WATER OPERATION AND MAINTENANCE

BULLETIN NO. 155

(SUPERSEDES BULLETIN NO. 60)

March 1991

IN THIS ISSUE

Pumping Plant Maintenance

UNITED STATES DEPARTMENT OF THE INTERIOR
Bureau of Reclamation

The Water Operation and Maintenance Bulletin is published quarterly for the benefit of those operating water supply systems. Its principal purpose is to serve as a medium of exchanging information for use by Bureau personnel and water user groups for operating and maintaining project facilities.

While every attempt is made to insure high quality and accurate information, Reclamation cannot warrant nor be responsible for the use or misuse of information that is furnished in this bulletin.

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Ferne Studer, Managing Editor
Bill Bouley, Technical Editor
Facilities Engineering Branch
Engineering Division
Denver Office, Code D-5210
PO Box 25007, Denver CO 80225
Telephone: (303) 236-8087 (FTS 776-8087)

Cover photograph:

Exterior of Brady Pumping Plant–Tucson Aqueduct, Central Arizona Project, Arizona.

UNITED STATES DEPARTMENT OF THE INTERIOR BUREAU OF RECLAMATION

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PUMPING PLANT MAINTENANCE

(Supersedes Bulletin No. 60)

FOREWORD

A good pumping plant maintenance program is essential in providing reliable service to water users at the lowest possible cost. A well-planned maintenance schedule can prevent emergency and unscheduled outages while reducing overall maintenance costs. With the wide variety of pumps in use today, it is impossible to provide an all-encompassing maintenance guide that is applicable to every component of every pumping plant. This bulletin is intended as a general guide to help in setting up a comprehensive maintenance program providing maintenance procedures for some of the most common equipment. For more complete maintenance information, the equipment manufacturer should be consulted. The Bureau of Reclamation's Denver Office can also be a source for information on pumping plant maintenance. For problems involving general mechanical and electrical maintenance, contact the Facilities Engineering Branch, D-5210. For problems involving material selection and protective coatings, contact Reclamation's research laboratory in Denver.

CHAPTER 1 – PREVENTIVE MAINTENANCE PROGRAM

The main reason for setting up a preventive maintenance program is to prevent unscheduled outages from failure of equipment. Depending on the circumstances, an unscheduled outage will be, at least, very inconvenient and can be extremely expensive. A well-designed program of preventive and routine maintenance should reduce equipment failures, extend the life of the equipment, and reduce the overall operating costs.

1. Scheduling and Record System

Probably the best place to start in setting up a maintenance program is the equipment manufacturer. The manufacturer should be the foremost authority on what is required to keep the equipment operating properly. Normally the manufacturer's operating manual will provide recommendations on lubricants, spare parts, maintenance procedures, and intervals between maintenance.

While preparing a maintenance schedule, keep in mind that the manufacturer's recommendations are general and are to be used only as a starting point. A particular piece of equipment may operate under much more severe conditions than the manufacturer expected. Conversely, the equipment may experience very mild service and not require as much attention as anticipated. This is why it is important to utilize personal experience and the equipment's history in preparing a maintenance schedule. An effective maintenance program requires tailoring the schedule to the equipment and the conditions under which it operates. Maintenance performed more frequently than required can cause undue wear and tear to the equipment being serviced as well as being a waste of time, while insufficient maintenance will cause premature equipment failure and a reduced service life.

An equipment maintenance record system is essential in establishing a successful preventive maintenance program. The record system should contain a description of the equipment and its location; manufacturer's data such as size, model, type and serial number; pertinent electrical and mechanical data; schedule for preventive maintenance and periodic inspections; data on repairs or maintenance performed including, actual work accomplished, material used, number of hours required to accomplish the work, and the cost of labor and materials.

There are any number of ways of keeping records of the above-mentioned information. The method used depends on personnel and equipment available. One simple and effective method is a card system. The pertinent information for each piece of equipment, including a description and frequency of the maintenance to be performed, is recorded on one or more 5- by 8-inch cards. A record of inspections and maintenance of the equipment should also be entered as the work is performed.

In order to keep track of when inspections or maintenance are due, a rotating file system can be employed. This system is illustrated in Figure 2. The entire file, including the dated index tabs, rotates forward with time, so that the current date is always at the front. As an inspection or maintenance task is completed, the cards are removed from the front and moved to the proper location toward the rear of the file corresponding to the next scheduled inspection. The rotating card file is intended to serve as a scheduling

FILE NO. LJE-5-3

EQUIPMENT 115 kv OCB No. 1162 INSPECTION DUE June

PROJECT Rio Grande LOCATION Elephant Butte Powerplant INSPECTIONS ANNUALLY 1

EQUIPMENT DATA

FURNISHED ON Spec. 892, Schedule 3 DATE Initial operation June 1955

CONTRACTOR Johns Manufacturing Co.

MFR. Johns Manufacturing Co. TYPE B20-60-115D

MODEL OR STYLE NO. SERIAL NO. 5894

VOLTS 115 kv AMPS. 600

H.P. HR. KVA. P.F.

R.P.M. FREQ. 60 PHASE 3 TEMP. °C

TAPS % IMPEDANCE

INTERRUPTING RATING – KVA. 1,000,000

SAMPLE

LINE LENGTH TYPE OF CONSTRUCTION

CONDUCTOR SIZE AND KIND CONDUCTOR SPACING

GPO 840304

FRONT

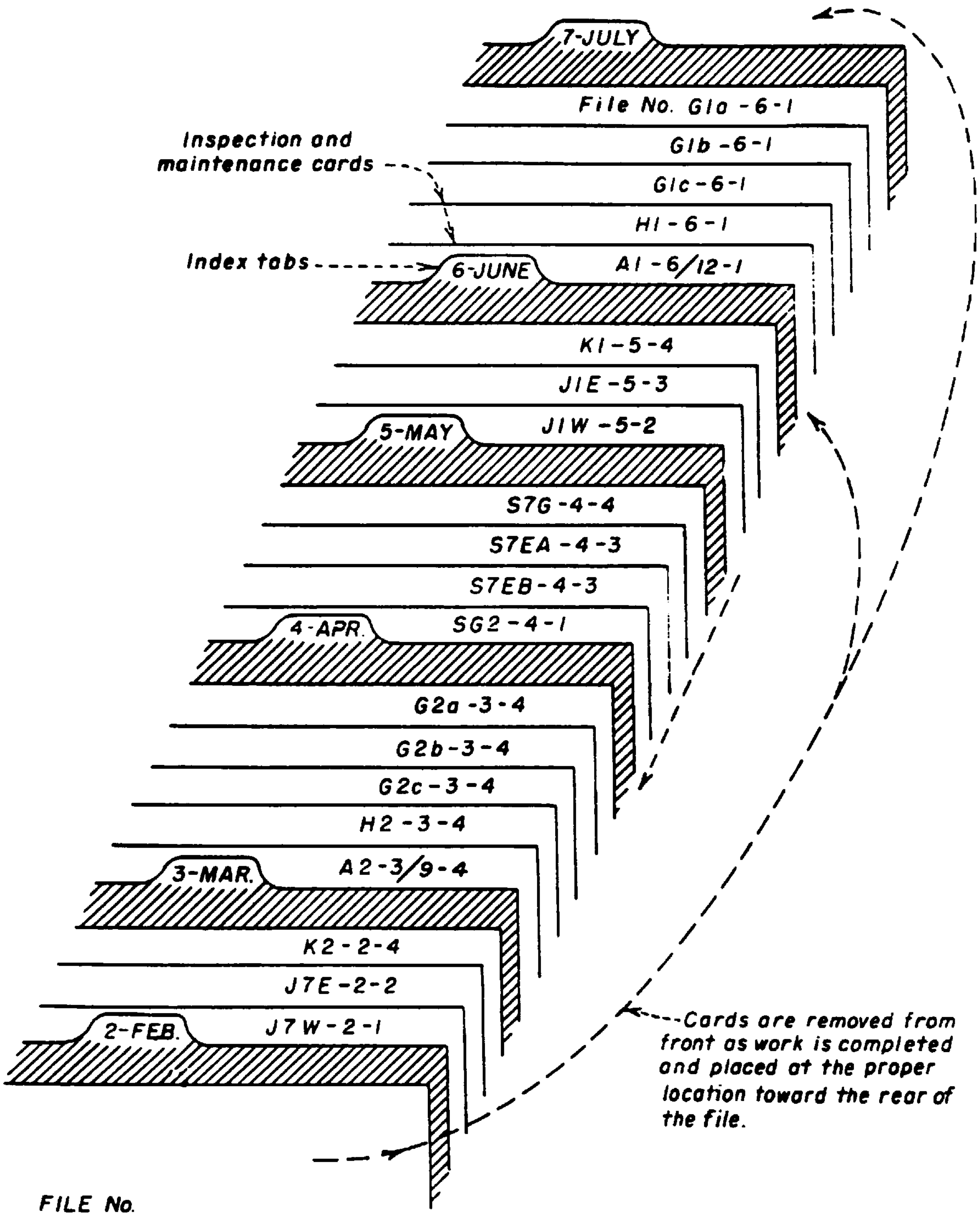
INSPECTION AND MAINTENANCE RECORD

DATE	INSPECTED BY	REPORT REFERENCE	DESCRIPTION OF WORK DONE	COST	
				LABOR	MATERIAL
6/9/56	AJF		Annual inspection - See report of 7/1/56		
6/18/57	AJF		" " " " 7/11/57		
9/24/57	RWH		Replaced open circuited trip coil	7.60	4.50
6/15/58	RWH		Annual inspection - See report of 6/30/58		

SAMPLE

REAR

Figure 1



FILE No.

1st. Symbol group = Equipment designation symbol as established for construction purposes and shown on switching diagrams. G1a = generator No.1. a, b, c, etc. represent parts such as exciters, etc. requiring separate cards. For old plant or equipment having no official symbol use word description such as Gen. 1, Line 1, etc.

2nd. Symbol = Month when inspection is due.

3rd. Symbol = Week when inspection is due.

Figure 2

ROTATING CARD FILE SYSTEM FOR MAINTENANCE SCHEDULES

tool for less frequent maintenance tasks and inspections. Because of the limited space on the cards, separate checklists should be prepared for daily and weekly inspections. Daily and weekly inspections should not be noted on the cards unless repairs are required.

Computers are another method of managing maintenance records. The wide variety of maintenance management software available for all types of computer systems makes converting to a computerized system relatively easy. There is commercial software available that can not only provide the recordkeeping ability of the card system but is also capable of manipulating data into a variety of reports and graphs. In choosing a software package, do not fall into the trap that more is always better. A complicated program may require more time and computer expertise to input and manage data than are available. The more "user-friendly" the program, the more likely that it will be used and the data kept up to date.

Regardless of the system used, after major overhauls or extraordinary maintenance, a more complete report should be written describing the work done and how it was accomplished. Pertinent photographs should be included in the report. This can be especially helpful in future maintenance if different personnel will be doing the work. These reports along with manufacturer's drawings and operation and maintenance material should be kept in a history file where they are readily accessible to maintenance personnel.

Well-kept maintenance records are invaluable in any maintenance program. They provide the necessary information for establishing a preventive maintenance and inspection schedule and a spare parts inventory. Through the analysis of the data from these records, trends indicating deterioration of equipment may become apparent, allowing corrective action to be taken before failure occurs.

2. Inspection Checklists

The information contained in the following chapters is intended to provide general maintenance and inspection information for some of the most common equipment. This information, combined with actual operating experience and manufacturer's recommendations should be used to develop specific inspection schedules and checklists. As an example, equipment maintenance intervals for an enclosed pumping plant may be less frequent than for an outside pumping plant.

The checklist should be concise, but descriptive enough to leave no question as to what information is required and how it should be obtained. For example, if a bearing temperature is to be checked, indicate where the thermometer is located and that the reading should be in degrees Fahrenheit, or degrees Celsius. This should infer to the person performing the inspection that a simple check mark indicating the temperature is okay is not acceptable. The checklist should also include the range of acceptable values or conditions for each item on the list. This will allow the person performing the checks to quickly recognize a problem, and notify maintenance personnel.

Since most irrigation pumping plants operate on a seasonal basis, major maintenance and annual inspections should be scheduled during the nonirrigation season. Any major work, such as a complete overhaul, should be started as soon as possible after the plant is shut down to allow ample time to get the equipment running before water delivery is required again. The person responsible for preparing the schedule for any major maintenance activity should be prepared for the unexpected. By planning ahead and having funds, personnel, spare parts, and special tools available prior to beginning the maintenance, time and money can be saved in the long run.

CHAPTER 2 – TERMINOLOGY

Pumping units at Red Rock Pumping Plant, Central Arizona Project. 3/15/90

1. Types of Pumps

Basically there are two general classifications of pumps, positive displacement and dynamic. These classifications are based on the method the pump uses to impart motion and pressure to the fluid. Positive displacement pumps enclose the fluid through the use of gears, pistons, or other devices; and push or "displace" the fluid out through the discharge line. Displacement pumps are divided into two groups — reciprocating such as piston and diaphragm pumps, and rotary such as gear, screw, and vane pumps. As there is very little use for displacement pumps in irrigation applications, there will be no more discussion of this classification of pumps in this bulletin.

Dynamic pumps continuously accelerate the fluid within the pump to a velocity much higher than the velocity at the discharge. The subsequent decrease of the fluid velocity at the discharge causes a corresponding increase in pressure. The dynamic pump category is made up of centrifugal pumps and special effect pumps such as eductor and hydraulic ram pumps. Centrifugal pumps in one form or another are the predominate choice for irrigation applications.

2. Centrifugal Pump Nomenclature

The impeller of a centrifugal pump, the rotating component of the pump which imparts the necessary energy to the fluid to provide flow and pressure, is classified according to the direction of flow in reference to the axis of rotation of the impeller. The three major classes of centrifugal impellers are:

a. Axial-flow
b. Radial-flow
c. Mixed-flow

Impellers may be further classified by their construction. The impeller construction may be:

a. Open
b. Semi-open
c. Closed

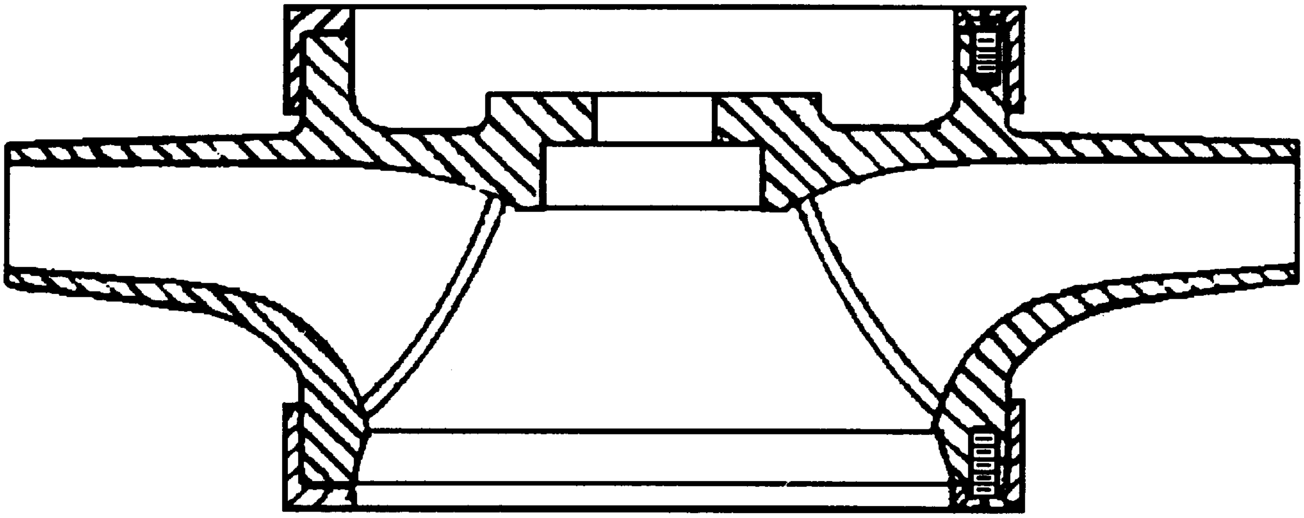
An open impeller consists of vanes attached to a central hub. A semi-open impeller has a single shroud supporting the vanes, usually on the back of the impeller. The closed impeller incorporates shrouds on both sides of the vanes. The shrouds totally enclose the impeller's waterways and support the impeller vanes. The closed impeller is the most common type found in irrigation pumping plants.

Pumps are also classified by the means in which the velocity energy imparted to the fluid by the impeller is converted to pressure. Volute pumps use a spiral- or volute-shaped casing to change velocity energy to pressure energy. Pumps which use a set of stationary diffuser vanes to change velocity to pressure are called diffuser pumps. The most common diffuser-type pumps are vertical turbine pumps and single-stage, low-head, propeller pumps. Large volute pumps may also have diffuser vanes, but while these vanes may direct the waterflow, their main purpose is structural and not energy conversion.

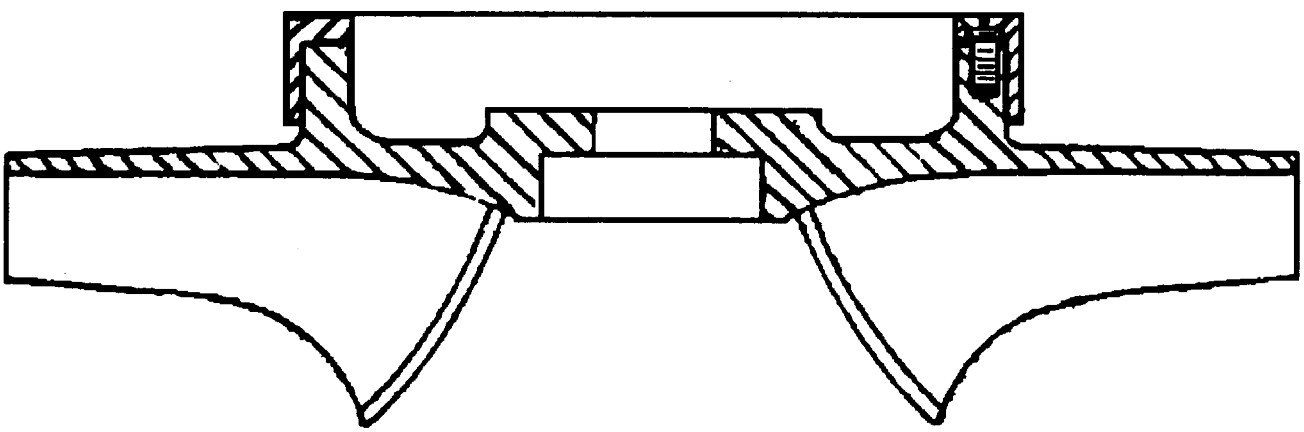
Pumps are further classified as either horizontal or vertical, referring to the orientation of the pump shaft. Vertical pumps are normally preferred for irrigation pumping plant purposes as they take up less floor space, the pump suction can be more easily positioned below the water surface to eliminate the need for priming, and the pump motor can be located above the water surface to prevent damage in the event of flooding. Vertical pumps can be either dry-pit or wet-pit. Dry-pit pumps are surrounded by air while wet-pit pumps are either fully or partially submerged. The dry-pit pumps are commonly used in medium-to-high head, large capacity pumping plants. These large dry-pit pumps are generally volute pumps with closed, radial-flow impellers.

There is a wide variety of wet-pit pump designs for a wide variety of applications. The most common type used in irrigation applications is the vertical turbine pump. The vertical turbine pump is a diffuser pump with either closed or semi-open, radial-flow or mixed-flow impellers. Vertical turbine pumps, while originally designed for deep-well applications, have a wide variety of uses, including irrigation pumping plants. This type of pump is normally constructed of several stages. A stage consists of an impeller and its casing, called a bowl. The main advantage of this type of construction is that system pressure can be varied by simply adding or reducing the number of stages of the pump. Vertical propeller pumps may also be used in pumping plants but their use is limited to low-head, high-capacity use.

Horizontal pumps are classified according to the location of the suction pipe. The suction can be from the end, side, top, or bottom. Also common in horizontal pumps is the use of double-suction impellers. In a double-suction impeller pump, water flows symmetrically from both sides into the impeller which helps to reduce the axial thrust load.



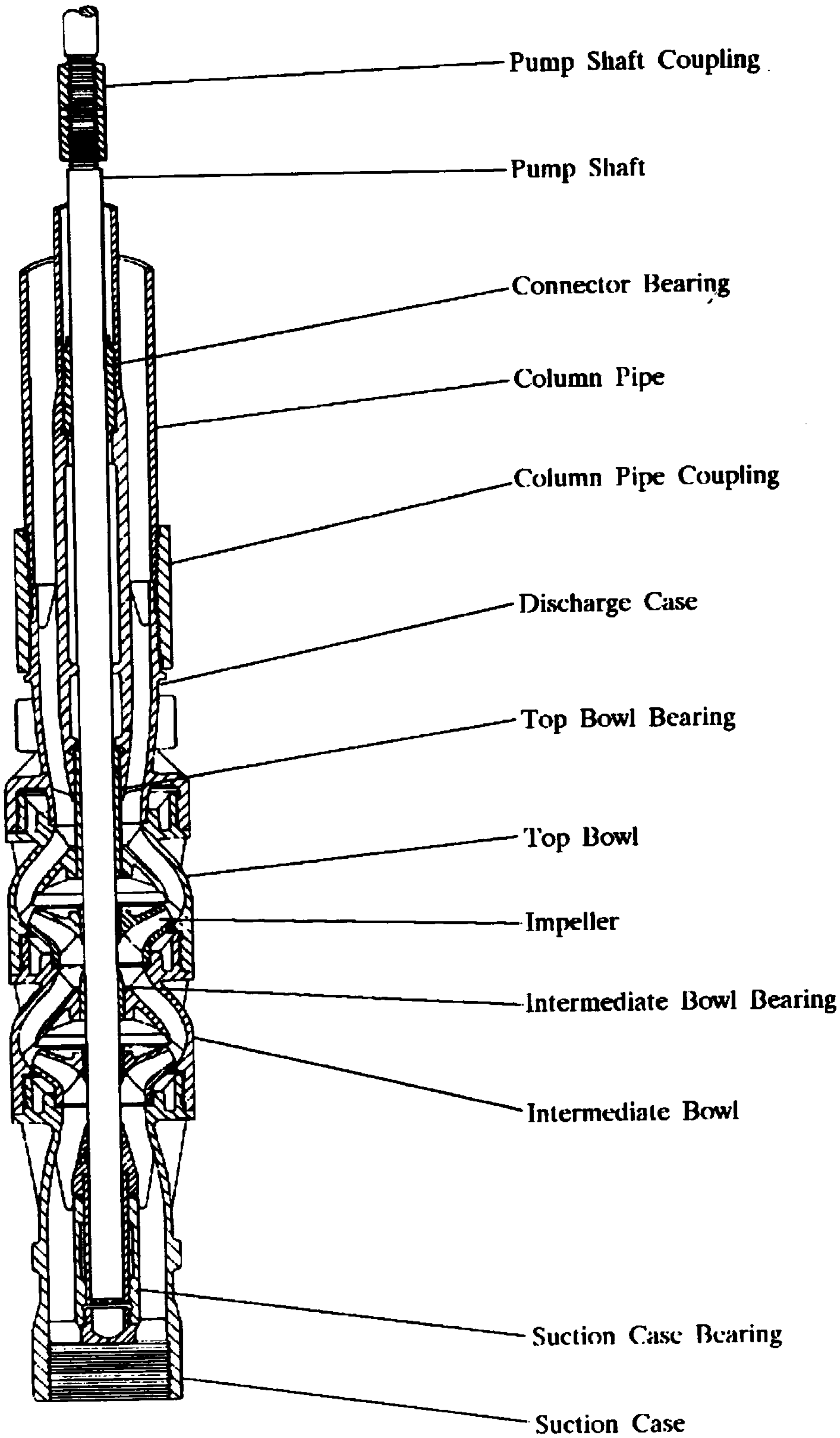
Closed Impeller



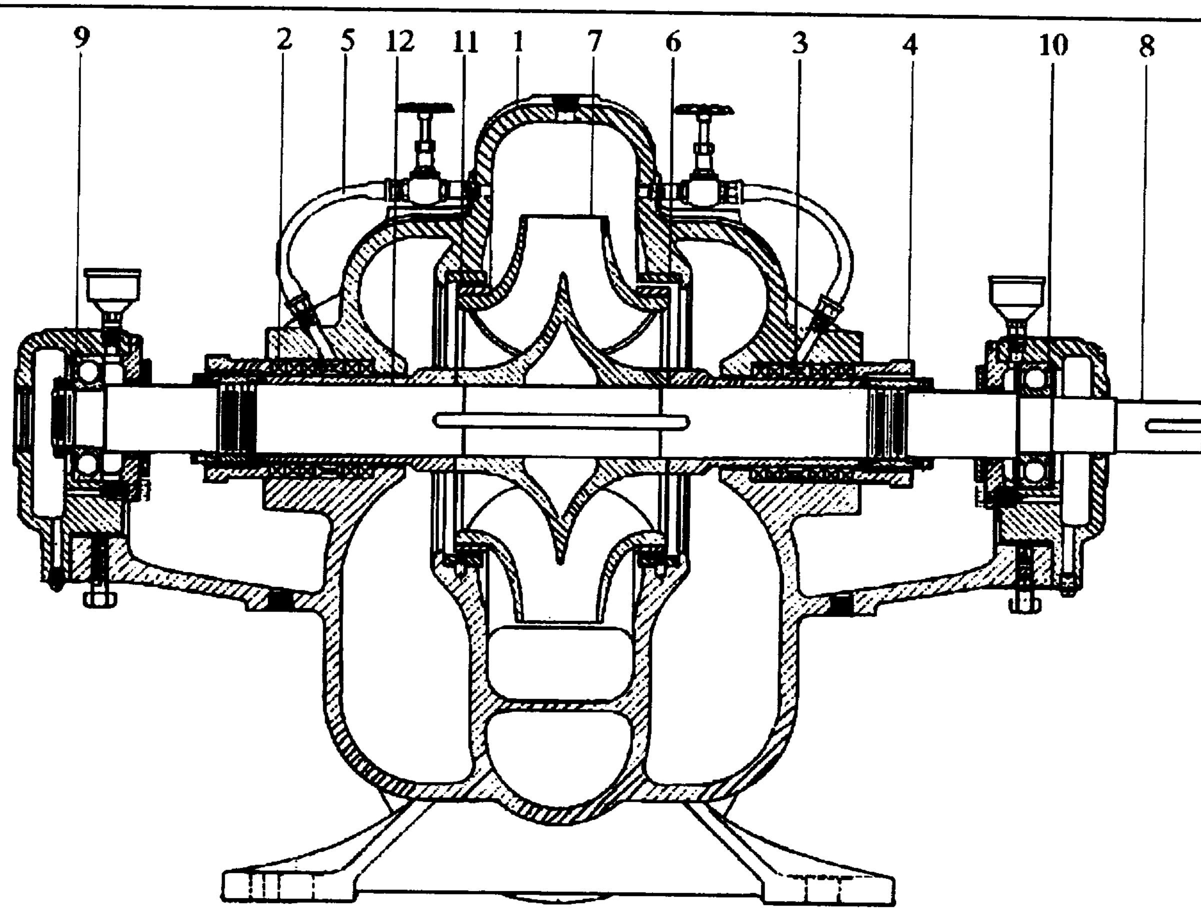
Semi-Open Impeller

Figure 3

(Courtesy of Dresser Pump Division)



Two Stage Vertical Turbine Pump
(Courtesy of Dresser Pump Division)
Figure 4

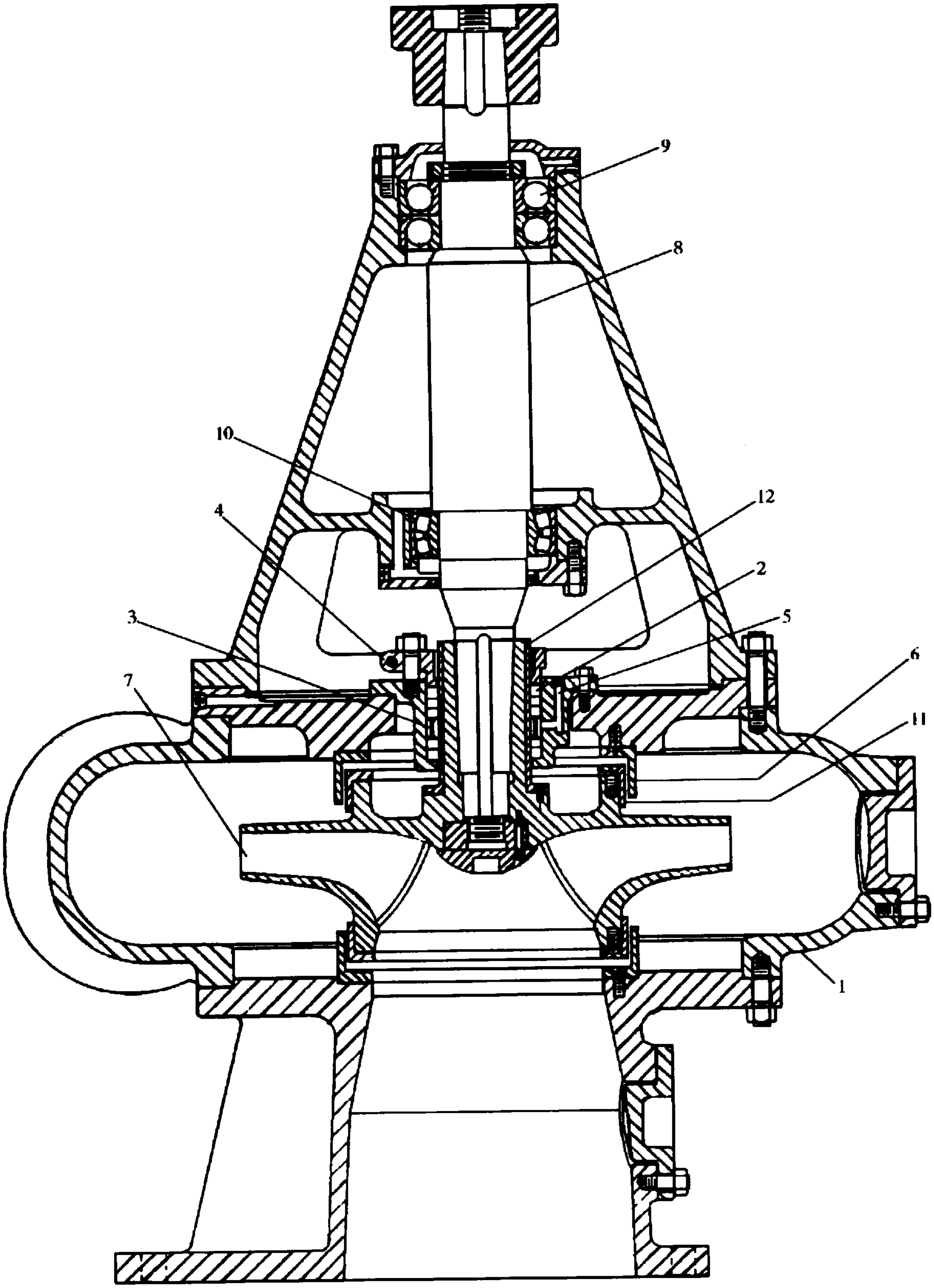


Double Suction Horizontal Volute Pump

PARTS LIST FOR HORIZONTAL AND VERTICAL PUMP DRAWINGS			
STATIONARY PARTS		ROTATING PARTS	
1	Pump Case	7	Impeller
2	Packing	8	Pump Shaft
3	Lantern Ring	9	Thrust Bearing
4	Packing Gland	10	Line Bearing
5	Packing Water Supply	11	Rotating Wear Ring
6	Stationary Wear Ring	12	Shaft Sleeve

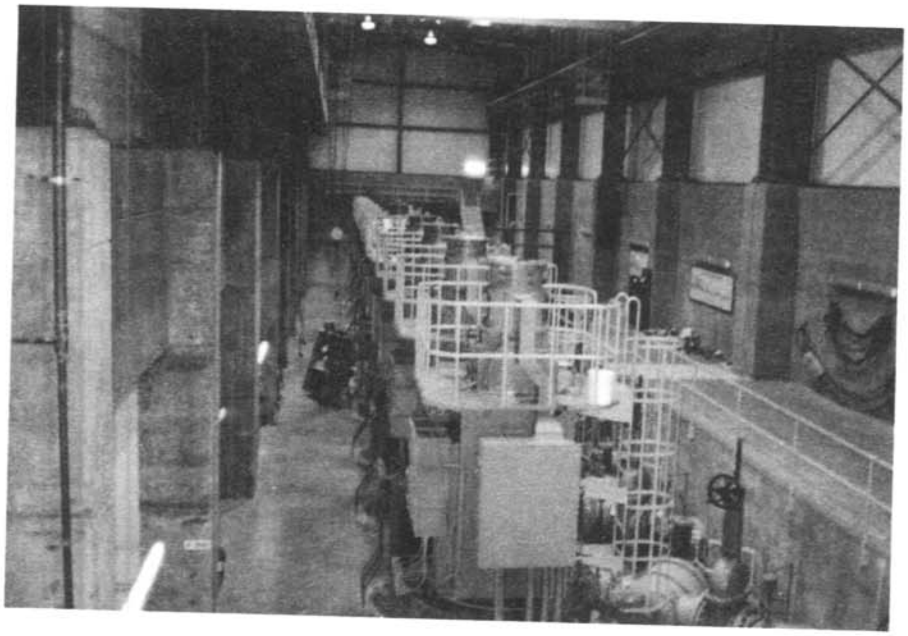
Figure 5

(Courtesy of Dresser Pump Division)



Vertical Volute Pump
(Courtesy of Dresser Pump Division)

Figure 6



Pumping units at Pacheco Pumping Plant, San Felipe Division, Central Valley Project

There is a wide variety of pump types and sizes in use in irrigation pumping plants with each having characteristics unique to a given application. This chapter includes a brief discussion of some of the more common maintenance problems followed by a general inspection checklist for pumps.

1. Impeller and Casing

A pump impeller, designed and sized correctly, pumping clean and noncorrosive water at its maximum efficiency capacity should have a long service life with very little maintenance required. Unfortunately, irrigation water is not always clean or noncorrosive and actual operating conditions do not always match those used as design criteria. Because of this, regular maintenance will generally be required.

The pump impeller and casing may be damaged by a number of different actions, the most common being cavitation erosion, abrasive erosion, and corrosion. The appropriate repair procedure will depend on the cause of the damage.

Cavitation is the formation of vapor bubbles or cavities in a flowing liquid subjected to an absolute pressure equal to, or less than, the vapor pressure of the liquid. These bubbles collapse violently as they move to a region of higher pressure causing shock pressures which can be greater than 100,000 lb/in^2. When audible, cavitation makes a steady crackling sound similar to rocks passing through the pump. Cavitation erosion or pitting occurs when the bubbles collapse against the metal surface of the impeller and occurs most frequently on the low-pressure side of the impeller inlet vanes. Cavitation cannot only severely damage the pump, but also can substantially reduce the pump's capacity and therefore lessen the efficiency.

Abrasive erosion is the mechanical removal of metal from the impeller surface by suspended solids, such as sand, in the liquid being pumped. The rate of wear is directly related to the velocity of the liquid, so wear will be more pronounced near the exit vanes and shrouds of the impeller where the liquid velocity is highest.

Corrosion damage to submerged or wet metal is the result of an electrochemical reaction. The electrochemical reaction occurs when a galvanic cell is created by immersing two different elements in an electrolyte, causing an electric current to flow between the two elements. The anode, or the positive electrode of the cell, gradually dissolves as a result of the reaction. With the water acting as an electrolyte, irregularities such as variation in surface finish or imperfections in the metal's composition create small galvanic cells over the entire surface of the metal. Corrosion damage occurs as the anodes of these cells dissolve. Corrosion, unlike abrasive erosion, is generally independent of the liquid velocity. Pitting caused strictly by corrosion will be uniform over the entire surface of the impeller or casing.

Diagnosis of the problem can be difficult as the damage may be caused by more than one action. As a metal corrodes, the products of corrosion form a protective film on the metal surface. This film protects the base metal from further corrosive attack. An erosive environment will tend to remove this film leaving the metal susceptible to corrosion damage. Similarly, where cavitation erosion is occurring, the metal will be prone to further damage from corrosion.

Extremely severe erosion or corrosion damage may warrant the replacement of the damaged parts with parts constructed of a material that is more erosion or corrosion resistant. If severe cavitation erosion occurs during normal operation, a new impeller or other design changes may be required. Obviously, replacing an impeller or other major components can be a very expensive endeavor, especially for large pumps, and should only be done after careful economic analysis. Some factors to take into consideration when making an analysis are the cost and effectiveness of past repairs, the current efficiency of the pump, the anticipated life of the current pump, and the desired life of the pumping plant.

Except for severe cases, repair instead of replacement is the most economical solution. The repair procedure will depend on the cause of the damage. Welding is the most successful method of repair for cavitation damage. Prior to any weld repair, a detailed welding procedure should be developed. Welding performed incorrectly can cause more damage by distortion and cracking than the cavitation did originally. Repair with nonfusing materials, such as epoxies and ceramics, is generally not successful because the low-bond strength of these materials, usually less than 3,000 lb/in^2, is not capable of withstanding the high-shock pressures encountered during cavitation. Where cavitation is minor or where welding is not possible, the nonfusing materials may be used with the understanding that frequent repair may be required. If weld repair is planned in the future, the use of the epoxies or ceramics is not recommended as these materials can be extremely difficult to remove completely prior to welding and the heat of welding will release toxic fumes. Cavitation repair is discussed in more detail in FIST [Facilities

Instruction, Standards, & Techniques (formerly Power O&M Bulletins)], Vol. 2-5 entitled "Turbine Repair."

Corrosion or erosion damage, if the pitting is deep enough, can also be repaired by welding. If the pitting is definitely not caused by cavitation, other coating or fillings may be acceptable. Epoxies and ceramics, if properly applied, can be helpful in filling in pitting damage caused by corrosion or erosion. In a corrosive environment, a coating of paint, after the original contour has been restored, can offer protection by forming a barrier between the metal and the electrolyte and preventing the electrochemical reaction.

Erosion-resistant coatings, in order to be effective, must be able to withstand the cutting action of the suspended abrasive. A coating of neoprene has been proven successful for sand erosion protection. There are other coatings available that have also been proven to be resistant to erosion, but many of these coatings can be difficult to apply and maintain, and may restrict water passages somewhat because of coating thickness. Erosion-resistant coatings should be chosen based on the design of the pump and the severity of erosion.

The pump manufacturer can be a good source of information on the repair of pumps. Many times the manufacturer will have experienced similar problems and will have solutions or at least suggestions to improve performance. Reclamations's research laboratory in Denver can also offer suggestions for protective coatings.

2. Wearing Rings

The purpose of wearing rings is to provide a renewable seal or leakage joint between the impeller and pump casing. As the name implies, these rings can wear over time and as the clearance increases, pump efficiency and discharge can decrease. As a general rule, when the wearing ring clearance exceeds 200 percent of the design clearance, the wearing rings should be replaced or renewed. If a pump design does not include replaceable wearing rings, it may be necessary to build up the wearing ring area by welding or other acceptable process and machining back to the original clearances; remachine the casing and impeller to accept replaceable wearing rings; or, on smaller pumps, replace the impeller and casing.

The location of the wearing rings depends on the design of the pump. Closed impeller pumps normally have a suction side wearing ring and many times have wearing rings on both the suction and stuffing box sides of the impeller. Open impeller and many semi-open impeller pumps do not have wearing rings, relying on a close fit between the impeller vanes and the pump casing to control leakage. Some semi-open impeller pumps have one stuffing box side wearing ring.

3. Packing/Mechanical Seals

Packing.–The most common method of controlling leakage past the pump shaft where it passes through the pump casing, is by the use of compression packing. The standard packing or stuffing box will contain several rings of packing with a packing gland to hold the packing in place and maintain the desired compression. Some leakage past the packing is usually necessary to cool and lubricate the packing and shaft. Lantern rings are installed where additional lubrication is required.

Over time, the packing gland will have to be tightened to control leakage. To prevent burning the packing or scoring the shaft when these adjustments are made, most compression packings contain a lubricant. As the packing is tightened, the lubricant is released to lubricate the shaft until leakage past the packing is reestablished. Eventually, the packing will be compressed to a point where no lubricant remains and replacement is required. Continued operation with packing in this condition can severely damage the shaft.

When packing replacement is necessary, remove all of the old packing. If the stuffing box is equipped with a lantern ring this also must be removed along with all of the packing below it. With the packing removed, special attention should be given to the cleaning and inspection of the stuffing box bore and the shaft or shaft sleeve. To provide an adequate sealing surface for the new packing, a severely worn shaft or shaft sleeve should be repaired or replaced. Likewise, severe pitting in the stuffing box bore should be repaired. Excessive compression of the packing is required in order for the packing to seal against a rough stuffing box bore. This over compression of the packing will lead to premature wearing of the shaft or shaft sleeve.

The shaft runout at the stuffing box should be checked with a dial indicator. On most pumps, total indicated runout should not exceed 0.003 inch, although the shaft runout on large vertical pumps can usually be somewhat greater than this. If the runout is excessive, the cause should be found and corrected. Bent shafts should be replaced and misalignment corrected.

There is a wide variety of packing types and materials available from a variety of sources. When choosing new packing, care should be taken to ensure that it is the correct size and type for the intended application. Be sure to inform the packing distributor of all the relevant conditions, such as shaft size and rotational speed, the packing will operate under. Installing the wrong packing can result in excessive leakage, reduced service life, and damage to the pump shaft or sleeve.

The new packing should be installed with the joints staggered 90° apart. It is sometimes helpful to lubricate the packing prior to installation. The packing manufacturer should be consulted for recommendations for a lubricant and for any special instructions that may be required for the type of packing being used. With all of the packing and the lantern ring in place the packing gland should be installed finger tight.

There should be generous leakage upon the initial startup of the pump. The packing gland should be tightened evenly and in small steps until the leakage is reduced sufficiently. The gland should be tightened at 15- to 30-minute intervals to allow the packing time to break in. The temperature of the water leaking from the packing should be cool or lukewarm, never hot. If the water is hot, back the packing gland off.

Mechanical Seals.–Mechanical seals are being used in a variety of pump applications. Mechanical seals allow very little leakage and can be designed to operate at high pressures. Properly installed mechanical seals will have a long service life and require little maintenance.

Basically, a mechanical seal consists of a stationary and a rotating member with sealing surfaces perpendicular to the shaft. The highly polished sealing surfaces are held together by a combination of spring and fluid pressure and are lubricated by maintaining a thin film of the fluid sealed between the surfaces.

Since mechanical seals are precisely made and rely on very tight tolerances in order to operate successfully, it is important that a great deal of care be taken during the installation. Just a small amount of dirt or other contaminants on the polished sealing surfaces can allow leakage past the seal and reduce the seal's life. There is a wide variety of mechanical seals available, each having its own distinct installation procedure; therefore, it is important to follow the seal manufacturer's installation instructions as closely as possible. The manufacturer should also provide information of the allowable shaft runout and end play for his particular seal.

4. Bearings

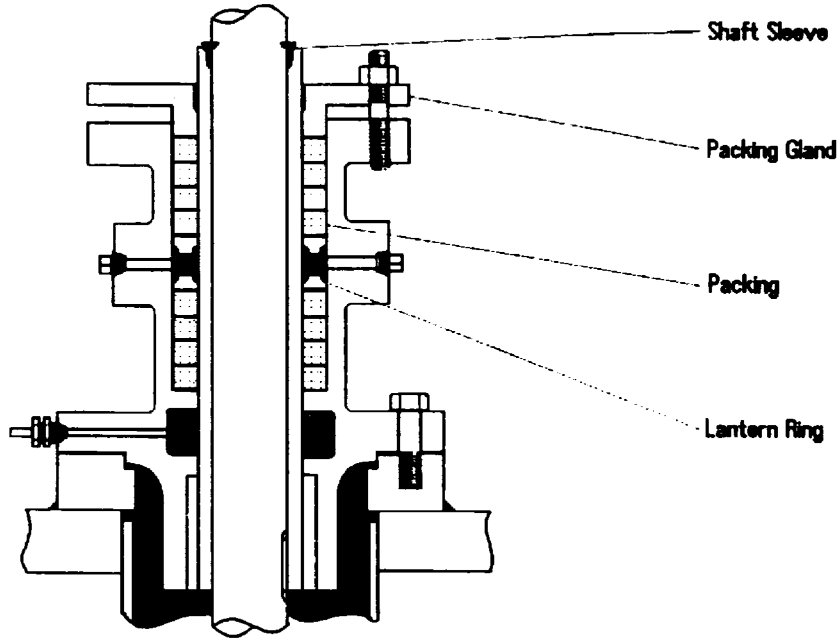
General.-The purpose of the bearings is to locate and support the pump and motor shafts. The bearings can provide radial support (line or guide bearings), axial support (thrust bearings), or both. The most common types of bearings used in pumps are fluid film and antifriction bearings.

Fluid Film Bearings.-Fluid film bearings derive their load-carrying capacity through the formation of an "oil wedge" as the shaft or thrust runner rotates. The formation of this "oil wedge" is similar to the fluid wedge that forms under a speeding boat, raising its bow out of the water. The force of the wedge in a bearing must be sufficient to balance the load to the bearing surfaces.

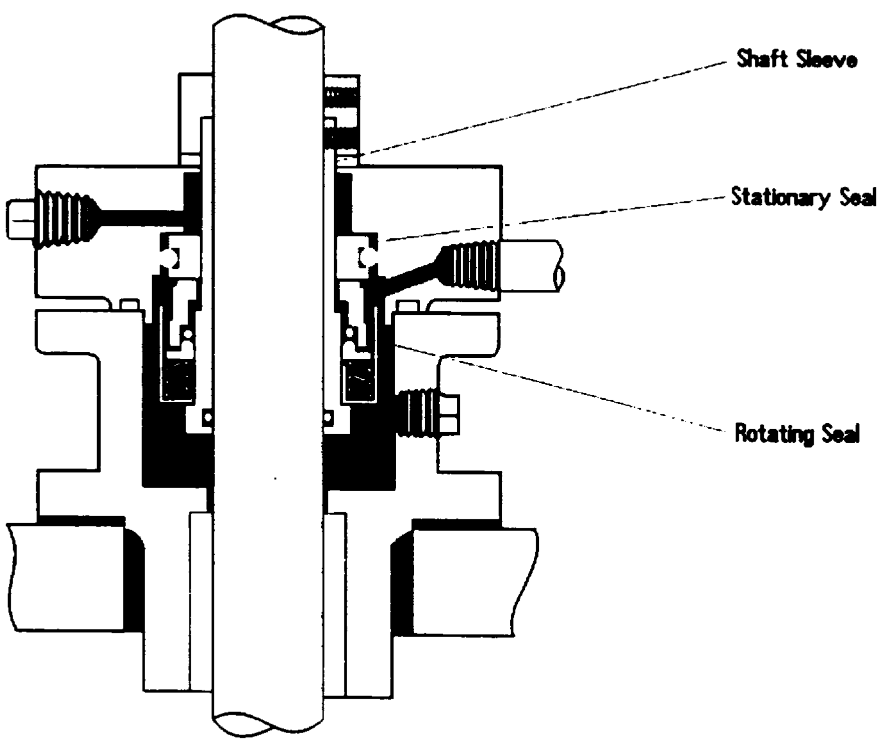
Fluid film, or plain, bearings are normally used on larger pumps and can be in the form of sleeve bearings, either solid or split, tilting pads, or pivoted thrust shoes. Large vertical dry-pit pumps most commonly use cast iron or steel bearing shells with a tin- or lead-based babbitt lining. Bronze bushings are used for line shaft bearings in vertical wet-pit pumps and on some horizontal pumps.

Antifriction Bearings.-The antifriction bearings, through the use of some sort of rolling elements, utilize the low coefficient of rolling friction as opposed to that of sliding friction of the fluid film bearing in supporting a load. The most common types of antifriction bearings are "ball" and "roller" bearings, referring to the shape of the bearings' rolling elements. These bearings are also classified as "radial," "radial-thrust," or "thrust" bearings according to the type of load they are meant to support.

An antifriction bearing is a delicate, precision made piece of equipment and a great deal of care should be taken during installation. The bearing manufacturer will usually provide instructions and precautions for the installation of a particular bearing and these instructions should be followed closely. Cleanliness is probably the most important thing to take into consideration in handling antifriction bearings. Any dust or dirt can act as an abrasive and quickly wear the bearing's rolling elements; therefore, it is important to work with clean tools and clean hands and to clean the bearing housings, covers, and shaft prior to installation. The new bearing should not be cleaned or wiped prior to installation unless it is recommended by the manufacturer. Bearings should be pressed onto shafts using adapters that apply even pressure to the inner race only. Never hammer a bearing onto a shaft.



Compression Packing



Mechanical Seal

Figure 7

(Courtesy of Dresser Pump Division)

5. Shaft Couplings

General.–Most pumps have some sort of coupling to connect the pump driver shaft to the pump shaft and to transmit rotary motion and torque from the driver to the pump. There are basically two types of couplings used with pumps – rigid and flexible.

Rigid couplings require precise alignment of the pump and its driver and are most commonly used where the impeller and impeller shaft are supported by thrust bearings in the pump driver. Flanged and threaded couplings are the most widely used rigid couplings used in pumping plant applications. Flanged couplings are used on large vertical units and consist of a flange on each shaft, connected by a series of coupling bolts around the perimeter of the flanges. Threaded couplings, used to connect the line shafts of vertical turbine pumps, are cylindrically shaped with internal threads matching the external threads on the line shafts. The shafts to be coupled are simply screwed tightly into either end of the coupling.

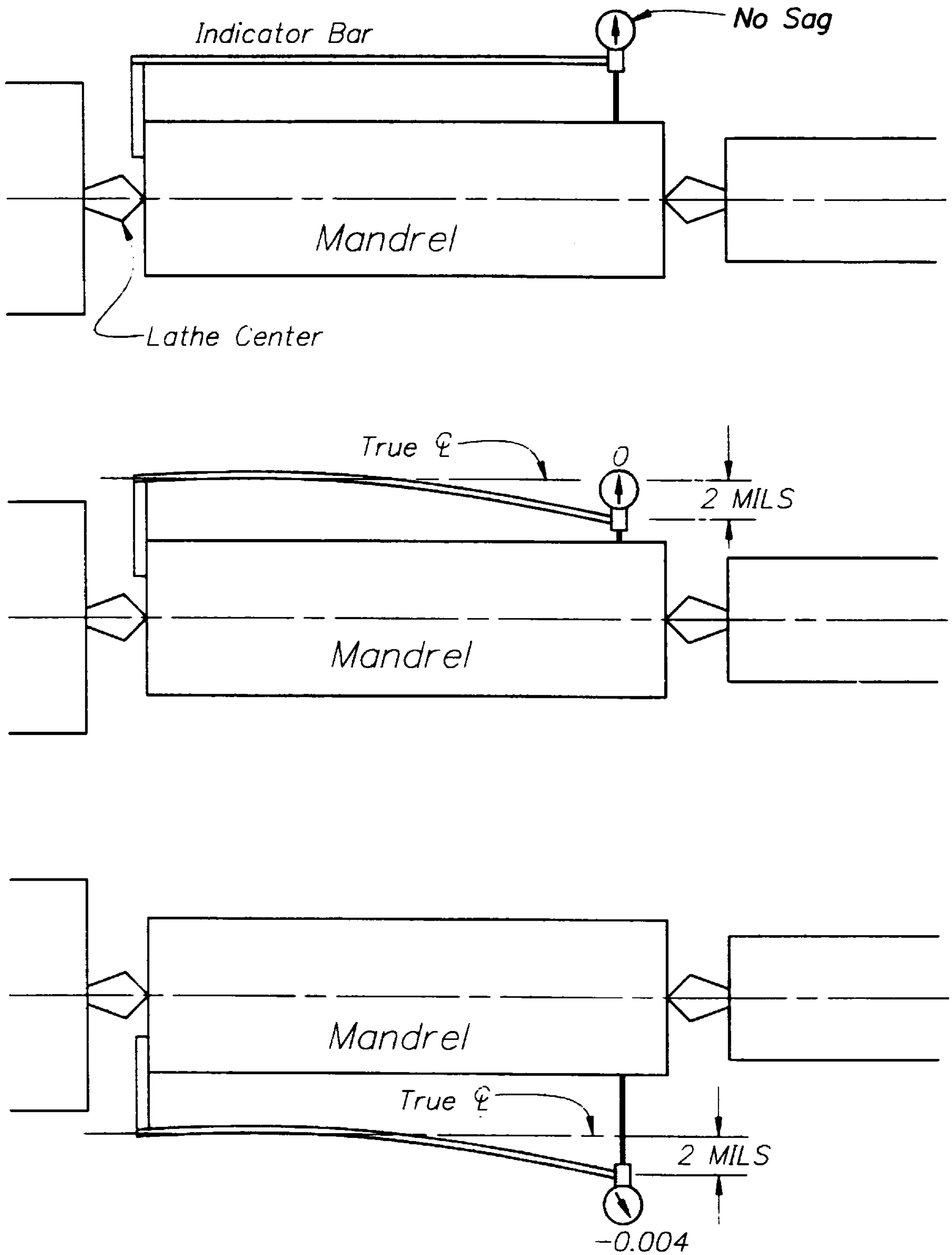
Flexible couplings are designed to accommodate slight misalignment between shafts and, to some extent, dampen vibration. The amount of misalignment allowable is completely dependent on the design of the particular coupling. Since there is a large variety of flexible coupling designs, tolerances should be obtained from the coupling manufacturer. The flexibility of the couplings can be provided through clearances between mating parts, as in gear and chain couplings, or through the use of a flexible material in the coupling, as in flexible disk and compression couplings. Horizontal pumps usually employ some sort of flexible coupling to connect the pump to its driver.

If properly aligned, most couplings should require very little maintenance outside of periodic inspection, and in some cases, lubrication. Over time, the alignment between the pump and its driver can deteriorate, increasing stress on the coupling which can lead to a shorter life. The condition of the coupling lubricant can be a good indication of the shaft alignment. Excessive oil separation from grease may indicate excessive heat in the coupling caused by misalignment. Shaft alignment is discussed in the following paragraphs.

6. Shaft Alignment

General.–The misalignment between the pump and its driver is a common problem. Poor alignment can cause premature wear or failure of bearings; overheating of shaft couplings; and, in extreme cases, cracked or broken shafts. The procedure used to align pump and pump driver shafts depends on the type of pump and its design.

Large vertical units, suspended from a thrust bearing in the motor, require plumbing the shaft and making all guide bearings concentric. The procedure for aligning these units is discussed in detail in FIST, Vol. 2-1, "Alignment of Vertical Shaft Hydro Units."



CHECKING INDICATOR BAR FOR SAG

Figure 8

The line shafts of vertical turbine pumps are held in alignment by line-shaft bearings in the pipe column. The proper alignment of the line shaft depends on the proper assembly of the pipe column and the bearing retainers. Depending on the design, the pump motor to line-shaft coupling may be aligned by the face and rim method or the reverse indicator method described below. Refer to the pump manufacturer's instructions for specific directions for assembly and alignment.

Horizontal pumps are usually coupled to the pump driver with a flexible coupling. The amount of misalignment a flexible coupling can tolerate is dependent on its design. The coupling's manufacturer should provide installation instructions indicating the allowable tolerances for a particular design. A horizontal pump can usually be aligned acceptably by either the face and rim method or reverse indicator method. Normally the pump driver is aligned to the pump, as the pump is usually connected to rigid piping and is more difficult of move.

Preliminary Checks for Alignment of Horizontal Pumps.–

a. At least 0.125 inch of nonrusting shims should be installed under each leg of the motor to allow for adjustments that may be required during the alignment procedure.

b. Compensation should be made for any "soft" or "dead" foot condition. A "soft foot" condition is comparable to a short leg on a four-legged table. To check for a "soft foot," make sure all four feet are securely bolted to the baseplate. With a dial indicator, check the rise of each foot as its holddown bolt is loosened. Retighten the holddown bolt after the rise is recorded, so that only one bolt is loose at a time. If one foot rises more than the other three, that foot is the "soft foot." If one foot rises 0.005 inch while the other three rise only 0.002 inch, a 0.003 inch shim should be added to the "soft foot."

c. The holddown bolt holes should be checked for sufficient clearance to allow for movement during the alignment procedure.

d. The mounting brackets and extension bars used for the indicators should be constructed to minimize sag. Sag is the effect of gravity on the indicator extension bar and can greatly affect the accuracy of the readings when using the Reverse Indicator Method or rim readings of the Face and Rim Method. The sag of an indicator bar can be determined by securely attaching the bar to a section of rigid bar stock or a shaft mandrel. The bar stock or mandrel can be supported and rotated by hand or between centers on a lathe. With the indicator bar positioned on top, zero the indicator and rotate the bar stock 180°. The indicator reading will be twice the actual amount of bar sag. To correct alignment readings for sag, add twice the amount of bar sag to the bottom indicator reading.

Important: The procedures described below for the Face and Rim and the Reverse Indicator Alignment Methods assume that movement towards the indicator, moves the indicator needle in the positive direction, while movement away from the indicator moves the needle in the negative direction.

If the indicator used has the opposite sign convention, that is movement towards the indicator moves the needle in the negative direction, the following corrections will have to made. In using the Face and Rim Method, simply make all movements in the opposite direction indicated in the procedure. When using the Reverse Indicator Alignment Worksheet, the value in column 2 should be subtracted from the bottom reading in column 1, instead of adding to obtain the corrected value in column 3. In determining the direction of the motor shaft from the pump shaft in column 6, circle the direction corresponding to the sign opposite that in column 5. For example, if the values in column 5 for the pump indicator are +5 and -1, the directions in column 6 would be Below and Left.

Face and Rim Alignment Method.-The face and rim method of alignment utilizes a dial indicator attached to one of the coupling flanges to check for angular and parallel misalignment. Indicator readings can be taken by rotating just one shaft, but in order to compensate for an untrue surface on the face or rim of the coupling flange, both shafts should be rotated together in the direction of normal rotation. If it is not possible to rotate both shafts, the indicator should be attached to the shaft that is rotated. The procedure is the same whether one or both shafts are rotated. The data obtained during the face and rim alignment procedure provide fairly accurate values for the movement or shims required to correct parallel misalignment, but some trial and error may be required to correct angular misalignment.

Angular Alignment.-

a. With the indicator attached to one coupling half and the indicator button resting near the outer edge of the other coupling's flange face, rotate the shaft with the indicator so that the indicator is at the top or 12 o'clock position and zero the indicator.

b. Rotate both shafts 180° and read indicator. If the reading is positive, the rear legs of the motor must be raised or the front legs lowered. A negative reading requires lowering the rear legs or raising the front legs.

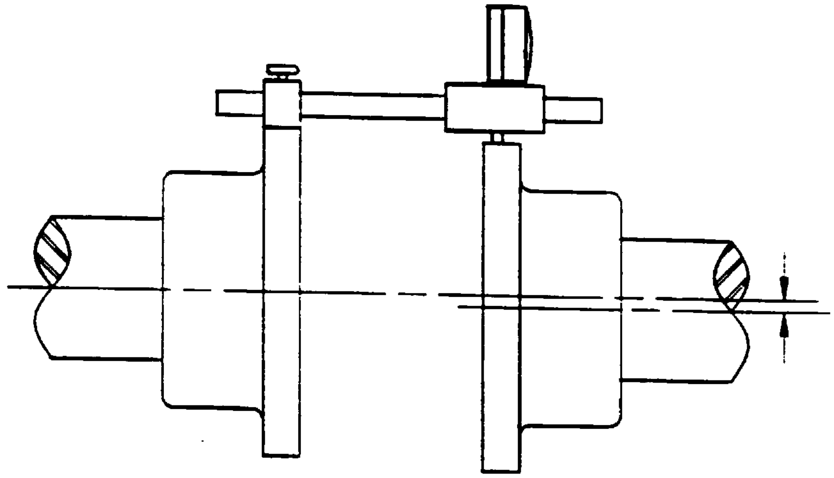
c. Looking from the pump end, rotate both shafts so that the indicator is at the 3 o'clock position and zero the indicator.

d. Rotate both shafts 180° and read indicator. If the reading is positive, the rear of the motor must be moved to the right or the front of the motor moved to the left. A negative reading requires moving the rear of the motor to the left or the front to the right.

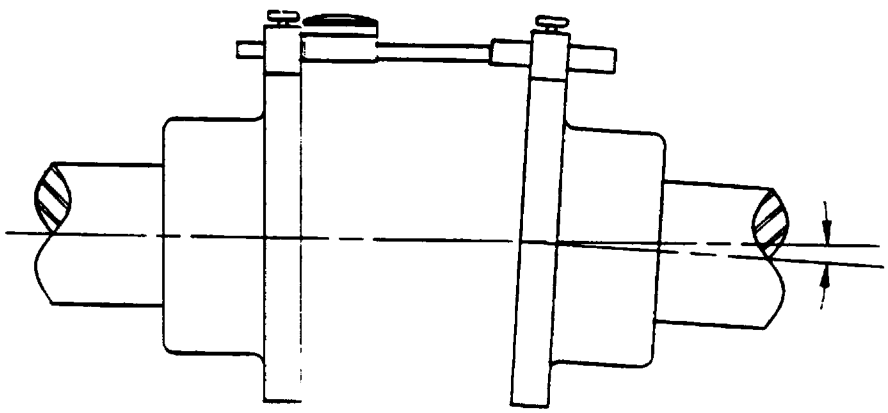
e. Angular alignment is acceptable when dial indicator readings are zero at all positions or within the tolerances specified by the coupling manufacturer.

Parallel Alignment.-

f. Reposition indicator so that the button rests on rim of coupling flange. Rotate shaft with indicator so that the indicator is on top or at the 12 o'clock position and zero indicator.



CHECK FOR PARALLEL MISALIGNMENT



CHECK FOR ANGULAR MISALIGNMENT

FACE AND RIM ALIGNMENT METHOD

Figure 9

g. Rotate both shafts 180° and read indicator. Add twice the amount of actual bar sag to obtain the corrected reading. If the indicator is attached to the pump coupling, a positive corrected reading requires raising the motor by half of the corrected reading. For example, if the reading is +0.010, a 0.005-inch shim should be added to each motor leg. A negative corrected reading requires lowering the motor. If the indicator is attached to the motor coupling, a positive reading requires lowering the motor and a negative reading requires raising the motor.

h. Looking from the pump end, rotate both shafts so that the indicator is at the 3 o'clock position and zero the indicator.

i. Rotate both shafts 180° and read indicator. If the indicator is attached to the pump coupling, a positive reading requires moving the motor to the right and a negative reading requires moving the motor to the left. If the indicator is attached to the motor coupling, a positive reading requires moving the motor to the left and a negative reading requires moving the motor to the right.

j. Parallel alignment is acceptable when dial indicator readings are zero at all positions or within the tolerances specified by the coupling manufacturer.

k. After any movement of the motor, repeat steps a. through d. to check angular alignment.

Reverse Indicator Method.–The reverse indicator method of alignment can be used when it is possible to rotate both shafts. This method utilizes two dial indicators, one attached to each shaft, taking a reading on the opposite shaft. Indicator brackets are available that allow the indicator to be attached directly to shaft, with the indicator button resting on the indicator bar. This arrangement reduces bar sag and eliminates inaccuracies caused by poor surface condition of the shaft. From the data obtained by the reverse indicator method, it is possible to determine, either analytically or graphically, the movement or shims necessary to align the shafts. A graphical method is described below.

Record Indicator Readings.–

a. Attach indicator bars and indicators to shafts and position shafts so that the pump indicator, that is the indicator nearest the pump, is on top and the motor indicator is on the bottom. By increasing the span between the indicators, the accuracy of the readings can usually be increased, although bar sag may also increase. Zero both indicators at this position.

b. Rotate both shafts, preferably in the direction of normal rotation, and record the indicator readings at 90° intervals. For consistency, right and left readings should be designated for both shafts looking from the pump end towards the motor end. Both indicators should read zero at 360°. If not, zero indicators and retake readings. **It is very important to record whether a reading is positive or negative and to keep track of each value's sign while performing the addition and subtraction in the following steps.**

Reverse Indicator Alignment Worksheet

		Column 1 Actual Reading	Column 2 Correction to bottom Reading for Bar Sag (Twice Actual Amount)	Column 3 Column 1 + Column 2	Column 4 Bottom - Top Right - Left	Column 5 1/2 Column 4 Distance of Meter Shaft Line from Pump Shaft Line	Column 6 Direction of Motor Shaft Line from Pump Shaft Line Circle Direction Corresponding to Sign of Valve in Column 5
Pump Indicator	Bottom						+ Above - Below
	Top	0	0				
	Right		0				+ Left - Right
	Left		0				
	Top						
Motor Indicator	Bottom	0					+ Below - Above
	Top		0				
	Right		0				+ Right - Left
	Left		0				
	Bottom						

1. Zero indicators with pump indicator at top position and motor indicator at the bottom. (Pump indicator is indicator nearest pump)
2. Left and right for both indicators is determined by looking from pump end towards motor end.
3. The second top reading for the pump indicator and the second bottom reading for the Motor Indicator should be zero. If not, repeat all readings.

Indicator Bar Sag = ____________ A = ____________ B = ____________ C = ____________

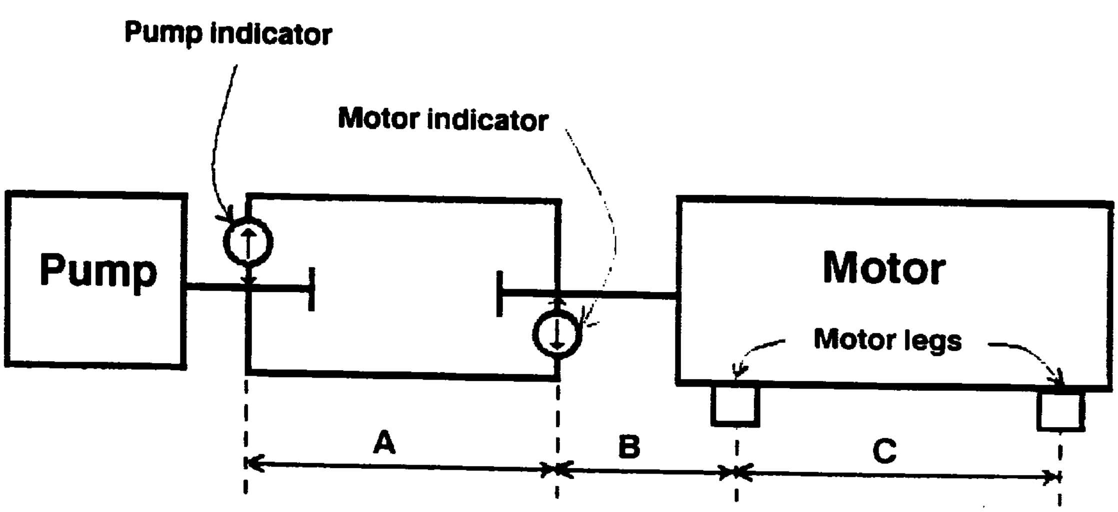


Figure 10

c. To correct for bar sag, add twice the actual amount of sag to the bottom readings.

d. Subtract the top reading from the corrected bottom reading and the left reading from the right reading and divide the differences by 2. These values will be used for plotting the position of the shafts.

Plot Data.–

e. Two graphs will be needed. One for the horizontal plane (top view) and one for the vertical plane (side view.) The horizontal scale of both graphs will represent the horizontal distance from the plane of the pump indicator to the plane of the rear motor feet. Since the pump shaft will not be moved, it will be used as the horizontal reference in determining the position of the motor shaft. The vertical scale will represent the misalignment of the motor shaft.

f. Establish the horizontal scale, marking with vertical lines, the relative position of both indicators and the front and rear motor feet. Draw two horizontal lines representing the pump shaft reference line for the horizontal and vertical planes. A vertical scale of 0.001 inch per division is usually satisfactory.

g. Plot the values from step d. These values represent the vertical distance from the pump shaft line to the motor shaft line at each of the indicator locations. The top-bottom readings are used in the vertical plane plot and the left-right readings are used in the horizontal plane plot. The sign convention is different for the two indicators. If the values for the pump indicator are positive, the plot will be above and left of the pump shaft reference line. The plot will be below and right of the pump shaft reference line for positive motor indicator readings.

h. Draw a line from the pump indicator point through the motor indicator pump point extending to the rear motor feet line. This line represents the position of the motor shaft. The vertical distances from the motor shaft line to the pump shaft line at the two motor feet lines are the required movements of the motor feet to align the motor to the pump. On the vertical plane plot, these distances represent the required amount of shims to be added or removed. On the horizontal plane, these distances represent the amount of lateral movement required at the motor feet.

i. After any shimming or movement of the motor, repeat steps a. through h. to verify the alignment.

7. Vibration Monitoring and Analysis

Vibration monitoring and analysis can be a useful part of a preventive maintenance program. There is a wide variety of vibration monitoring systems available, some use permanently mounted sensors to continually monitor vibration levels while other systems require periodic readings to be taken with hand-held accelerometers. The maintenance supervisor should compare the potential benefits of a vibration monitoring system, such as preventing major failures and reducing outages, to the overall cost before deciding which system to use or whether to use any system at all.

Reverse Indicator Alignment Worksheet

		Column 1 Actual Reading	Column 2 Correction to bottom Reading for Bar Sag (Twice Actual Amount)	Column 3 Column 1 + Column 2	Column 4 Bottom - Top Right - Left	Column 5 1/2 Column 4 Distance of Motor Shaft Line from Pump Shaft Line	Column 6 Direction of Motor Shaft Line from Pump Shaft Line Circle Direction Corresponding to Sign of Valve in Column 5
Pump Indicator	Bottom	12	+2	- 10	-10	-5	+ Above
	Top	0	0	0			- Below
	Right	-5	0	-5	+2	+1	+ Left
	Left	-7	0	-7			- Right
	Top	0					
Motor Indicator	Bottom	0	+2	+2	+12	+6	+ Below
	Top	-10	0	-10			- Above
	Right	-4	0	-4	+2	+1	+ Right
	Left	-6	0	-6			- Left
	Bottom	0					

1. Zero indicators with pump indicator at top position and motor indicator at the bottom. (Pump indicator is indicator nearest pump)
2. Left and right for both indicators is determined by looking from pump end towards motor end.
3. The second top reading for the pump indicator and the second bottom reading for the Motor Indicator should be zero. If not, repeat all readings.

Indicator Bar Sag = 0.001" A = 16" B = 4" C = 40"

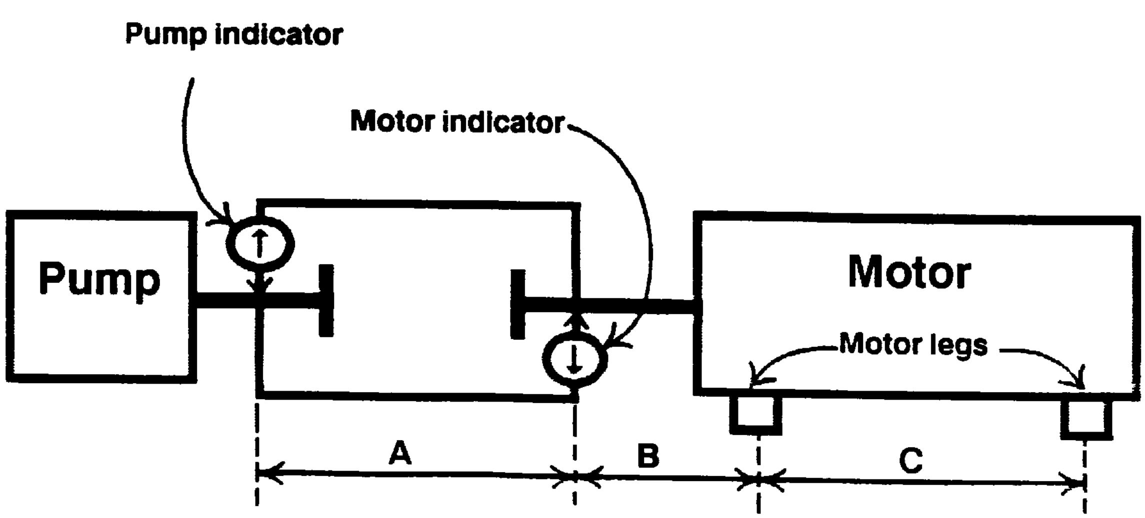


Figure 11

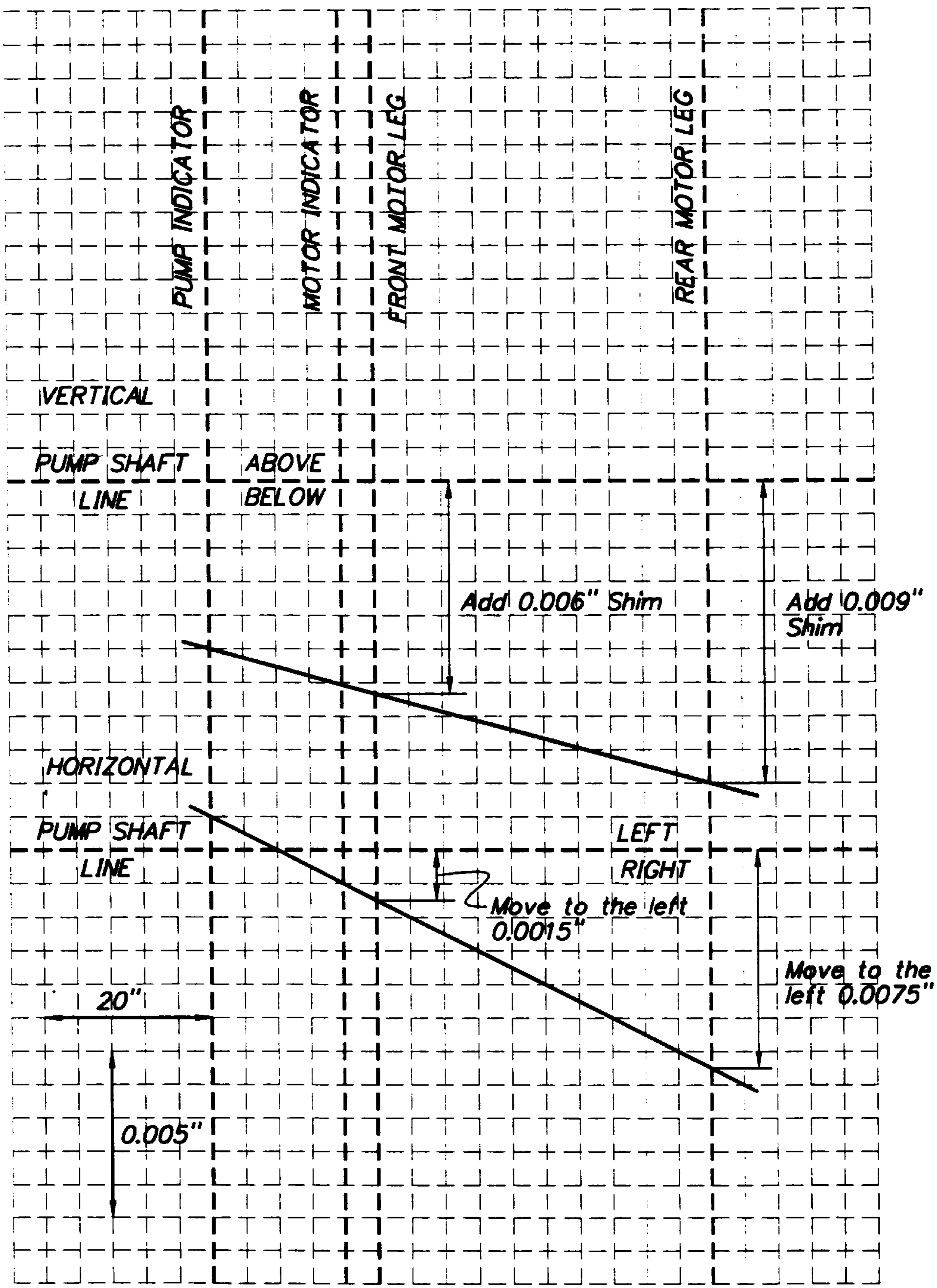

PUMP INDICATOR
MOTOR INDICATOR
FRONT MOTOR LEG
REAR MOTOR LEG
VERTICAL
PUMP SHAFT
LINE
ABOVE
BELOW
Add 0.006" Shim
Add 0.009"
Shim
HORIZONTAL
PUMP SHAFT
LINE
LEFT
RIGHT
Move to the left
0.0015"
Move to the
left 0.0075"
20"
0.005"

Figure 12

Centrifugal Pump Troubleshooting

Symptoms	**Possible Cause** (Each number is defined below)
Pump does not deliver water	1 · 2 · 3 · 4 · 6 · 11 · 14 · 16 · 17 · 22 · 23
Insufficient capacity delivered	2 · 3 · 4 · 5 · 6 · 7 · 8 · 9 · 10 · 11 · 14 · 17 · 20 · 22 · 23 · 29 · 30 · 31
Insufficient pressure developed	5 · 14 · 16 · 17 · 20 · 22 · 29 · 30 · 31
Pump loses prime after starting	2 · 3 · 5 · 6 · 7 · 8 · 11 · 12 · 13
Pump requires excessive power	15 · 16 · 17 · 18 · 19 · 20 · 23 · 24 · 26 · 27 · 29 · 33 · 34 · 37
Stuffing box leaks excessively	13 · 24 · 26 · 32 · 33 · 34 · 35 · 36 · 38 · 39 · 40
Packing has short life	12 · 13 · 24 · 26 · 28 · 32 · 33 · 34 · 35 · 36 · 37 · 38 · 39 · 40
Pump vibrates or is noisy	2 · 3 · 4 · 9 · 10 · 11 · 21 · 23 · 24 · 25 · 26 · 27 · 28 · 30 · 35 · 36 · 41 · 42 · 43 · 44 · 45 · 46 · 47
Bearings have short life	24 · 26 · 27 · 28 · 35 · 36 · 41 · 42 · 43 · 44 · 45 · 46 · 47
Pump overheats and seizes	1 · 4 · 21 · 22 · 24 · 27 · 28 · 35 · 36 · 41

Suction Problem

1. Pump not primed
2. Pump or suction pipe not completely filled with liquid
3. Suction lift too high
4. Insufficient margin between suction pressure and vapor pressure
5. Excessive amount of air or gas in liquid
6. Air pocket in suction line
7. Air leaks into suction line
8. Air leaks into pump through stuffing boxes
9. Foot valve too small
10. Foot valve partially clogged
11. Inlet of suction pipe insufficiently submerged
12. Water-seal pipe plugged
13. Seal cage improperly located in stuffing box, preventing sealing fluid entering space to form the seal

System Problem

14. Speed too low
15. Speed too high
16. Wrong direction of rotation
17. Total head of system higher than design head of pump.
18. Total head of system lower than pump design head
19. Specific gravity of liquid different from design
20. Viscosity of liquid differs from that for which designed
21. Operation at very low capacity
22. Parallel operation of pumps unsuitable for such operation

Mechanical Problem

23. Foreign matter in impeller
24. Misalignment
25. Foundations not rigid
26. Shaft bent
27. Rotating part rubbing on stationary part
28. Bearings worn
29. Wearing rings worn
30. Impeller damaged
31. Casing gasket defective permitting internal leakage
32. Shaft or shaft sleeves worn or scored at the packing
33. Packing improperly installed
34. Incorrect type of packing for operating conditions
35. Shaft running off center because of worn bearings or misalignment
36. Rotor out of balance resulting in vibration
37. Gland too tight resulting in no flow of liquid to lubricate packing
38. Failure to provide cooling liquid to water-cooled stuffing boxes
39. Excessive clearance at bottom of stuffing box between shaft and casing, causing packing to be forced into pump interior
40. Dirt or grit in sealing liquid, leading to scoring of shaft or shaft sleeve
41. Excessive thrust caused by a mechanical failure inside the pump or by the failure of the hydraulic balancing device, if any
42. Excessive grease or oil in antifriction-bearing housing or lack of cooling, causing excessive bearing temperature
43. Lack of lubrication
44. Improper installation of antifriction bearings (damage during assembly, incorrect assembly of stacked bearings, use of unmatched bearings as a pair, etc.)
45. Dirt getting into bearings
46. Rusting of bearings due to water getting into housing
47. Excessive cooling of water-cooled bearing resulting in condensation in the bearing housing of moisture from the atmosphere

(Courtesy of Dresser Pump Division)

Figure 13

NOTE: Following certain fundamental rules will help obtain the most reliable service, the least expensive maintenance, and the longest possible life from centrifugal pumps. Proper maintenance does not start with repairs or replacement of worn parts, but right at the time of selection and installation. These rules can, therefore, be broken into four separate groups: selection, installation, operation and maintenance.

Selection	**1.** Advise the pump manufacturer of the exact nature of the liquid to be handled. **2.** Check into required capacities. **3.** Analyze the suction conditions. **4.** Analyze the discharge conditions. **5.** Advise the manufacturer whether service is continuous or intermittent. **6.** Determine what type of power is best suited for the drive. **7.** Check space limitations. **8.** Be sure that sufficient spare equipment is available. **9.** Keep sufficient spare parts on hand.
Installation	**10.** Pump foundations should be rigid. **11.** Pump bedplate should be grouted. **12.** Pump and driver alignment must be checked. **13.** Piping should not impose strains on pump. **14.** Use liberal piping, especially at suction. **15.** Provide vent valves at high points of the pump. **16.** Provide warm-up connections. **17.** Provide a by-pass connection. **18.** Provide a suitable source of cooling water. **19.** Install suitable gages and flowmeters.
Operation	**20.** Don't throttle the pump suction to reduce its delivery. **21.** Don't run a pump dry. **22.** Don't run a pump at excessively low flows. **23.** Make hourly observations. **24.** Don't stop leakage from stuffing box completely. **25.** Don't use excessive cooling water in water-cooled bearings. **26.** Don't use excessive lubricant with anti-friction bearings. **27.** If stuffing boxes need repacking, use new packing. **28.** Semi-annual Inspection. **29.** Annual Inspection.
Repair and Maintenance	**30.** Don't open a pump for general inspection. **31.** Great care need be exercised in the dismantling operation. **32.** Special care is needed in examination and reconditioning of metal to metal fits. **33.** Clean casing waterways thoroughly and repaint. **34.** New gaskets should be available for complete overhaul. **35.** Examine impellers for corrosion, erosion or cavitation. **36.** Check concentricity on new wearing rings after mounting on impeller. **37.** Check all parts mounted on rotor. **38.** Restore shaft or shaft sleeves to proper service condition at stuffing box. **39.** Exercise great care in mounting anti-friction bearings on the shaft. **40.** Keep a complete record of inspections and repairs.

(Courtesy of Dresser Pump Division)

Figure 14

Proximity Probe Systems.- Proximity probe systems are generally installed to continually monitor shaft runout, alarming or shutting a unit down before extensive damage occurs to the bearings or other components. A proximity probe is a noncontacting-type sensor which provides a direct-current voltage directly proportional to shaft position relative to the probe. The proximity probe can be looked upon as sort of an electronic dial indicator. A typical proximity probe system normally utilizes two probes per bearing location, radially mounted and 90° apart. The monitors for the probes are centrally located and are provided with relays for alarm and shutdown with continuous indication of shaft runout in mils.

The primary purpose of a proximity probe system is to provide unit protection, but when hooked up to a strip chart recorder or a spectrum analyzer, it can also be useful in vibration analysis or unit balancing. In order to perform vibration analysis, a basic understanding of the characteristics of machine vibration and some knowledge of use of the test equipment is required. Several of the manufacturers of proximity probe systems provide seminars and training for vibration analysis.

Because of the expense, proximity probe systems are usually only used on large pumps. Their use on smaller pumps may be feasible if a pump is highly critical to a water delivery system or if a pump has a history of vibration problems.

Accelerometer Systems.-There are a number of hand-held accelerometer-based vibration-monitoring systems available varying greatly in complexity and capability. Accelerometers are lightweight vibration sensors that, as the name implies, provide an electrical output proportional to the acceleration of the vibration of the machine being checked. The method readings are taken depends on the design of the accelerometer. Some require holding a probe against the bearing housing or shaft while the reading is being taken while others use a magnet to hold the accelerometer in place.

An accelerometer system requires periodic readings to be taken at different points on each machine. The data from these readings are stored in a portable recording instrument or plotted directly on what is known as a signature card. The data in the recording instrument, in many systems, can be down loaded into a personal computer. The data can then be manipulated in various manners to compare it to data from previous readings at the same points, or to determine if there is any increase in the vibration levels indicating an impending failure.

The data on the signature card, and in many cases in the computer comparison, are in the form of a spectrum plot (figure 15). A spectrum plot is an X-Y plot with the X-axis represents the vibration frequency, usually in cycles per minute or cycles per second (Hertz), and the Y-axis represents vibration amplitude either in acceleration, velocity, or displacement. A spectrum plot features amplitude spikes or peaks corresponding to operating frequencies of components of the equipment being tested. The initial plot provides a "signature" of the vibration for that particular piece of equipment. An increase in the amplitude of vibration at any of the various frequencies in subsequent plots may indicate an impending failure. By determining what component operates at the frequency corresponding to the amplitude peak, corrective action can be taken.

An accelerometer system is most useful when there is a relatively large number of rotating machines at a particular site or if one maintenance crew is maintaining several sites. Regardless of the number of machines involved, in order to fully utilize such a