 19, 27, 28, 29, 35, 38, 77
8. Pump vibrates or is noisy at high flows	2, 3, 10, 11, 12, 13, 14, 15, 16, 17, 18, 33, 34, 41
9. Shaft oscillates axially	17, 18, 19, 27, 29, 35, 38
10. Impeller vanes are eroded on visible side	3, 12, 13, 14, 15, 17, 41
11. Impeller vanes are eroded on invisible side	12, 17, 19, 29
12. Impeller vanes are eroded at discharge near center	37
13. Impeller vanes are eroded at discharge near shrouds or at shroud/vane fillets	27, 29
14. Impeller shrouds bowed out or fractured	27, 29
15. Pump overheats and seizes	1, 3, 12, 28, 29, 38, 42, 43, 45, 50, 51, 52, 53, 54, 55, 57, 58, 59, 60, 61, 62, 77, 78, 82
16. Internal parts are corroded prematurely	66
17. Internal clearances wear too rapidly	3, 28, 29, 45, 50, 51, 52, 53, 54, 55, 57, 59, 61, 62, 66, 77
18. Axially-split casing is cut through wire-drawing	63, 64, 65
19. Internal stationary joints are cut through wire-drawing	53, 63, 64, 65
20. Packed box leaks excessively or packing has short life	8, 9, 45, 55, 57, 68, 69, 70, 71, 72, 73, 74
21. Packed box: sleeve scored	8, 9
22. Mechanical seal leaks excessively	45, 54, 55, 57, 58, 62, 75, 76
23. Mechanical seal: damaged faces, sleeve, bellows	45, 54, 55, 57, 58, 62, 75, 76
24. Bearings have short life	3, 29, 41, 42, 45, 50, 51, 54, 55, 58, 77, 78, 79, 80, 81, 82, 83, 84, 85
25. Coupling fails	45, 50, 51, 54, 67

TABLE 2B Possible causes of problems

Suction Problems

1. Pump not primed
2. Pump suction pipe not completely filled with liquid
3. Insufficient available NPSH
4. Excessive amount of air or gas in liquid
5. Air pocket in suction line
6. Air leaks into suction line
7. Air leaks into pump through stuffing boxes or through mechanical seal

7a. Air in source of sealing liquid

8. Water seal pipe plugged
9. Seal cage improperly mounted in stuffing box
10. Inlet of suction pipe insufficiently submerged
11. Vortex formation at suction
12. Pump operated with closed or partially closed suction valve
13. Clogged suction strainer
14. Obstruction in suction line
15. Excessive friction losses in suction line
16. Clogged impeller
17. Suction elbow in plane parallel to the shaft (for double-suction pumps)
18. Two elbows in suction piping at 90° to each other, creating swirl and prerotation
19. Selection of pump with too high a suction specific speed

Other Hydraulic Problems

20. Speed of pump too high
21. Speed of pump too low
22. Wrong direction of rotation
23. Reverse mounting of double-suction impeller
24. Uncalibrated instruments
25. Impeller diameter smaller than specified
26. Impeller diameter larger than specified
27. Impeller selection with abnormally high head coefficient
28. Running the pump against a closed discharge valve without opening a by-pass
29. Operating pump below recommended minimum flow
30. Static head higher than shut-off head

Other Hydraulic Problems (continued)

31. Friction losses in discharge higher than calculated
32. Total head of system higher than design of pump
33. Total head of system lower than design of pump
34. Running pump at too high a flow (for low specific speed pumps)
35. Running pump at too low a flow (for high specific speed pumps)
36. Leak of stuck check valve
37. Too close a gap between impeller vanes and volute tongue or diffuser vanes
38. Parallel operation of pumps unsuitable for the purpose
39. Specific gravity of liquid differs from design conditions
40. Viscosity of liquid differs from design conditions
41. Excessive wear at internal running clearances
42. Obstruction in balancing device leak-off line
43. Transients at suction source (imbalance between pressure at surface of liquid and vapor pressure at suction flange)

Mechanical Problems—general

44. Foreign matter in impellers
45. Misalignment
46. Foundation insufficiently rigid
47. Loose foundation bolts
48. Loose pump or motor bolts
49. Inadequate grouting of baseplate
50. Excessive piping forces and moments on pump nozzles
51. Improperly mounted expansion joints
52. Starting the pump without proper warm-up
53. Mounting surfaces of internal fits (at wearing rings, impellers, shaft sleeves, shaft nuts, bearing housings, and so on) not perpendicular to shaft axis
54. Bent shaft
55. Rotor out of balance
56. Parts loose on the shaft
57. Shaft running off-center because of worn bearings

TABLE 2B Continued.

Mechanical Problems—general (continued)

58. Pump running at or near critical speed
59. Too long a shaft span or too small a shaft diameter
60. Resonance between operating speed and natural frequency of foundation, baseplate, or piping
61. Rotating part rubbing on stationary part
62. Incursion of hard solid particles into running clearances
63. Improper casing gasket material
64. Inadequate installation of gasket
65. Inadequate tightening of casing bolts
66. Pump materials not suitable for liquid handled
67. Certain couplings lack lubrication

Mechanical Problems—sealing area

68. Shaft or shaft sleeves worn or scored at packing
69. Incorrect type of packing for operating conditions
70. Packing improperly installed
71. Gland too tight, prevents flow of liquid to lubricate packing
72. Excessive clearance at bottom of stuffing box allows packing to be forced into pump interior

Mechanical Problems—sealing area (continued)

73. Dirt or grit in sealing liquid
74. Failure to provide adequate cooling liquid to water-cooled stuffing boxes
75. Incorrect type of mechanical seal for prevailing conditions
76. Mechanical seal improperly installed

Mechanical Problems—bearings

77. Excessive radial thrust in single-volute pumps
78. Excessive axial thrust caused by excessive wear at internal clearances or, if used, failure or excessive wear of balancing drive
79. Wrong grade of grease or oil
80. Excessive grease or oil in rolling element bearing housings
81. Lack of lubrication
82. Improper installation of rolling element bearings such as damage during installation, incorrect assembly of stacked bearings, use of unmatched bearings as a pair, and so on
83. Dirt getting into bearings
84. Moisture contaminating lubricant
85. Excessive cooling of water-cooled bearings

TABLE 2C Diagnosis from appearance of stuffing box packing in centrifugal pumps

Symptom	Cause
Wear on one or two rings next to packing gland; other rings OK	Improper packing installation
Wear on O.D. of packing rings	Packing rings rotating with shaft sleeve or leakage between rings and I.D. of box. Wrong packing size or incorrectly cut rings
Charring or glazing of inner circumference of rings	Excessive heating. Insufficient leakage to lubricate packing or unsuitable packing
I.D. of rings excessively increased or heavily worn on part of inner circumference	Rotation eccentric

TABLE 2D Vibration symptoms and causes in centrifugal pumps

Vibration frequency	Cause
Several times pump RPM	Bad rolling element bearings
Twice pump RPM	Loose parts on rotor, axial misalignment of coupling, influence of twin-volute when gap is insufficient
Running Speed	Imbalance of rotor, clogged impeller, coupling misaligned or loose
Running speed times number of impeller vanes	Vane passing syndrome—insufficient gap between impeller vanes and collector vanes. This is also sometimes seen during operating with suction recirculation.
One-half running speed	Oil whirl in bearing
Random low frequency	Internal circulation in impeller or cavitation
Random high frequency	Usually resonance
Subsynchronous frequency at 70% to 90% of running speed	Hydraulic excitation of resonance

TABLE 3 Check chart for rotary pump problems

Symptom	Possible cause of trouble (each number is defined in the list below)
Pump fails to discharge	1, 2, 3, 4, 5, 6, 8, 9, 16
Pump is noisy	6, 10, 11, 17, 18, 19
Pump wears rapidly	11, 12, 13, 20, 24
Pump not up to capacity	3, 5, 6, 7, 9, 16, 21, 22
Pump starts, then loses suction	1, 2, 6, 7, 10
Pump takes excessive power	14, 15, 17, 20, 23

Suction problems
1. Pump not properly primed
2. Suction pipe not submerged
3. Strainer clogged
4. Foot valve leaking
5. Suction lift too high
6. Air leaking into suction
7. Suction pipe too small

System problems

8. Wrong direction of rotation
9. Low speed
10. Insufficient liquid supply
11. Excessive pressure
12. Grit or dirt in liquid

System problems (continued)

13. Pump runs dry
14. Viscosity higher than specified
15. Obstruction in discharge line

Mechanical troubles

16. Pump worn
17. Drive shaft bent
18. Coupling out of balance or alignment
19. Relief valve chatter
20. Pipe strain on pump casing
21. Air leak at packing or seal
22. Relief valve improperly seated
23. Packing too tight
24. Corrosion

TABLE 4 Check chart for reciprocating pump problems

Symptom	Possible cause of problem (each number is defined in the list below)
Liquid end noise	1, 2, 7, 8, 9, 10, 14, 15, 16
Power end noise	17, 18, 19, 20
Overheated power end	10, 19, 21, 22, 23, 24
Water in crankcase	25
Oil leak from crankcase	26, 27
Rapid packing or plunger wear	11, 12, 28, 29
Pitted valves or seats	3, 11, 30
Valves hanging up	31, 32
Leak at cylinder valve hole plugs	10, 13, 33, 34
Loss of prime	1, 4, 5, 6

Suction problems

1. Insufficient suction pressure
2. Partial loss of prime
3. Cavitation
4. Lift too high
5. Leaking suction at foot valve
6. Acceleration head requirement too high

System problems

7. System shocks
8. Poorly supported piping, abrupt turns in piping, pipe too small, piping misaligned
9. Air in liquid
10. Overpressure or overspeed
11. Dirty liquid
12. Dirty environment
13. Water hammer

Mechanical problems

14. Valves broken or badly worn
15. Packing worn
16. Obstruction under valve
17. Main bearings loose
18. Bearings worn
19. Oil level low
20. Plunger loose
21. Main bearings tight
22. Ventilation inadequate
23. Belts too tight
24. Driver misaligned
25. Condensation
26. Seals worn
27. Oil level too high
28. Pump not level and rigid
29. Packing loose
30. Corrosion
31. Valve binding
32. Valve spring broken
33. Cylinder plug loose
34. O-ring seal damaged

TABLE 5 Check chart for steam-pump problems

Symptoms	Possible cause of problem (each number is defined in the list below)
Pump does not develop rated pressure	4, 5, 7, 8
Pump loses capacity after starting	1, 2, 6
Pump vibrates	9, 10, 11, 14
Pump has short strokes	12, 13, 14
Pump operation is erratic	1, 2, 3, 6

Suction problems

1. Suction line leaks
2. Suction lift too high
3. Cavitation

System problems

4. Low steam pressure
5. High exhaust pressure
6. Entrained air or vapors in liquid

Mechanical problems

7. Worn piston rings in steam end
8. Binding piston rings in liquid end
9. Misalignment
10. Foundation not rigid
11. Piping not supported
12. Excessive steam cushioning
13. Steam valves out of adjustment
14. Liquid piston packing too tight

FURTHER READING

1. American Petroleum Institute. "Centrifugal Pumps for Refinery, Heavy Duty Chemical, and Gas Industry Services." API Standard 610, 8th ed., 1220 L Street, Washington, DC, 20005, 1995, www.api.org.

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