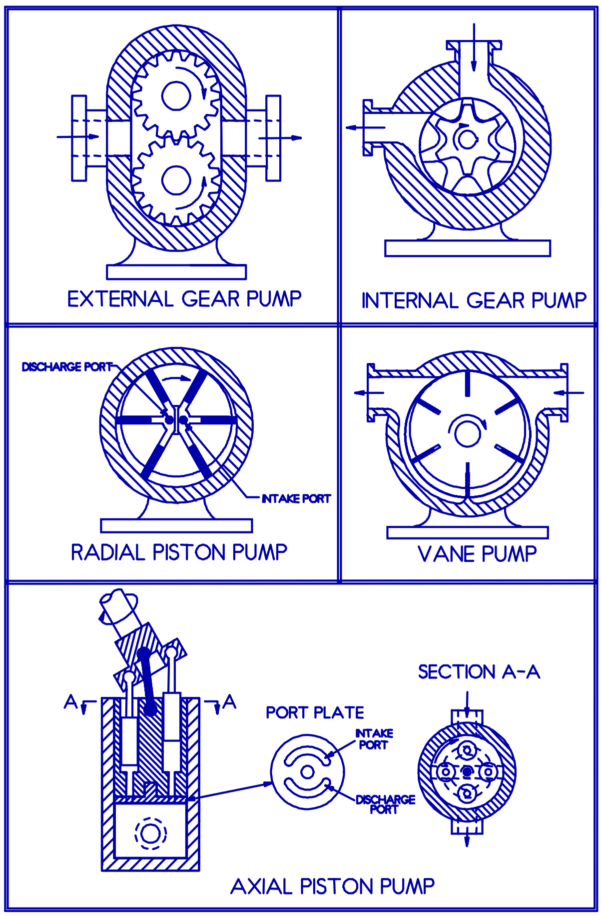
WATER OPERATION AND MAINTENANCE BULLETIN

No. 206 December 2003



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♦ Pumping Plant Maintenance

UNITED STATES DEPARTMENT OF THE INTERIOR Bureau of Reclamation

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This *Water Operation and Maintenance Bulletin* is published quarterly for the benefit of water supply system operators. Its principal purpose is to serve as a medium to exchange information for use by Bureau of Reclamation personnel and water user groups in operating and maintaining project facilities.

The *Water Operation and Maintenance Bulletin* and subject index may be accessed on the Internet at: **http://www.usbr.gov/pmts/infrastructure/inspection/waterbulletin**

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Cover photographs: *Positive displacement pumps.*

UNITED STATES DEPARTMENTOF THE INTERIOR **Bureau of Reclamation**

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PUMPING PLANT MAINTENANCE

Section 1 – Introduction

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 Technical Service Center can also be a source for information on pumping plant maintenance. For problems involving general mechanical and electrical maintenance, contact the Hydroelectric Research and Technical Services Group, D-8450. For problems involving material selection and protective coatings contact the Materials Engineering and Research Laboratory Group, D-8180.

Maintenance

General

This document is intended to establish recommended practice as well as to give general advice and guidance in the maintenance of electrical and mechanical equipment owned and operated by the Bureau of Reclamation. Specific technical details of maintenance are included in other documents which are referenced in this document.

Maintenance recommendations are based on industry standards and experience in Reclamation facilities. However, equipment and situations vary greatly, and sound engineering and management judgment must be exercised when applying these recommendations. Other sources of information must be consulted (e.g., manufacturer's recommendations, unusual operating conditions, personal experience with the equipment, etc.) in conjunction with these maintenance recommendations.

Preventive Maintenance

Preventive maintenance (PM) is the practice of maintaining equipment on a regular schedule based on elapsed time or meter readings. The intent of PM is to “prevent” maintenance problems or failures before they take place by following routine and comprehensive maintenance procedures. The goal is to achieve fewer, shorter, and more predictable outages.

Some advantages of preventive maintenance are:

- It is predictable, making budgeting, planning, and resource leveling possible.
- When properly practiced, it generally prevents most major problems, thus reducing forced outages, "reactive maintenance," and maintenance costs in general.[1]
- It gives managers a level of assurance that equipment is being maintained.
- It is easily understood and justified.

Preventive maintenance does have some drawbacks:

- It is time consuming and resource intensive.
- It does not consider actual equipment condition when scheduling or performing the maintenance.
- It can cause problems in equipment in addition to solving them (e.g., damaging seals, stripping threads).

Despite these drawbacks, PM has proven generally reliable in the past and is still the core of most maintenance programs.

Preventive maintenance traditionally has been the standard maintenance practice in Reclamation. The maintenance recommendations in this document are based on a PM philosophy and should be considered as "baseline" practices to be used when managing a maintenance program.

However, care should be taken in applying preventive maintenance recommendations. Wholesale implementation of PM recommendations without considering equipment criticality may result in a workload that is too large to achieve. This may result in important equipment not receiving needed maintenance, which defeats the purpose of PM management.

[1] *World Class Maintenance Management*, Terry Wireman, Industrial Press Inc., 1990, pg. 7, 73.

To mitigate this problem, maintenance managers may choose to apply a ***consciously chosen, effectively implemented, and properly documented*** reliability-centered maintenance (RCM) program.

Whether utilizing a PM or RCM program, the primary focus of the in-house maintenance staff should be scheduled maintenance.[2] This will reduce reactive (emergency and corrective) maintenance. Scheduled maintenance should have priority over special projects in use of in-house staff.

Reliability Centered Maintenance

Reliability-centered maintenance programs are gaining in popularity and have been piloted in a few Reclamation power facilities with good results. The goal of these programs is to provide the appropriate amount of maintenance at the right time to prevent forced outages while at the same time eliminating unnecessary maintenance.

Implemented properly, RCM can eliminate some of the drawbacks of preventive maintenance and may result in a more streamlined, efficient maintenance program. RCM seems very attractive in times of diminishing funding, scarcity of skilled maintenance staff, and the pressure to "stay on-line" due to electric utility industry deregulation.

Some features of RCM are:

- May require additional monitoring of quantities like temperature and vibration to be effective. This may mean new monitoring equipment or more human monitoring with multiple inspections.

- May result in a "run-to-failure" or deferred maintenance philosophy for some equipment which may cause concern for some staff and managers.

- May require initial and later revisions to the maintenance schedule in a "trial-and-error" fashion depending on the success of the initial maintenance schedule and equipment condition.

- Should result in a more manageable maintenance workload focused on the most important equipment.

[2] *World Class Maintenance Management*, Terry Wireman, Industrial Press Inc., 1990, pg. 32.

RCM is not an excuse to move to a "breakdown maintenance" philosophy or to eliminate critical preventive maintenance in the name of reducing maintenance staff/ funding. However, to mitigate problems associated with a PM program, maintenance managers may choose to apply a ***consciously chosen, effectively implemented, and properly documented*** RCM program.

For RCM to be a viable program at Reclamation facilities, it must:

- Be chosen as the local maintenance philosophy by management.
- Be implemented according to generally accepted RCM practices.
- Be documented so that maintenance decisions are defensible.

Implementation of an acceptable RCM program will be defined in a Facilities Instructions, Standards, and Techniques (FIST) volume. For more information on Reclamation RCM program implementation, contact the Hydroelectric Research and Technical Services Group, D-8450, at 303-445-2300.

Standards and References

Reclamation Standards

Electrical and mechanical maintenance recommended practices for some equipment are contained in other FIST volumes that will be referenced in this report. For equipment not covered by other FIST volumes, requirements defined in this report are the recommended practices. Manufacturer's maintenance requirements, as defined in instruction books also must be incorporated into a complete maintenance program.

Recommended practices, including recommended intervals, defined in FIST volumes are based on power industry best practices, published standards, and Reclamation's experience maintaining equipment in hydroelectric powerplants. This volume includes references to published standards produced by the Institute of Electrical and Electronics Engineers (IEEE), National Fire Protection Association (NFPA), and other professional organizations where they exist. Additional references to published standards may be found in other FIST volumes.

To access Reclamation's FIST volumes:

- Printed FIST volumes:

  Contact National Technical Information Service, Operations Division, 5285 Port Royal Road, Springfield, Virginia 22161.

- Access to Internet FIST volumes (www.usbr.gov) Select:

  Programs; Power; Reports and Data; Power Reports.

Recommended Standards and References

Current editions of the following published standards and references should be maintained locally for use by electrical engineers, electrical foremen, electrical supervisors, and other O&M personnel:

- FIST Volume 1-1, Hazardous Energy Control Program

  Copies of all Electrical Maintenance and Safety FIST Volumes
  Manufacturers' instruction/maintenance manuals for all equipment

- NFPA 70 - National Electric Code (The handbook can be more useful than the code because of the included explanations and drawings.)

- NESC (National Electrical Safety Code) American National Standards Institute (ANSI) C2 and Handbook - available through IEEE/ANSI

  NFPA 70B - Recommended Practice for Electrical Equipment Maintenance
  NFPA 70E - Safety Requirements for Employee Work Places
  NFPA 101 - Life Safety Code
  Reclamation Safety and Health Standards

- Occupational Safety and Health Administration (OSHA) Code of Federal Regulations (CFR) 29 Part 1910.310-399 - Electrical Safety Standards

  American Electricians Handbook available through NFPA
  Industrial Power Systems Handbook by Beeman, published by McGraw Hill

- Westinghouse's Transmission and Distribution Handbook and Westinghouse Applied Protective Relaying Handbook (These are out of print but may be available in personal libraries.)

- Electric Power Research Institute (EPRI) Electrical Power Reference Series, Volumes 1 through 13

Maintenance and Test Procedures

General

Electrical and mechanical maintenance activities fall into three general categories:

- *Routine Maintenance* – Activities that are conducted while equipment and systems are in service. These activities are predictable and can be scheduled and budgeted. Generally, these are the activities scheduled on a time-based or meter-based schedule derived from preventive or predictive maintenance strategies. Some examples are visual inspections, infrared scans, cleaning, functional tests, measurement of operating quantities, lubrication, oil tests, governor, and excitation system alignments.

- *Maintenance Testing* – Activities that involve the use of test equipment to assess condition in an off-line state. These activities are predictable and can be scheduled and budgeted. They may be scheduled on a time or meter basis but may be planned to coincide with scheduled equipment outages. Since these activities are predictable, some offices consider them "routine maintenance" or "preventive maintenance." Some examples are Doble testing, meggering, relay testing, circuit breaker trip testing, alternating current (AC) hipot tests, high-voltage direct current (HVDC) ramp tests, battery load tests.

- *Diagnostic Testing* - Activities that involve use of test equipment to assess condition of equipment after unusual events such as faults, fires, or equipment failure/ repair/ replacement or when equipment deterioration is suspected. These activities are not predictable and cannot be scheduled because they are required after a forced outage. Each office must budget for these events. Some examples are Doble testing, AC hipot tests, HVDC ramp tests, partial discharge measurement, wedge tightness, core magnetization tests, pole drop tests, turns ratio, and core ground.

This bulletin addresses scheduling of maintenance activities in the first two categories. It does not address followup work generated by routine maintenance or maintenance testing, nor does it address diagnostic testing (with a few exceptions). Also, maintenance staff may be used for other activities such as improvements and construction, but this guide does not address these activities.

Infrared Scanning

Annual infrared scans of electrical equipment are required by NFPA 70B, 18-17.5. Throughout this bulletin, infrared (IR) scanning is recommended as a regular maintenance procedure. Infrared scanning and analysis have become an essential diagnostic tool throughout all industries and have been used in Reclamation to detect many serious conditions requiring immediate corrective action. Several forced outages have already been avoided. Infrared scanning is non-intrusive and is accomplished while equipment is in service. It can be used not only for electrical equipment but also to detect mechanical and structural problems. Therefore, infrared scanning is HIGHLY recommended as a regularly scheduled maintenance procedure.

Effective infrared scanning and analysis require the following:

- The scanning equipment (IR camera and accessories) must be high quality and correctly maintained and calibrated.

- The IR camera operator must be trained to use the equipment and deal with complicating issues such as differing emissivities of surfaces and reflectivity. Certified Level 1 Thermographer (e.g., Academy of IR Thermography) credentials, or higher, is recommended.

- The IR system operator must be able to analyze results using state-of-the-art software critical to successful interpretation of problems.

Field offices with adequate resources may find it possible to achieve professional results by operating a local IR program. Others may find it more cost effective to use the resources in the Hydroelectric Research and Technical Services Group (D-8450). Call 303-445-2300 for more information.

Maintenance Schedules and Documentation

Complete, thorough, and current documentation is essential to an effective maintenance program. Whether you are performing preventive, predictive, or reliability centered maintenance, keeping track of equipment condition and maintenance performed or planned is critical.

Maintenance recommendations contained in this report should be used as the basis for establishing or refining a maintenance schedule. Recommendations can be converted into Job Plans or Work Orders in MAXIMO or another maintenance management system. Once these job plans and work orders are established, implementation of well-executed predictive or reliability centered maintenance is possible.

The maintenance recordkeeping system must be kept current so that a complete maintenance history of each piece of equipment is available at all times. This is important for planning and conducting an ongoing maintenance program and provides documentation needed for the

Annual, Periodic, and Comprehensive Power Reviews of O&M. Regular maintenance and emergency maintenance must be well documented as should special work done during overhauls and replacement.

The availability of up-to-date drawings to management and maintenance staff is extremely important. Accurate drawings are very important to ongoing maintenance, testing, and new construction; but they are essential during emergencies for trouble-shooting. In addition, accurate drawings are important to the continued safety of the staff working on the equipment.

Limitations

This volume summarizes maintenance recommendations for electrical and mechanical equipment and directs the reader to related references. It should not be the sole source of information used in conducting maintenance activities. Other references, training, and work experience are also necessary to fully understand and carry out the recommended maintenance.

Safety During Maintenance

Performing maintenance on electrical and mechanical equipment can be hazardous. Electrical and mechanical energy can cause injury and death if not managed properly. All maintenance activity should be conducted in accordance with FIST Volume 1-1, Hazardous Energy Control Program (HECP) and Reclamation Safety and Health Standards. A job hazard analysis (JHA) must be conducted as well. Visitors, contractors, and others working under clearances must be trained in HECP and must follow all JHA and clearance procedures.

Section 2 – Pump Maintenance

Pumps

Basically there are two general classifications of pumps; dynamic and positive displacement. These classifications are based on the method the pump uses to impart motion and pressure to the fluid.

Dynamic Pumps

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.

Eductors, or jet pumps as they are sometimes called, use a high pressure stream of fluid to pump a larger volume of fluid at a lower pressure. An eductor consists of three basic parts, the nozzle, the suction chamber, and the diffuser. The high pressure fluid is directed through a nozzle to increase its velocity. The high velocity creates a low pressure area that causes the low pressure fluid to be drawn into the suction chamber. The low pressure fluid is then mixed with the high velocity fluid as it flows through the diffuser and the velocity energy of the mixture is converted into pressure at the discharge. Eductors are commonly used in powerplants and dams to dewater sumps below the inlet of the sump pumps.

By far the most common type of dynamic pump is the centrifugal pump. 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:

(1) Axial-flow
(2) Radial-flow
(3) Mixed-flow

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

(1) Open
(2) Semi-open
(3) 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 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.

Centrifugal 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 direct the water flow, their main purpose is structural and not energy conversion.

Centrifugal pumps are further classified as either horizontal or vertical, referring to the orientation of the pump shaft. A vertical volute pump is shown in figure 1. In comparison to horizontal pumps, vertical pumps 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 are a variety of wet-pit pump designs for differing applications. One of the most common types 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 most commonly used for deep well applications, have a wide variety of uses, including irrigation pumping plants and sumps in powerplants and dams. (figure 2) 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. The use of vertical propeller pumps is normally 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. (figure 3) In a hydro-electric plant, horizontal pumps are normally used for fire water and cooling water applications.

Positive Displacement Pumps

Positive displacement pumps enclose the fluid through the use of gears, pistons, or other devices, and push or "displace" the fluid out though 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. Since positive displacement pumps do "displace" the fluid being pumped, relief valves are required in the discharge line, ahead of any shutoff valve or any device that could conceivably act as a flow restriction.

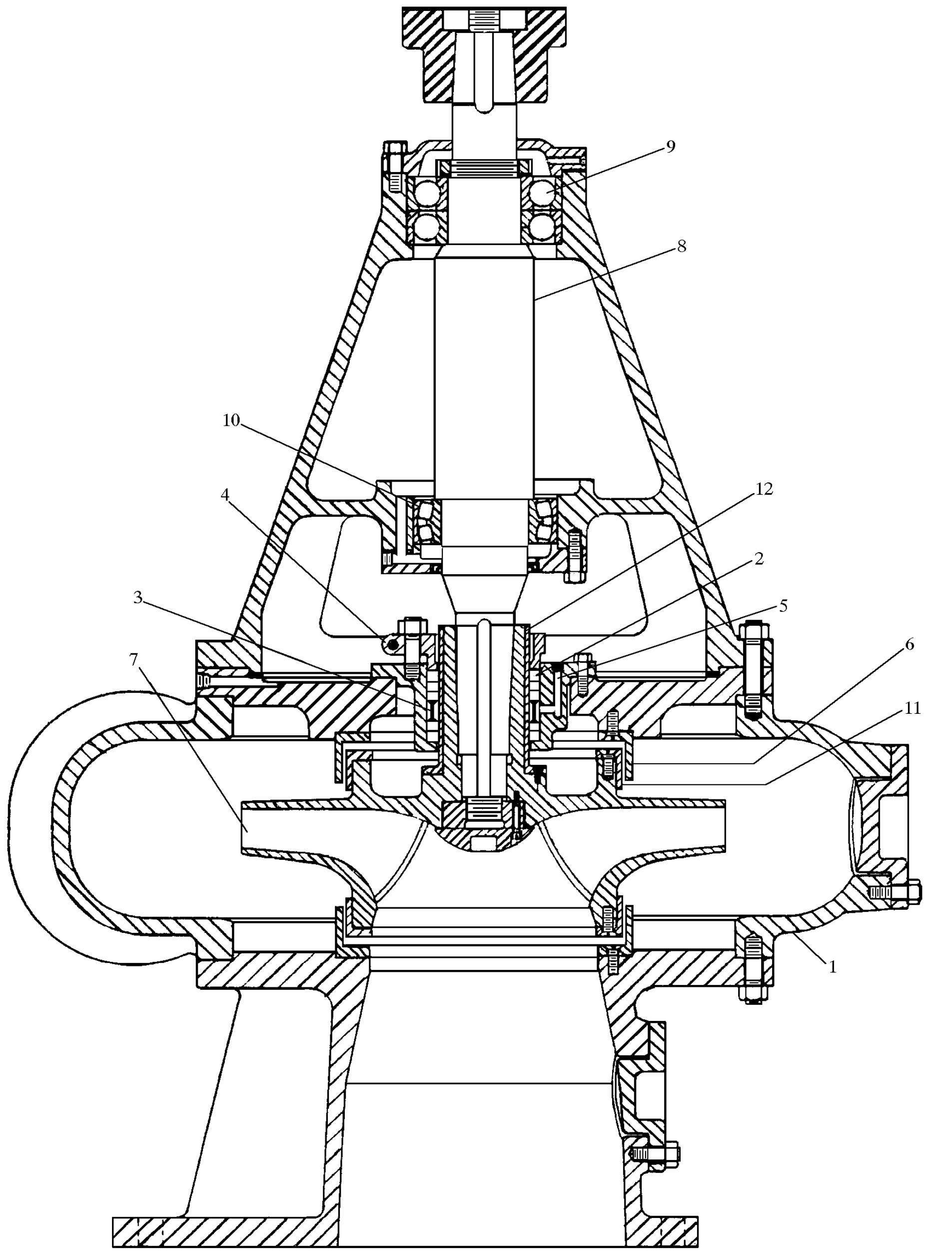
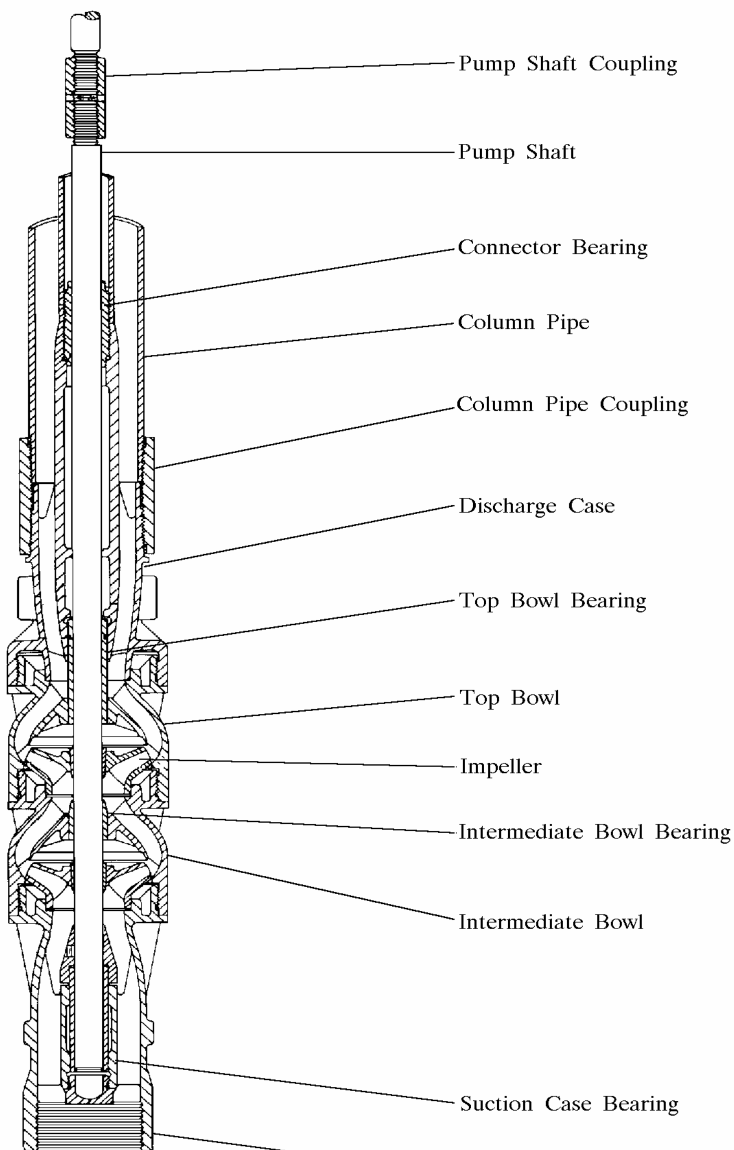
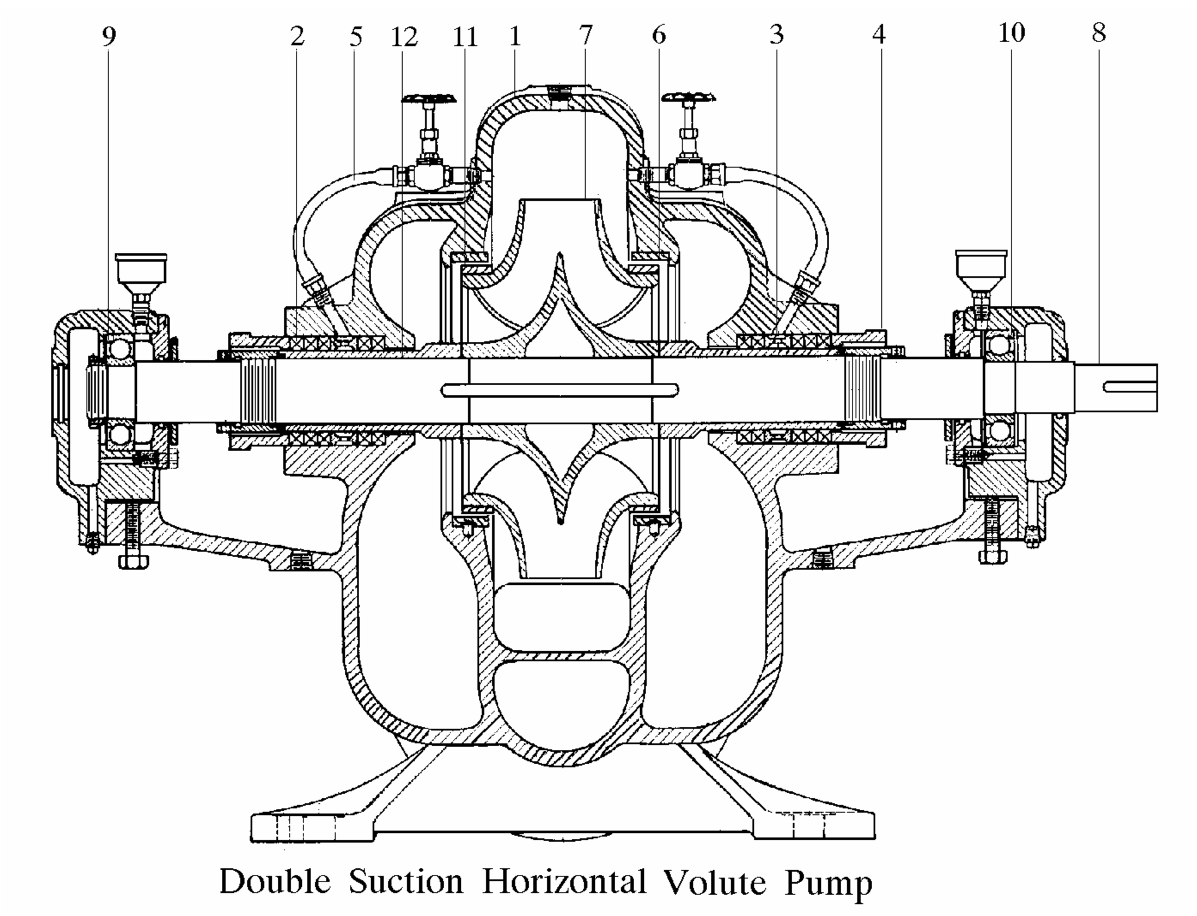


Figure 1.—Vertical volute pump.



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

Figure 2.—Two stage vertical turbine 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 3.—Double suction horizontal volute pump and parts list.

Reciprocating piston or plunger pumps are suitable where a constant capacity is required over a variety of pressures. Piston and plunger pumps are capable of developing very high pressures, although capacities are somewhat limited. These pumps provide a pulsating output which, depending on the application, may be objectionable. The use of reciprocating pumps in hydroelectric powerplants is limited.

Rotary positive displacement pumps are used in a variety of applications, one of the most common being hydraulic systems. Some of the most common rotary pumps used in hydraulic systems are gear, vane, radial piston, and axial piston pumps. (figure 4) Screw pumps, with a single helical screw or meshing multiple screws, are most commonly used for fluid transfer although they are sometimes used in hydraulic system applications such as governor oil pumps.

Gear pumps are relatively simple in design relying on the meshing of the mating gears and the fit of the gears in the pump casing to pump the fluid. External gear pumps utilize two meshing gears, usually spur or herringbone types, in a close fitting casing. The fluid is pumped as it is trapped between the rotating gears and the casing and moved from the suction of the pump to the discharge. An internal gear pump utilizes an external gear rotating eccentrically within, and driving an internal gear to pump the fluid.

Vane pumps consist of a case and a single eccentric rotor with multiple vanes sliding in slots in the rotor. Centrifugal force keeps the vanes in contact with the interior of the pump casing. As the rotor rotates, the fluid is drawn into the pump by the gradually increasing volume between the vanes, and is pushed out through the discharge as the volume gradually decreases.

The radial piston pump is similar in construction to the vane pump in that it has a single rotor, eccentric to the pump housing, but instead of vanes, it has radial pistons. The pistons are held against the pump housing by centrifugal force and the fluid is pumped by the reciprocating action of the pistons in their bore. The fluid ports are in the center of the rotor.

The axial piston pump rotor consists of a round cylinder block with multiple cylinders, parallel to the cylinder block axis. The cylinder block rotates at an angle to the axis of the drive shaft and the fluid is pumped by reciprocating action of the pistons in the cylinder block.

Cavitation Erosion, Abrasive Erosion, and Corrosion

Pump impellers, turbine runners, and their related components 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.

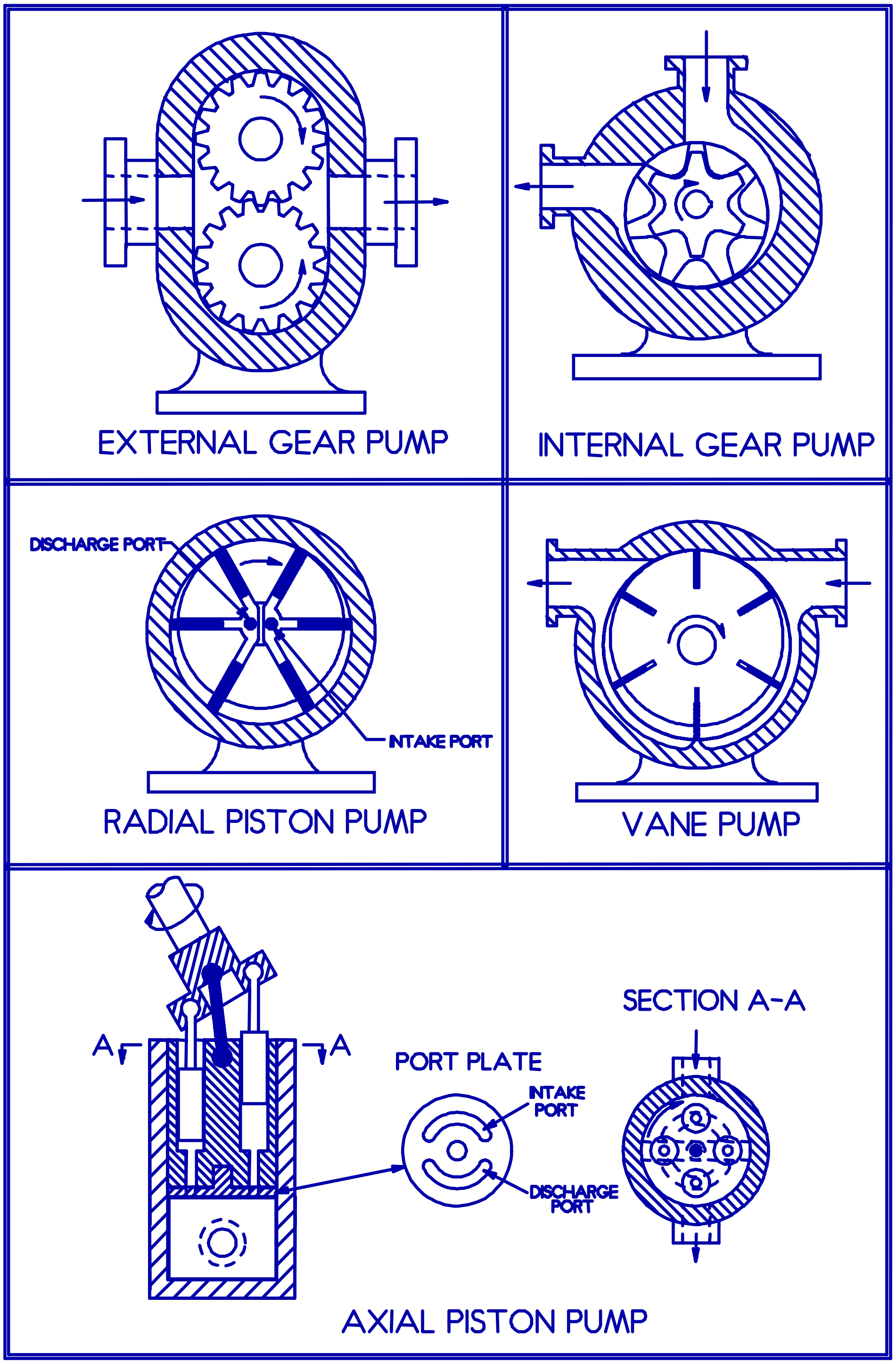


Figure 4.—Positive displacement pumps.

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 pounds per square inch. When audible, cavitation makes a steady crackling sound similar to rocks passing through the pump or turbine. Cavitation erosion or pitting occurs when the bubbles collapse against the metal surface of the impeller or turbine runner and occurs most frequently on the low pressure side of the impeller inlet vanes or turbine buckets. Cavitation can not only severely damage the pump or turbine, but it can also substantially reduce the capacity and therefore lessen the efficiency.

Abrasive erosion is the mechanical removal of metal by suspended solids, such as sand, in the liquid flowing through an impeller or turbine. The rate of wear is directly related to the velocity of the liquid, so wear will be more pronounced at the discharge of the nozzle of impulse turbines, near the exit vanes and shrouds of pump impellers, and near the leading edge of reaction turbines buckets 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.

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.

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 runner, or other design changes may be required. Obviously, replacing an impeller or other major components can be a very expensive endeavor, 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 and any gain in efficiency or output that may be obtained by replacement.

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. Repair with non-fusing materials, such as epoxies and ceramics, is generally not successful because the low bond strength of these materials, usually less than 3,000 pounds per square inch, is not capable of withstanding the high shock pressures encountered during cavitation. 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. Cavitation repair is discussed in more detail in Facilities Instructions, Standards, and Techniques (F.I.S.T.), Volume 2-5, 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 coatings or fillings may be acceptable. The epoxies and ceramics discussed earlier, 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, because of coating thickness, restrict water passages somewhat. Erosion resistant coatings should be chosen based on the design of the turbine or pump and the severity of erosion.

Wearing Rings

The purpose of wearing rings, or seal rings as they are also called, is to provide a renewable seal or leakage joint between a pump impeller or a turbine runner and its casing. As the name implies, these rings can wear over time and as the clearance increases, efficiency 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 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 wear ring area and impeller or runner to accept replaceable wearing rings; or, on small pumps, replace the impeller and casing.

The location of the wearing rings depends on the design of the pump or turbine. Francis turbines and most closed impeller pumps have two wearing rings, although some pump impellers may only have suction side wearing ring. Propeller turbines, open impeller and many semi-open impeller pumps do not have wearing rings, relying instead on a close fit between the runner or impeller vanes and the casing to control leakage.

Packing/Mechanical Seals

Packing

The most common method of controlling leakage past a pump, turbine, or wicket gate shaft 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 necessary to cool and lubricate the packing and shaft. If additional lubrication or cooling is required a lantern ring may be also be installed along with an external packing water source.

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 packing 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 packing 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 packing box bore should be repaired. In order for the packing to seal against a rough packing box bore requires excessive compression of the packing. This over compression of the packing will lead to premature wear of the shaft or shaft sleeve.

On small pumps the shaft runout at the packing box should be checked by manually rotating the shaft and measuring the runout with a dial indicator. In most cases, total indicated runout should not exceed 0.003 inch. If the runout is excessive, the cause should be found and corrected. Bent shafts should be replaced and misalignment corrected.

There are a number of different types of packing available, so when choosing new packing, care should be taken to ensure that it is the correct size and type for the intended application. All of the relevant conditions the packing will operate under, such as shaft size and rotational speed, must be considered. Installing the wrong packing can result in excessive leakage, reduced service life, and damage to the shaft or sleeve.

The new packing should be installed with the joints staggered 90 degrees 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 after the installation of new packing. 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 off the packing gland.

Mechanical Seals

Mechanical seals are used in both pump and turbine 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 on a small pump 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.

There is a wide variety of mechanical seals available for small pump applications, 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 endplay for their particular seal.

Mechanical seals used in hydraulic turbines and large pumps consist of sealing segments, usually made of carbon, held against the shaft by spring tension and lubricated by a thin film of water. These seals usually require grease lubrication prior to start up if the unit is shut down for extended periods.

Since mechanical seals are precisely made and rely on very tight tolerances in order to operate successfully, a great deal of care must 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.

Seal water is provided on most larger seals to help cool and keep the seals clean. The seal water must be clear clean water. Some type of filtration should be installed if there is any silt or sand in the seal water supply as any contaminants can quickly damage the seals.

Bearings

The purpose of the bearings is to locate and support the shafts of a pump or turbine. The bearings can provide radial support (line or guide bearings), axial support (thrust bearings) or both. The most common types of bearings 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 turbines and large pumps and can be in the form of sleeve bearings, either solid or split, tilting pads, or pivoted thrust shoes. These bearings usually consist of a cast iron or steel bearing shell 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.

The thrust and upper guide bearings of large vertical generators are insulated from the frame to prevent circulating current from passing through the bearing. The bearing can be quickly damaged or destroyed if not adequately insulated. Test terminals are usually provided to check the insulation. Refer to F.I.S.T. Volume 3-11, Miscellaneous Power O&M Instructions for more information on bearing insulation testing.

Antifriction Bearings

The antifriction bearing, through the use 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 type of antifriction bearings are "ball" and "roller" bearings, referring to the shape of the bearing's 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.

Shaft Couplings

Couplings are used to connect the shaft of a driver, such as a turbine or a motor, to the shaft of a driven machine, such as a pump or generator. There are basically two types of couplings, rigid and flexible.

Rigid couplings require precise alignment and are most commonly used in vertical units where the entire weight is supported by thrust bearings in the motor or generator. Flanged and threaded couplings are the most widely used rigid couplings. Flanged couplings are used on large vertical units and consist of precisely machined flanges 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 of the design of the particular coupling. Since there are a number of flexible coupling designs, tolerances for misalignment 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.

Shaft Alignment

Misalignment is a common and sometimes serious 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 for alignment depends on the type of equipment and its design.

Large vertical units, suspended from a thrust bearing in the motor or generator, require making the shaft plumb and the guide bearings concentric. The procedure for aligning these units is discussed in detail in F.I.S.T. Volume 2-1, Alignment of Vertical Shaft Hydro Units.

The lineshafts of vertical turbine pumps are held in alignment by lineshaft bearings in the pipe column. The proper alignment of the lineshaft depends on the proper assembly of the pipe column and the bearing retainers. Depending on the design, the pump motor to lineshaft 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 Pump 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 the coupling's design and characteristics, such as speed and torque, of the machines being coupled. 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. In most cases, the pump driver is aligned to the pump, as the pump is usually connected to rigid piping and is more difficult of move.

There are a number of laser alignment systems available for horizontal shaft alignment. These systems typically have a laser that mounts to one shaft and a target that mounts to the other shaft. A microprocessor takes the data from the laser and target and calculates the required movement and shim placement. These systems greatly reduce the time required for the alignment process.

Preliminary Checks for Alignment of Horizontal Pumps.—

1. 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.

2. 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 hold-down bolt is loosened. Retighten the hold-down 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." For example, 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."

3. The hold-down bolt holes should be checked for sufficient clearance to allow for movement during the alignment procedure.

4. Jacking bolts or other fixtures for moving the motor should be fabricated or procured.

5. 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 degrees. The indicator reading will be twice the actual amount of bar sag. (figure 5) To correct alignment readings for sag, add twice the amount of bar sag to the bottom indicator reading. The bar sag is always expressed as a positive number regardless of indicator convention.

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, enter the opposite sign than what is read onto the worksheet.

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 (dogleg) and parallel (offset) misalignment (figure 6) 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 base should be attached to the shaft that is rotated. The procedure is the same whether one or both

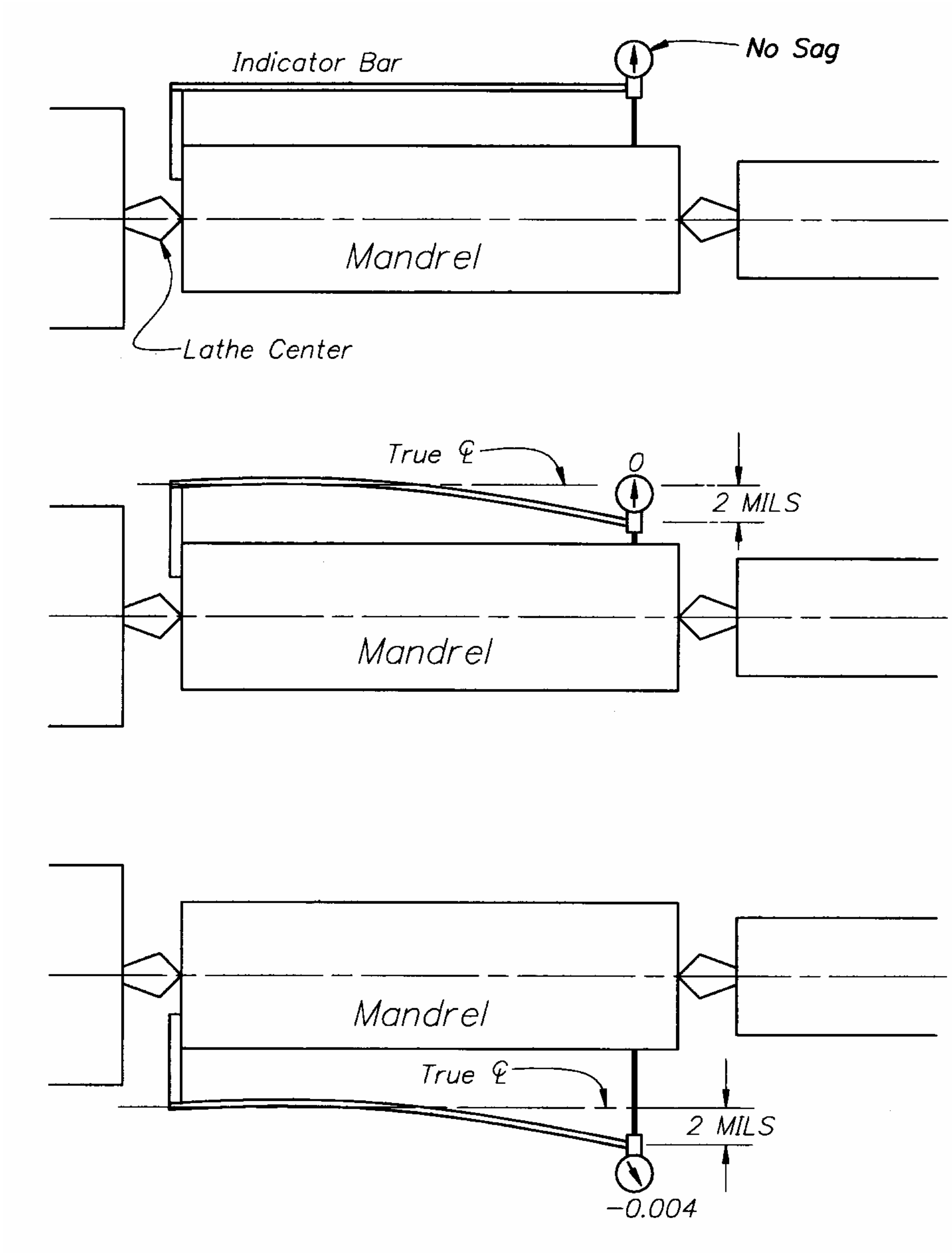


Figure 5.—Checking indicator bar for sag

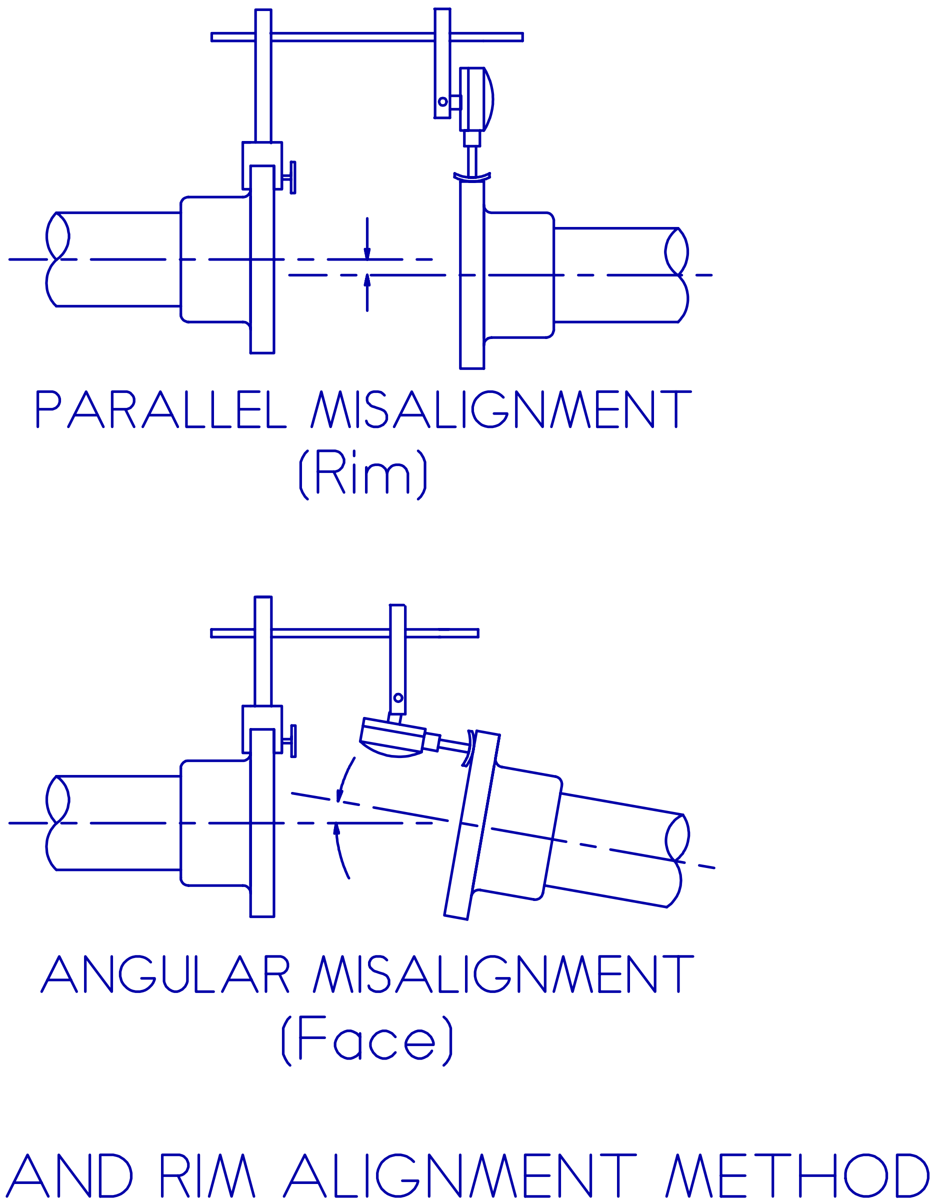


Figure 6.—Face and rim alignment method.

shafts are rotated. From the dial indicator readings and the dimensions of the motor, the amount each leg should moved can be determined analytically. The Face and Rim Worksheet simplifies the required calculations. The following procedure uses the Face and Rim Worksheet (figures 7 and 8).

FACE AND RIM ALIGNMENT WORKSHEET

FACE READINGS

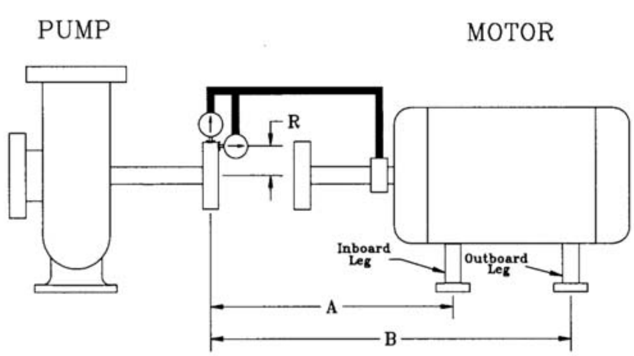
	Column 1 Reading	Column 2 Twice Bar Sag	Column 3 Readings Corrected for Bar Sag Column 1 + Column 2	Column 4 Bottom - Top Left - Right	Column 5 Outboard Leg Move Column 4 * B/2R	Column 6 Inboard Leg Move Column 4 * A/2R
Top		0				
Bottom		0				
Right		0				
Left		0				
Top						

RIM READINGS

	Column 1 Reading	Column 2 Twice Bar Sag	Column 3 Readings Corrected for Bar Sag Column 1 + Column 2	Column 4 Top - Bottom Right - Left	Column 5 Outboard Leg Move 1/2 Column 4	Column 6 Inboard Leg Move 1/2 Column 4
Top		0				
Bottom						
Right		0				
Left		0				
Top						

TOTAL MOVEMENT FOR MOTOR LEGS

	Column 1 Total Move for Outboard Legs FACE Col. 5 + RIM Col. 5	Column 2 Direction of Move for Outboard Legs (Sign of Col. 1) + Up Right - Down Left	Column 3 Total Move for Inboard Legs FACE Col. 6 + RIM Col. 6	Column 4 Direction of Move for Inboard Legs (Sign of Col. 3) + Up Right - Down Left
Top/Bottom				
Right/Left				



A = _______ B = _______ R = _______

Bar Sag = _______

Figure 7.—Face and rim alignment worksheet.

FACE AND RIM ALIGNMENT WORKSHEET

FACE READINGS

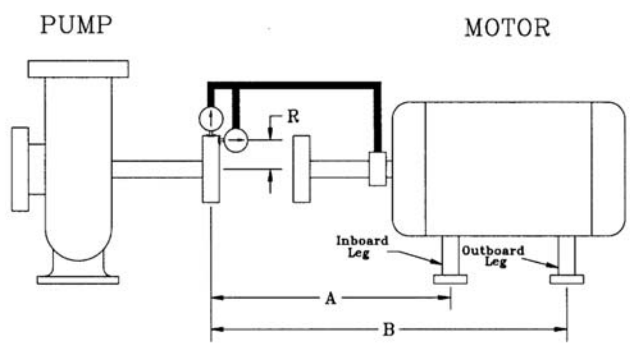
	Column 1 Reading	Column 2 Twice Bar Sag	Column 3 Readings Corrected for Bar Sag Column 1 + Column 2	Column 4 Bottom - Top Left - Right	Column 5 Outboard Leg Move Column 4 * B/2R	Column 6 Inboard Leg Move Column 4 * A/2R
Top	0	0	0	+1	+4	+1
Bottom	+1	0	+1			
Right	+3.5	0	+3.5	-2.5	-10	-2.5
Left	+1	0	+1			
Top	0					

RIM READINGS

	Column 1 Reading	Column 2 Twice Bar Sag	Column 3 Readings Corrected for Bar Sag Column 1 + Column 2	Column 4 Top - Bottom Right - Left	Column 5 Outboard Leg Move 1/2 Column 4	Column 6 Inboard Leg Move 1/2 Column 4
Top	0	0	0	+10	+5	+5
Bottom	-12	+2	-10			
Right	-5	0	-5	+2	+1	+1
Left	-7	0	-7			
Top	0					

TOTAL MOVEMENT FOR MOTOR LEGS

	Column 1 Total Move for Outboard Legs FACE Col. 5 + RIM Col. 5	Column 2 Direction of Move for Outboard Legs (Sign of Col. 1) + Up Right - Down Left	Column 3 Total Move for Inboard Legs FACE Col. 6 + RIM Col. 6	Column 4 Direction of Move for Inboard Legs (Sign of Col. 3) + Up Right - Down Left
Top/Bottom	+9	Up	+6	Up
Right/Left	-9	Left	-1.5	Left



A = 10" B = 40" R = 5"

Bar Sag = 0.001"

Figure 8.—Face and rim alignment worksheet example.

Face Reading.—

1. Attach the indicator base to the motor coupling and adjust the indicator so that the button is resting near the outer edge of the pump coupling flange face. Measure the distance from the centerline of the indicator button to the shaft centerline and enter this value on the worksheet as dimension R. Measure the horizontal distance from the face of the pump coupling flange to the center of the inboard leg and enter this value on the worksheet as the dimension A. Measure the horizontal distance from the face of the pump coupling flange to the center of the outboard leg and enter this value on the worksheet as the dimension B.

2. Rotate the shaft with the indicator so that the indicator is at the top or 12 o'clock position and zero the indicator.

3. Rotate both shafts, preferably in the direction of normal rotation, and record the indicator readings at 90 degrees intervals. For consistency, right and left readings should be designated for both shafts looking from the pump end towards the motor end. The indicator should read zero at 360 degrees. If it doesn't, zero the indicator and retake the readings.

Rim Reading.—

1. Enter twice the actual amount of bar sag in Column 2, Bottom Reading. Attach the indicator base to the motor coupling flange and adjust the indicator so that the button is resting on the rim of the pump coupling flange.

2. Rotate the shaft with the indicator so that the indicator is at the top or 12 o'clock position and zero the indicator.

3. Rotate both shafts, preferably in the direction of normal rotation, and record the indicator readings at 90 degrees intervals. For consistency, right and left readings should be designated for both shafts looking from the pump end towards the motor end. The indicator should read zero at 360 degrees. If it doesn't, zero the indicator and retake the readings.

Calculations.—With all the readings entered in Column 1 for both the Face and Rim readings, follow the directions in each column.

***Face and Rim Readings*.—**

Column 1

These are the actual readings obtained from the dial indicator.

Column 2

Enter twice the actual amount of bar sag for the fixture being used.

Column 3

Add Columns 1 and 2. Column 2 is the effect of bar sag and is only added to the bottom reading of the Rim Readings.

Column 4

Face: Subtract the top from the bottom and the right from the left from the corrected readings in Column 3.

Rim: Subtract the bottom from the top and the left from the right from the corrected readings in Column 3.

Column 5

Face: This is the amount of movement required at the outboard legs to correct the angular misalignment. Multiply the value in Column 4 by the dimension B, divided by 2 times the dimension R.

Rim: This is the amount of movement required at the outboard legs to correct the parallel misalignment. Multiply the value in Column 4 by 1/2.

Column 6

Face: This is the amount of movement required at the inboard leg to correct the angular misalignment. Multiply the value in Column 4 times the dimension B, divided by 2 times the dimension R.

Rim: This is the amount of movement required at the inboard leg to correct the parallel misalignment. Multiply the value in Column 4 by 1/2.

Total Movement for Motor Legs.—This part of table sums the required movement at each leg for parallel and angular misalignment to determine total required movement.

Column 1

Add the value in Face Column 5 to the value in Rim Column 5 to determine total movement required for outboard legs.

Column 2

Determine the direction of the required movement by the sign of the value in Column 1. A positive value means the motor should be moved up or right. A negative value means the motor should be moved down or left.

Column 3

Add the value in Face Column 6 to the value in Rim Column 6 to determine total movement required for inboard legs.

Column 4

Determine the direction of the required movement by the sign of the value in Column 1. Positive values mean the motor should be moved up or right. Negative values mean the motor should be moved down or left.

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, indicating off 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 presented below using the Reverse Indicator Alignment Worksheet (figures 9 and 10)

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						+ Above
	Top	0	0				- Below
	Right		0				+ Left
	Left		0				- Right
	Top						
Motor Indicator	Bottom	0					+ Below
	Top		0				- Above
	Right		0				+ Right
	Left		0				- Left
	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 = ____________

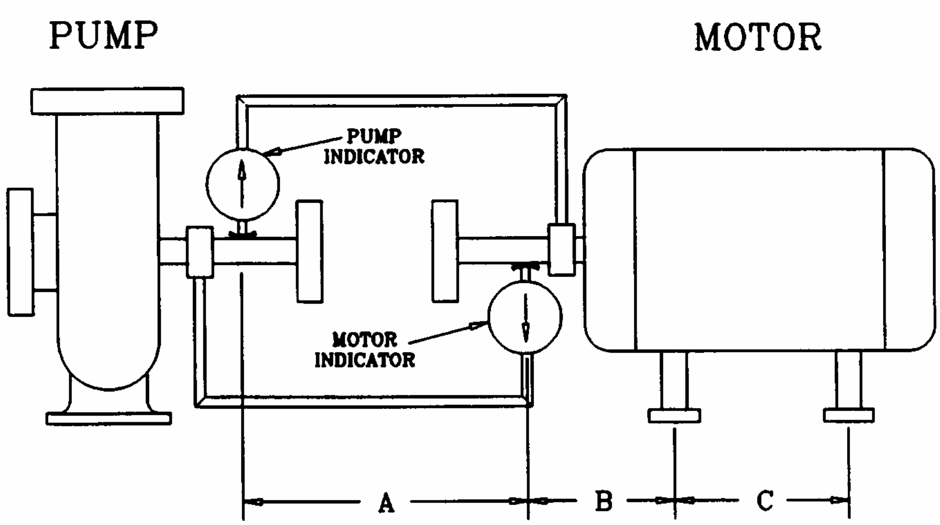


Figure 9.—Reverse indicator alignment worksheet.

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"

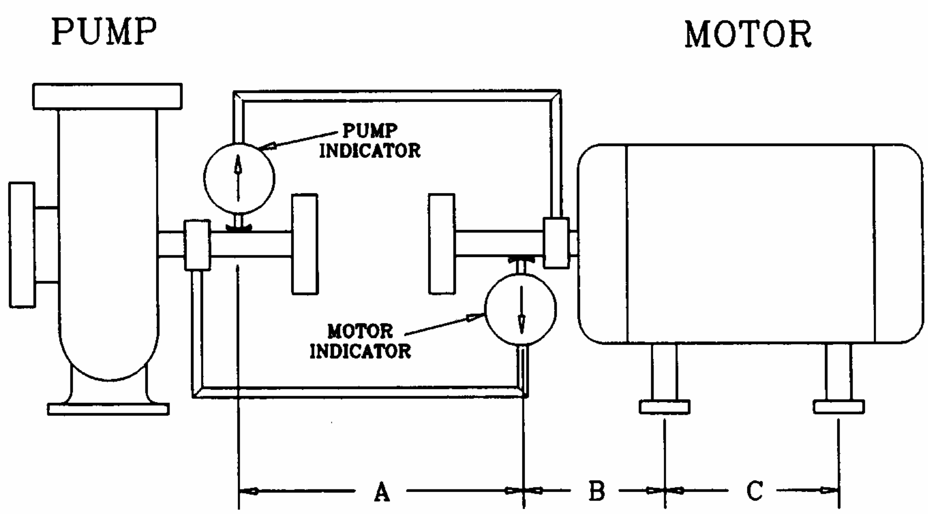


Figure 10.—Reverse indicator alignment worksheet (example).

***Record Indicator Readings*.—**

1. 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.

2. Rotate both shafts, preferably in the direction of normal rotation, and record the indicator readings at 90 degree 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 degrees. 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.

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

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

***Plot Data*.—**

1. Two graphs will be needed (figure 11). 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.

2 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.

3. Plot the values from step 4 above. 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.

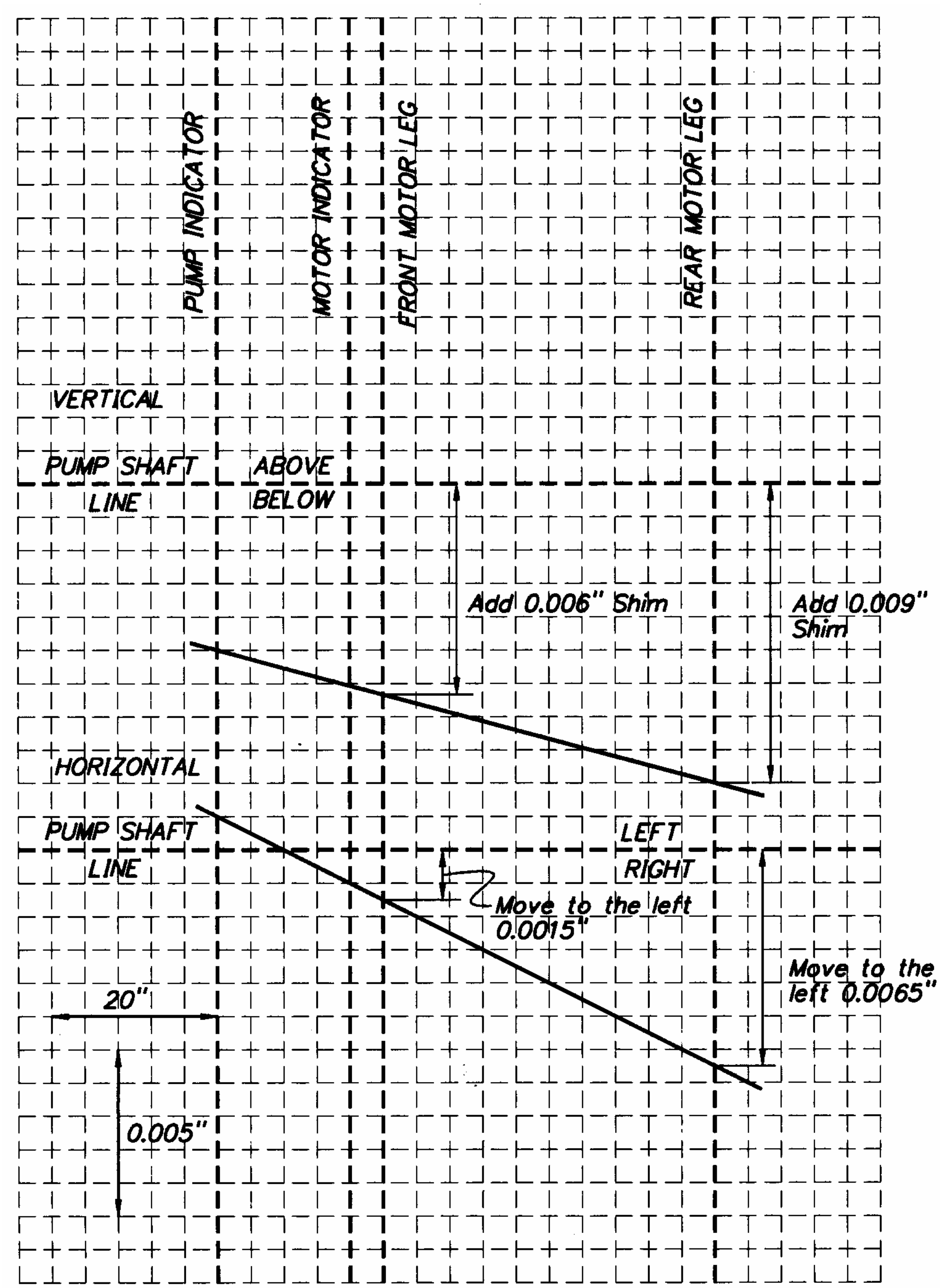


Figure 11.—Reverse indicator alignment plot.

4. 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.

5. After any shimming or movement of the motor, repeat readings and plot data to verify the alignment.

Vibration Monitoring and Analysis

Vibration monitoring and analysis can be a useful part of a preventive or predictive maintenance program. There are a variety of vibration monitoring systems available. Some use permanently mounted sensors to continually monitor vibration levels while other systems require readings to be taken periodically with hand held sensors. The type of system used depends on the equipment being monitored. The maintenance supervisor should compare the potential benefits of a vibration monitoring system, such as preventing damage and reducing outages, to the overall cost before deciding which system to use or whether to use any system at all.

Proximity Probe System

A proximity probe is a noncontacting type sensor which provides a dc voltage directly proportional to shaft position relative to the probe. In a hydroelectric powerplant or a large pumping plant, proximity probes are used to measure the main shaft runout on the turbine/generator or pump/motor. A typical proximity probe system utilizes two probes per guide bearing location, radially mounted and 90 degrees 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 optimum alarm and shutdown points will vary from unit to unit. The best way to set these points is experimentally. The runout amplitude should be measured from speed-no-load to full load noting the normal amplitude of runout as well as the amplitude at any rough zones. If operation in the rough zone is not desirable the alarm should be set high enough above normal amplitude to prevent nuisance alarms but low enough to indicate when the unit is in the rough zone. If the operation in the rough zone is allowed, the alarm point should be set above the maximum amplitude observed at any load. The shutdown point, if one is desired, should be set high enough to prevent nuisance tripping, but low enough to prevent damage to the machine. A timer or deadband circuit may be required to avoid alarms as the unit passes through rough zones.

Accelerometer Systems

There is a number of accelerometer based vibration monitoring systems available varying greatly in complexity and capability. Accelerometers are light weight vibration sensors that, as the name implies, provide an electrical output proportional to the acceleration of the vibration of the machine being checked. Although accelerometers are available that can measure low frequency vibration, (less than 5 Hz) they are primarily used for higher frequency vibrations such as 1800 rpm electric motors. Accelerometers are generally ineffective for use on slow speed equipment such as hydroelectric units as the primary frequencies are low and the critical measurement is displacement.

Depending on the system, accelerometers may be permanently mounted, handheld, or attached with a magnetic base. A typical accelerometer system requires periodic readings to be taken at different points on each machine. The data from these readings are usually stored in a portable recording instrument, and downloaded to a computer. This data must then be analyzed and compared to previous readings to determine if there is a significant increase in the vibration levels indicating an impending failure.

Signature Analysis

A common means of analyzing vibration data is through the use of a spectrum plot (figure 12). A spectrum plot is an X-Y plot where the X-axis represents the vibration frequency, usually in cycles per minute or cycles per second (Hertz), and the Y-axis represents vibration amplitude in acceleration, velocity, or displacement units. 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 or the appearance of a new spike in subsequent plots may indicate an operational problem or impending failure.

A signature analysis program can helpful in scheduling outages for bearing replacement on small motors and pumps. The amplitude of vibration at the bearing pass frequency will increase as an antifriction bearing starts to fail. Signature analysis is also a good tool for hydroelectric units. Spectrum plots from proximity probes at each of the guide bearings can be used to diagnose problems such as misalignment, unbalance, or draft tube surging. To be effective with hydroelectric units, spectrum plots should taken frequently as vibration levels will vary with the water level of the forebay and tailrace. Subsequent readings can then be compared to readings under the same operating conditions.

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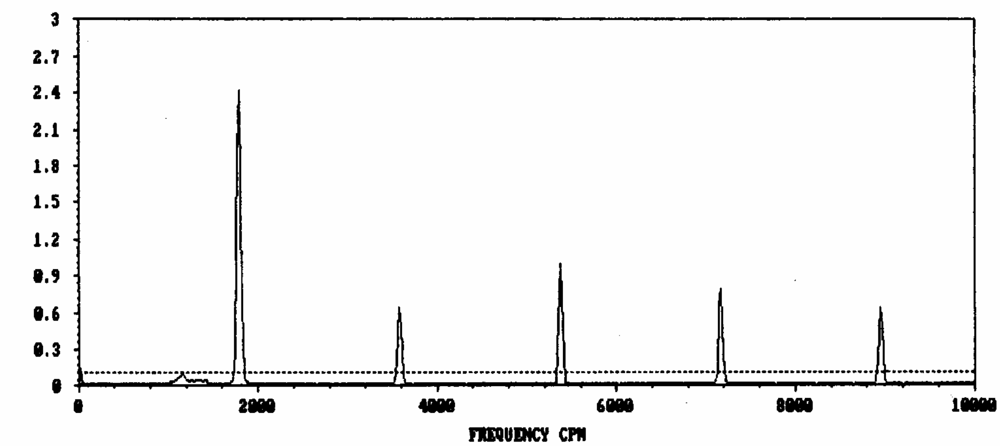
SINGLE SPECTRUM PLOT

SET: POWER GENERATION TYPE: FFT DATE: 08-NOV-90 13:01:32
POINT ID: TEST DESC:
WINDOW: HANNING LINES: 400 AVER: 1 FREQ: 0 - 10000 CPM
DETECT: PEAK TO PEAK RPM: 1800 THRESHOLD: 0.1000 UNITS: mils

FREQ: 0.00 AMP: 0 ORDER: 0.000 DEG: ---



IDENTIFICATION OF SPECTRAL PEAKS ABOVE THRESHOLD

NO.	AMP.	FREQ.	ORDER	NO.	AMP.	FREQ.	ORDER
1.	0.1349	25.0	0.014				
2.	2.3978	1800.0	1.000				
3.	0.6228	3575.0	1.986				
4.	0.9849	5375.0	2.986				
5.	0.7759	7175.0	3.986				
6.	0.6270	8950.0	4.972				

SPECTRAL ENERGY SUMMARY

OVERALL	SYNC	SUBSYNC	NONSYNC
3.049	2.908	0.2776	0.8761

Figure 12.—Single spectrum plot.

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. Training is available from many of the manufacturers of vibration monitoring systems.

Oil and Lubricants

Lubrication

The primary purpose of a lubricant is to reduce friction and wear between two moving surfaces, but a lubricant also acts as a coolant, prevents corrosion, and seals out dirt and other contaminants. In order for a lubricant to perform as intended, careful attention must be given to its selection and application as well as its condition while in use. F.I.S.T. Volume 2-4, Lubrication of Powerplant Equipment provides more information on lubricants and their use. The equipment manufacturer should provide specific information on the type lubricant and periodic maintenance recommended for a particular application.

Oil Lubrication

Oil lubrication can take many forms, from a simple squirt oil can to a complex circulating system. Regardless of the method by which the oil is applied, the intent is the same, and that is to keep a lubricant film between moving surfaces. For successful lubrication, it is critical that the proper oil be chosen, properly applied, and kept clean and uncontaminated.

While it is beneficial to have as few types of oil in stock as possible, there is no one all purpose oil that can be used in all applications. Various additives, such as emulsifiers, rust and corrosion inhibitors, detergent and dispersants, are added to oil to enhance their performance for a given application. Characteristics that may be desirable in one case, may be very undesirable in another. For example, emulsifiers are added to motor oil allow the oil to hold water in an emulsion until the engine's heat can boil it away. In bearing lubrication, where there is not sufficient heat to evaporate the water, the oil must be capable of readily separating from water.

Grease Lubrication

Grease is a lubricant consisting of a lubricating oil combined with a thickening agent. The base oil makes up 85 to 95 percent of the grease and performs the actual lubrication. The thickening agent, usually some type of soap, determines many of the characteristics of a grease such as, heat resistance, water resistance, and cold weather pumpability. Various additives may also be added to improve performance.

Overheating and subsequent failure of grease lubricated bearings caused by over lubrication is a common problem. The idea that more is better coupled with the fact that it usually difficult to determine the actual amount of grease in a bearing housing, causes many bearings to be "over greased."

Ideally a grease lubricated bearing should be "packed" by hand so that the bearing housing is approximately one third full of grease. When grease is applied using a grease gun, the relief plug, if so equipped, should be removed so that as the new grease is applied, all of the old grease is purged from the bearing housing. The unit should be operated approximately 30 minutes before the plug is replaced to allow excess grease to escape. If the bearing housing doesn't have a relief plug, grease should be added very infrequently to prevent over lubrication.

Many of the soap bases used in making grease are incompatible. Mixing two different types of grease will many times result in a mixture inferior to both of the component greases. As a general rule, different greases should not be mixed. If it becomes necessary to change the type of grease used on a piece of equipment, the bearing housing should be completely disassembled and thoroughly cleaned to remove all the old grease. If this is not possible, as much of the old grease as possible should be flushed out by the new grease during the initial application and the greasing frequency should be increased until it is determined that all of the old grease has been purged from the system.

In wicket gate greasing systems and other underwater applications, a grease must be chosen that is water resistant, somewhat adhesive, and has extreme pressure characteristics, as well as being pumpable. A grease that is impervious to water and has excellent lubricating qualities is useless if it doesn't get to the bearing. The consistency must be thin enough to be pumped through the grease lines, but thick enough to stay in the bearings once it is there. Some compromise in the desired qualities is required to obtain a workable grease.

Hydraulic Oil

The main purpose of a hydraulic oil is to transmit power but it must also lubricate the components of the hydraulic system. In many systems a lubricating oil such as turbine oil can be used as the hydraulic fluid. If the system uses a gear pump, operates at pressures less than 1000 psi, and has similar viscosity requirements, a turbine oil can function very well as a hydraulic oil. In systems that operate over 1000 psi or use a piston or sliding vane pump, a fluid with an anti-wear additive is usually required. Where the system operates in an area of great temperature extremes, such as gate operators, an oil with a high viscosity index might be required to provide desirable high and low temperature viscosity characteristics.

Testing and Filtering

Cleanliness is extremely important. All seals should be installed and in good condition. Dirt, water, or other contaminants not only can cause premature wear of the bearings and hydraulic system components, they also can cause the depletion of some of the oil's additives. Samples of the oil from large bearings and hydraulic systems should be tested for viscosity, acidity, and water content. The tests should be performed at least annually and more frequently if a problem is suspected or previous tests have indicated an impending problem. In any testing program it is important to keep complete and accurate records of the tests. A significant change in any of the measured properties from previous tests may indicate a problem although the oil may still be acceptable for service.

The oil from large bearings should be periodically drained, filtered, and the oil reservoir thoroughly cleaned. The most efficient method of determining when to filter is through the results of the oil tests. Filtering more frequently than is necessary is a waste of time, while waiting too long to filter the oil will shorten the oil's life and damage the equipment being lubricated.

The oil from small bearings should be periodically drained, the reservoir or case cleaned and filled with new oil. Care should be taken when filling a bearing oil reservoir so as not to under or over fill. In many cases, over filling an oil reservoir can cause as much damage as an underfilling.

Another possible source of contamination is the mixing of incompatible oils. Different types of oils or even similar oils from different manufacturers should never be mixed. Additives in different oils may not be compatible and when mixed, may have an adverse reaction, reducing the effectiveness of the oil.

Inspection Checklist

	Hydraulic Turbines and Large Pumps	**Inspection Interval**
1.	Runner or Impeller	NS, A
2.	Spiral Case and Draft Tube or Pump Casing and Suction Inlet	NS, A
3.	Wearing Rings	NS, A
4.	Main Shaft Packing	W, NS
5.	Mechanical Seals	W, NS
6.	Bearings	NS, D, A
7.	Shaft and Coupling	A
8.	Generator or Motor Rotor	A
9.	Air Coolers	NS, A
10.	Unit Brakes	M, A

11.	Inspection Reports	A
	Auxiliary Pumps	
12.	Pump Impeller or Rotor and Casing	NS, A
13.	Shaft and Coupling	W, A
14.	Packing	NS, W
15.	Mechanical Seals	W
16.	Bearings	W
17.	Pressure Relief Valves	A
18.	Eductors	NS

Notes:

D – Daily
W – Weekly
M – Monthly
S – Semiannual
A – Annual
NS - Not Scheduled (Extraordinary maintenance. Usually 5 year or longer intervals.)

Hydraulic Turbines and Large Pumps

1. Runner or Impeller

Annual. Examine runner or impeller thoroughly for cavitation or other damage. Use a nondestructive test to check for cracks in runner buckets or impeller vanes. Refer to F.I.S.T. Volume 2-5 entitled Turbine Repair for repair recommendations and techniques.

Not Scheduled. Remove runner or impeller and inspect and repair areas not normally accessible.

2. Spiral Case and Draft Tube or Pump Casing and Suction Inlet

Annual. Check condition of interior coating and repair as required. Weld repair cavitation damaged areas of draft tube liner. Inspect riveted and welded joints for leaks and corrosion and repair as required. Check mandoors for leaks and condition of door hinges. The draft tube or suction tube liner should be checked for voids between the liner and the concrete and grouted if necessary. Any leaks between the concrete and the spiral case, pump casing, draft tube, or suction tube should be monitored and if excessive or if an increase is noted, the source of the leak should be found and repaired. The spiral case is a pressure vessel and the repair procedure must take this into account.

Not Scheduled. If condition of interior coating is such that spot repairs are no longer effective, sandblast and repaint entire surface. Draft tube liners severely damaged by cavitation may be repaired by cutting out the damaged area and welding stainless steel plates in place that have been rolled to the proper diameter.

3. Wearing Rings

Annual. Check top and bottom wearing ring clearances at four points, 90 degrees apart. Compare to the design clearance and previous readings. If clearance is approaching 200 percent of design clearance, schedule wearing ring replacement.

Not Scheduled. Remove runner or impeller and replace or renew wearing rings when clearance exceeds 200 percent of design clearance. Wearing rings that are an integral part of the runner or impeller or the casing in some cases may be built up by welding and remachined. Replaceable wearing rings, in most cases, should not be built up by welding, as the heat of welding can induce stresses or distort the rings. If the wearing rings are replaced, the stationary rings should be supplied with an undersized inner diameter and bored concentric to the center of the unit.

4. Main Shaft Packing

Weekly. Check flow and pressure of packing cooling water. Check for excessive heat and for leakage past the packing. Tighten the packing gland as leakage becomes excessive and grease the packing box if and when required.

Not Scheduled. Remove old packing and lantern ring and thoroughly clean packing box. Check packing sleeve for excessive wear and repair as required. Install new packing, staggering adjacent rings so that joints do not coincide.

5. Mechanical Seals

Weekly. Check for excessive leakage. Properly installed mechanical seals should require very little attention. Follow manufacturer's recommendations for lubrication during extended outages. When excessive leakage does occur it normally is an indication that new seals are required.

Not Scheduled. Disassemble seal and thoroughly clean seal components and shaft sleeve. Check shaft sleeve for excessive wear and repair as required. Replace segments or other components as required.

6. Bearings

Daily. Check the bearing temperature and lubricant level. Check flow and pressure of cooling water. Check flow and pressure of turbine guide bearing oil pump.

Annual. Take oil sample from all bearings, preferably while unit is running some time before a scheduled outage. If it is not possible to obtain samples with unit running, samples should be taken immediately after shutdown while the oil is still hot. The viscosity, acidity, water content of the samples should be checked as a minimum. The oil may also be checked for the presence of wear particles or other contaminants. Based on the results of the oil tests, the oil should be drained and filtered.

Check bearing clearances with dial indicators and by "jacking" the shaft or with feeler gauges. Any change in previous readings should be investigated. Calibrate temperature sensors and oil level indicators. Check operation of a.c. and d.c. turbine guide bearing and thrust bearing high pressure lubrication system oil pumps. Note operating pressure of high pressure lubrication system and investigate if it is significantly different from previous readings. Check filters on high pressure lubrication system and clean or replace as required.

Check the generator thrust bearing and upper guide bearing insulation with an ohmmeter following the procedure in FIST Volume 3-11, Generator Thrust Bearing Insulation and Oil Film Resistance. If resistance is low, investigate cause immediately.

Not Scheduled. Remove bearings and check for any damage. Light scoring and other minor damage can be removed by scraping babbitt bearings. If there is severe damage to the babbitt surface, the bearing should be rebabbitted.

Remove cooling coils and clean out any deposits. Hydrostatic test coils for several hours to check for leaks before reinstalling. Check normally inaccessible portions of thrust bearing high pressure lubrication system for leaks or broken hoses.

7. Shaft and Coupling

Annual. Check shaft runout with dial indicator or with proximity probes and a strip chart recorder. At minimum, check runout at full load, and if possible, record the runout as the unit is loaded from speed-no-load to full load. Make note of the maximum runout magnitude and the load at which it occurred. Investigate if runout is excessive or has changed significantly from previous readings.

8. Generator or Motor

Annual. Thoroughly inspect stress carrying parts of rotor for cracks. Pay particular attention to welds on the rotor spider. Any cracks should be evaluated by engineering personnel and a repair procedure developed. Check bolted connections for tightness and any evidence of movement. Check stator frame for loose connections, cracks, or other damage. Check stator air gap at a minimum of four positions, top and bottom.

9. Air Coolers

Annual. Clean exterior surfaces of coils and check for leaks.

Not Scheduled. Check interior of coils for excessive scale buildup. If scale is excessive, clean mechanically or with an approved chemical treatment. Perform a hydrostatic test after cleaning to check for leaks.

10. Unit Brakes

Monthly. Check condition of brake air line filters and lubricators. If lubricator is not installed, operate unit jacks to lubricate brake cylinders.

Annual. Measure brake shoe thickness and check condition of brake ring. Operate brake cylinders to check for any binding or sticking. If necessary disassemble brake cylinders, and repair. If brake ring causes excessive vibration, it may require replacement or repair.

11. Inspection Reports

Inspection reports detailing what work was performed during an inspection should be filled out annually to record data obtained during the annual inspection.

Auxiliary Pumps

12. Impeller or Rotor and Casing

Annual. If inspection ports are available, the pump impeller should be inspected annually. Check for leaks from casing at gasketed joints and tighten or replace gaskets as required. Take ammeter readings of pump motor with pump at full capacity. A decrease in amperage indicates a decrease in pump output, which suggests some maintenance is required.

Not Scheduled. Disassemble pump if there is a reduction in capacity or pressure, an increase in vibration, or other indication that a problem exists or at intervals determined by past maintenance experience. Check for worn parts and repair or replace as required.

13. Shaft and Coupling

Weekly. Check shaft and coupling visually for excessive runout or vibration. Look for loose coupling bolts or other damaged coupling components. Lubricate if required.

Annual. Check shaft runout with dial indicator or with proximity probes. Check shaft alignment if runout is excessive.

14. Packing

Weekly. Check for excessive heat and for proper amount of leakage. Tighten packing as required.

Not Scheduled. Remove old packing and lantern ring and thoroughly clean packing box. Check packing sleeve for excessive wear and repair or replace as required. Install new packing, staggering adjacent rings so that joints do not coincide.

15. Mechanical Seals

Weekly. Check for excessive leakage. Properly installed mechanical seals should require very little maintenance. When excessive leakage does occur it normally is an indication that new seals are required.

16. Bearings

Weekly. Check for vibration and for adequate lubrication. Prior to complete failure, vibration will increase and the bearing will usually become extremely noisy. As it is sometimes difficult to detect an increase in noise or vibration, some sort of vibration monitoring system can be helpful. If a bearing fails prematurely, determine cause and correct it before restarting the pump. Insufficient or excessive lubrication, contamination of the lubricant, or misalignment of the shaft or bearings are some possible causes of premature bearing failure.

17. Pressure Relief Valves

Annual. All positive displacement pumps, such as in hydraulic systems, must have a pressure relief valve installed in its discharge line ahead of any valve or obstruction that could restrict flow. In some pumps, the relief valve is an integral part of the pump. Test all relief valves for proper operation and setting.

18. Eductors

Not Scheduled. Disassemble and clean any scale or rust build up from nozzle, eductor body, and piping. Repair or replace nozzle if damaged by corrosion or cavitation.

Section 3 - Discharge Lines, Piping, Gates, and Valves

Discharge Lines and Piping

Pumping plants, depending on their size, can have a wide variety of piping. While the piping of a small pumping plant may consist of only the discharge and suction lines with some type of shutoff valves, a large pumping plant can have a great deal of auxiliary piping as well. Cooling, fire protection, and domestic water as well as various hydraulic and pneumatic systems are common in large plants. Since visual inspection of the interior of large diameter pipes and valves is possible, protective coatings can be periodically repaired or replaced to keep them in good condition. Besides periodic inspections and maintenance, the condition of the suction and the discharge pipes should be evaluated as to their safety, depending upon the age of the pipes. Reclamation's FIST Volume 2-8, "Inspection of Steel Penstocks and Pressure Conduits", provides useful information and engineering techniques for the assessment of all types of pipes and should be consulted in setting up an evaluation program.

The auxiliary piping systems, except for the painting of their exterior surfaces, many times are ignored until leaks or other problems occur. Although a leak may be just an isolated event, frequently it can be an indication of the entire system's condition. By monitoring a system's condition, repair or replacement can be scheduled, preventing an unscheduled outage. Determining the condition of a piping system can be difficult. Partial disassembly can provide a good indication of the condition of the system but may damage the piping or valves. Radiographs or X-rays are nondestructive, easy to interpret, and provide a permanent record of the pipe wall thickness and the amount of mineral deposits or corrosion products built up in the pipe. Other nondestructive tests such as ultrasonic can also determine pipe wall thickness.

If a piping system fails prematurely because of a corrosion problem, it may be beneficial to replace the piping with a nonmetallic material. Pipe constructed of fiberglass and PVC (polyvinyl chloride) as well as other plastics have been used successfully in corrosive environments. Before switching to one of these materials give careful consideration to their temperature and pressure limitations.

Gates and Valves

General

Large pumping plants may use various types of valves or gates, such as fixed wheel gates or butterfly valves, for the discharge and suction lines. These large gates or valves are usually specially designed for that application so it should be noted that not all of items on the inspection checklist will apply to all types of gates and valves. Specific maintenance instructions, if available, should be followed when working on this equipment.

Small pumping plants and auxiliary piping systems most commonly use gate valves as shutoff valves. These valves should require little maintenance unless the water is corrosive or the valve is used for throttling flow, in which case, cavitation erosion may occur. If flow throttling is necessary and there is severe cavitation damage, consideration should be given to replacing the gate valve with a valve designed for throttling, such as a globe valve.

Check valves are also used in pumping plants in various applications. The most common type is the swing-check valve. This valve, depending on its service, should require very little attention outside of regrinding the seat if excessive leakage occurs.

There are numerous types of gates and valves installed in pumping plants. Figures 13, 14, and 15 illustrate some common gate and valve layouts. A gate or valve's primary purpose is to regulate flow, or to act as a secondary shutoff. The following definitions are taken from the Handbook of Applied Hydraulics, Third Edition:

Gate.—A gate is a closure device in which a leaf or closure member is moved across the fluidway from an external position to control the flow of water.

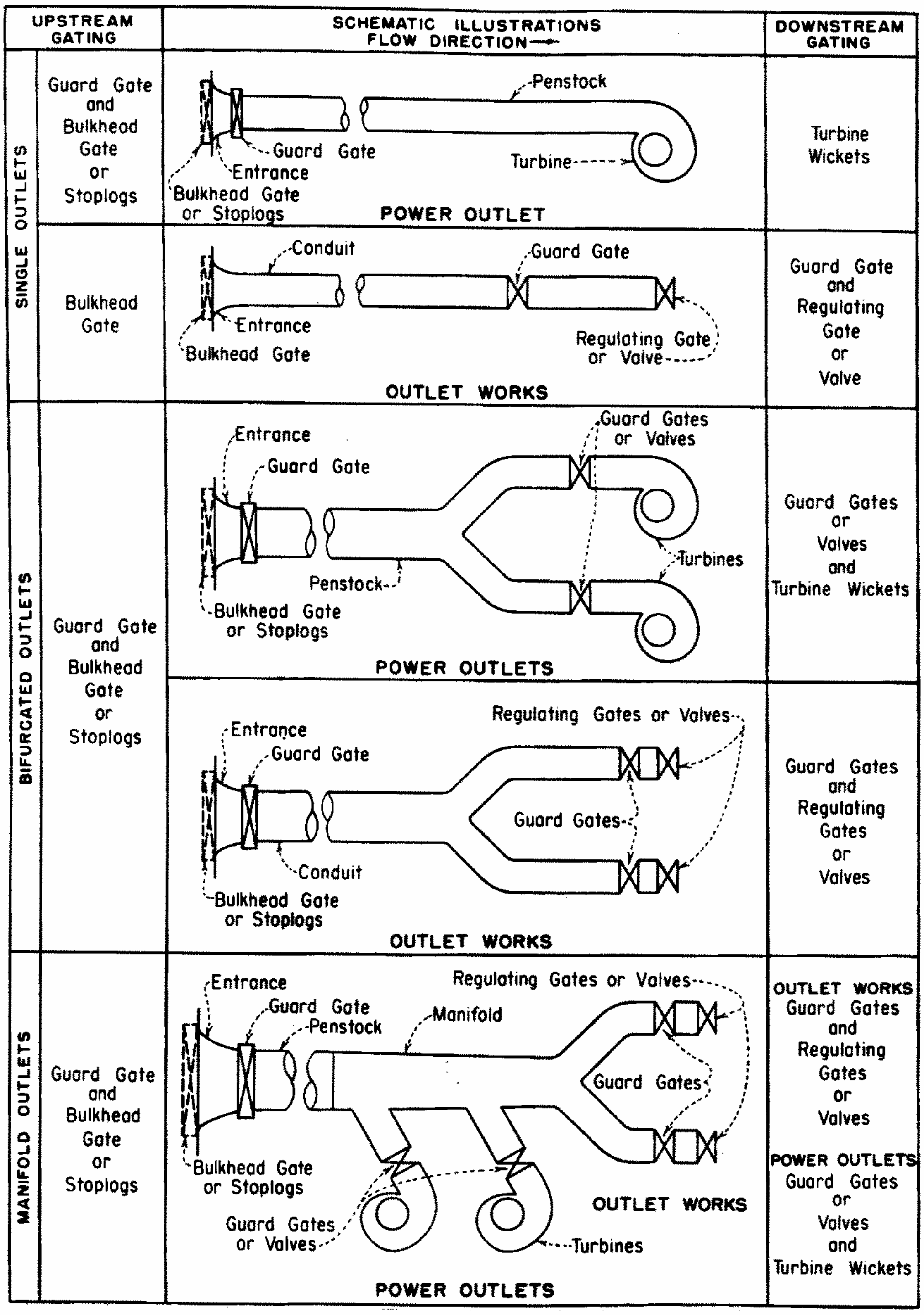


Figure 13.—Common gate and valve arrangements.

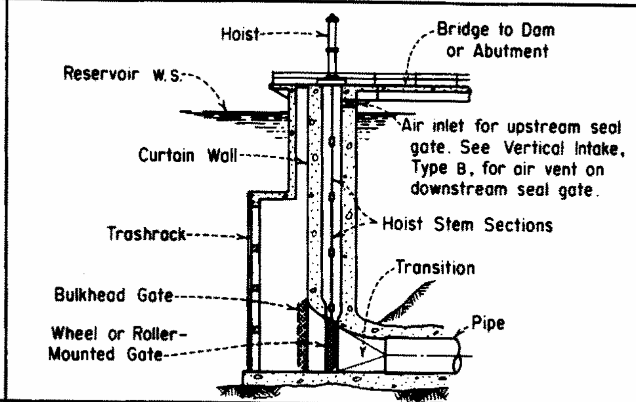
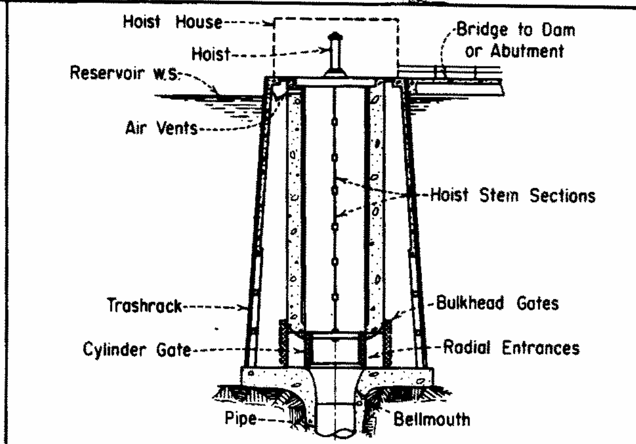
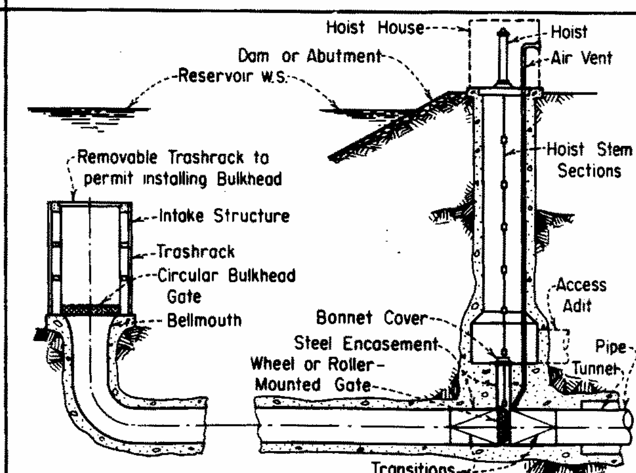
TYPE	SCHEMATIC ILLUSTRATION FLOW DIRECTION ⟶	NOTES AND COMMENTS
TOWER INTAKE (RECTANGULAR GATE)		Tower intakes are used principally on earth dams where abutments are not suitable for intake structures. Also used for concrete dams where intakes must be located on abutments and other types are not suitable. Basic arrangement is similar to vertical abutment intake. Bridge is usually provided to dam or abutment.
TOWER INTAKE (CYLINDER GATE)		Tower intake used primarily where intake entrance is vertical. Other selection factors are similar to those stated above for vertical towers for rectangular gates.
SHAFT (SUBMERGED UPSTREAM INTAKE)		Intake arrangement used principally on earth dams. Shaft usually located near axis of dam, either in dam or abutment. Abutment location is preferrable to avoid joint between abutment rock and dam fill. Intake Bulkhead installation requires drawing reservoir down or placement from a barge and the employment of divers.

Figure 14.—Intake arrangements.

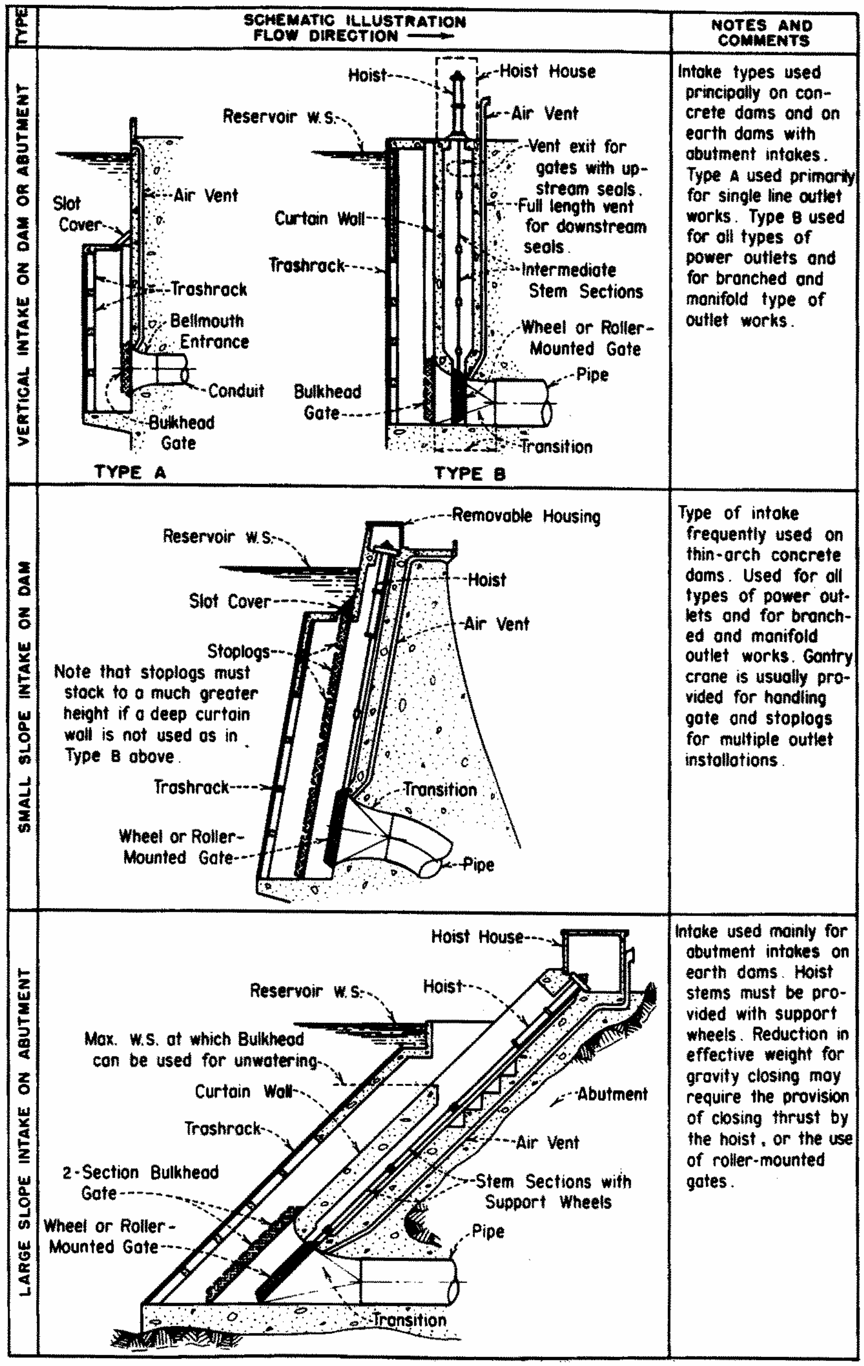


Figure 15.—Intake arrangements.

Valve.—A valve is a closure device in which the closure member remains fixed axially with respect to the fluidway and is either rotated or moved longitudinally to control the flow of water.

Guard Gates or Valves.—Guard gates or valves operate fully open or closed and function as a secondary device for shutting off the flow of water in case the primary closure device becomes inoperable. Guard gates are usually operated under balanced-pressure no-flow conditions, except for closure in emergencies.

Regulating Gates and Valves.—Regulating gates and valves operate under full pressure and flow conditions to throttle and vary the rate of discharge.

Bulkhead Gates.—Bulkhead gates are usually installed at the entrance and used to unwater fluidways for inspection or maintenance, and are nearly always opened or closed under balanced pressures.

Stop Logs.—Stop logs are installed in the same manner and perform the same function as bulkhead gates. A stop log may be considered as a section of a bulkhead gate which has been made of several units to permit easier handling."

Gates

Closure or regulating devices meeting the above definition of "gates" appear in a variety of forms. The more common types are discussed in the following sections.

1. *Radial or Tainter Gates*. Radial gates (figure 16) or tainter gates as they are also called, are used primarily as spillway crest gates but are also used in canals or other open channel applications. A radial gate basically consists of a skinplate, shaped like a cylindrical section, connected to radial arms which converge to a horizontal pivot pin. The gate is raised or lowered usually by a wire rope or chain and sprocket hoist.

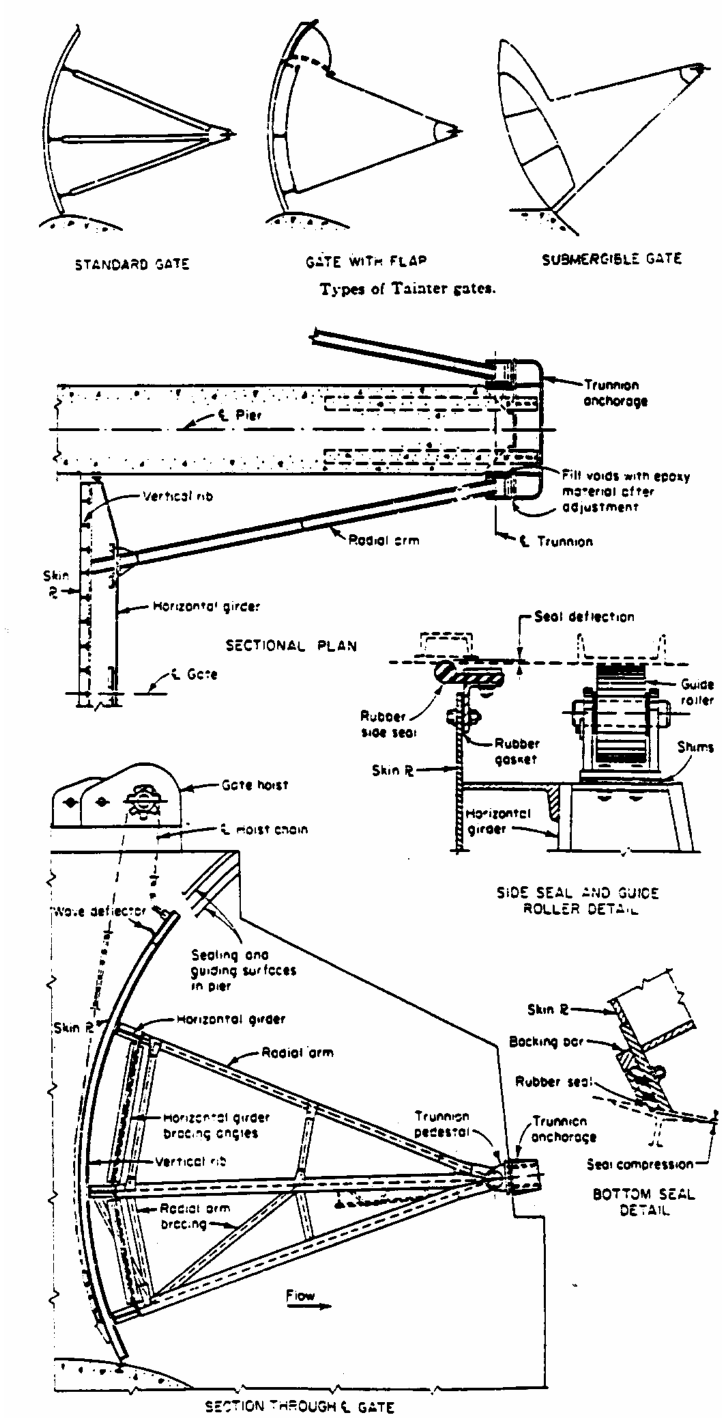


Figure 16.—Radial gates.

2. *Slide Gates*. Slide gates, in their various configurations, may be used as guard or regulating gates for closed, high pressure conduits, such as penstocks and outlet works, or for open channel flow such as canals. The construction of a slide gate can vary a great deal. The cast iron slide gate consists of a flat or rectangular leaf that is moved within a frame over a circular or rectangular opening. The leaf is connected to a hoist by a stem which is supported by guides attached to the concrete above the opening. High pressure gates and outlet gates are also slide gates. They consist of a leaf, a body and bonnet embedded in concrete, and some type of hoist for raising and lowering the leaf. Since slide gates usually seal downstream, the downstream mating surfaces between the leaf and the body act as bearing and sealing surfaces. Figure 17 shows an outlet works slide gate.

3. *Wheel- and Roller-Mounted Gates*. Wheel-mounted (fixed wheel gates) and roller-mounted (coaster gates) gates consist of a flat structural steel gate leaf with a roller system or a series of wheels fixed to the leaf to transfer the hydraulic load from the gate to tracks imbedded in concrete. These gates are used as spillway gates or as the primary guard gate for a penstock or outlet conduit. Depending on the application, the hoist for the gate may be a hydraulic cylinder or some type of a mechanical hoist. Figures 18 and 19 show typical installations.

4. *Jet Flow Gates*. Jet flow gates are used strictly for water regulation through outlet conduits. A jet flow gate is similar to a slide gate consisting of a leaf, a body, a bonnet, and a hoist to position the leaf. The outlet of the gate is circular in cross section, rather than square or rectangular as a slide gate, with a conical nozzle upstream of the gate. This nozzle produces a contracted, jet type discharge that jumps over the gate leaf slot. Figure 20 shows a jet flow gate.

5. *Ring-Follower Gates*. Ring-follower gates are used as guard gates for penstocks or outlet conduits and are not suitable for water regulation. A ring-follower gate is a slide gate with a leaf, body, bonnet, and a hoist, usually a hydraulic cylinder, to move the leaf. The ring-follower gate leaf consists of two parts, the bulkhead part which blocks the fluid flow in the closed position, and the "ring" portion which has a circular opening matching the diameter of the penstock or conduit, to provide a unobstructed water passage in the open position. A ring-follower gate is shown in figure 21.

6. *Ring-Seal Gates*. Ring-seal gates are a type of ring-follower gate with a movable seal and a wheel- or roller-mounted gate leaf. The gate seal is hydraulically actuated by water pressure, either from the conduit or an external source, and may be located in the housing or the leaf. The hoist may be mechanical or a hydraulic cylinder. Ring-seal gates are shown in figures 22 and 23.

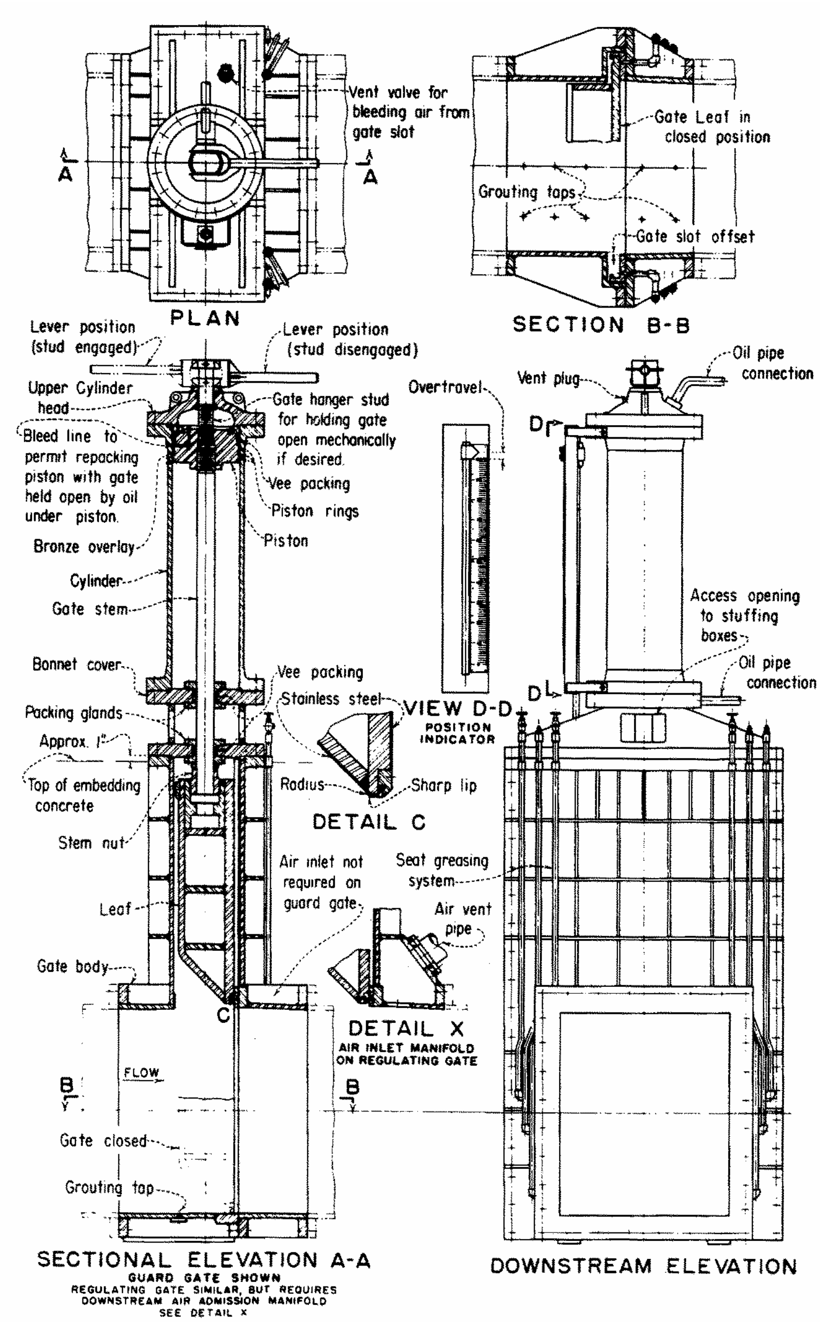


Figure 17.—Slide gate.

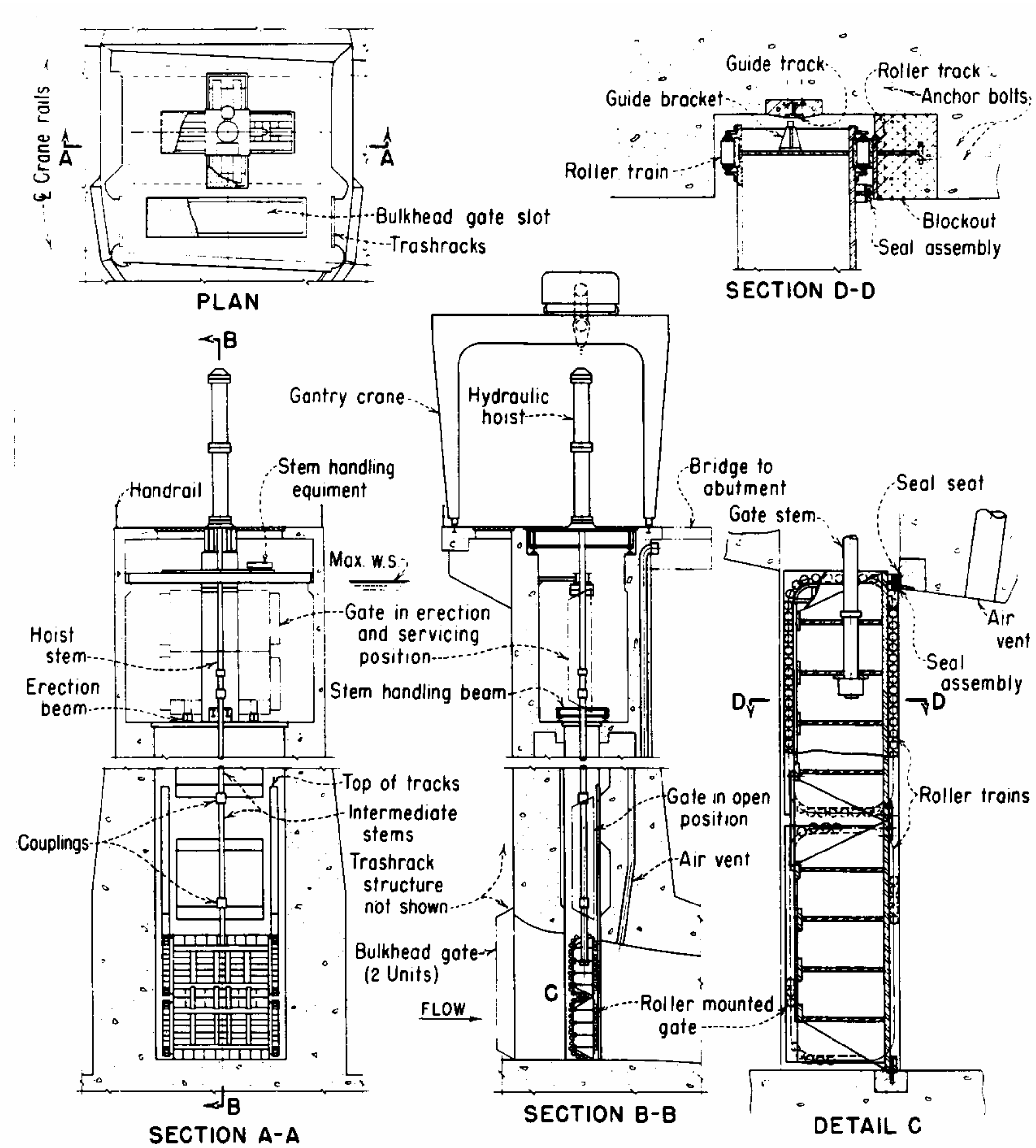


Figure 18.—Roller-mounted gate (coaster gate).

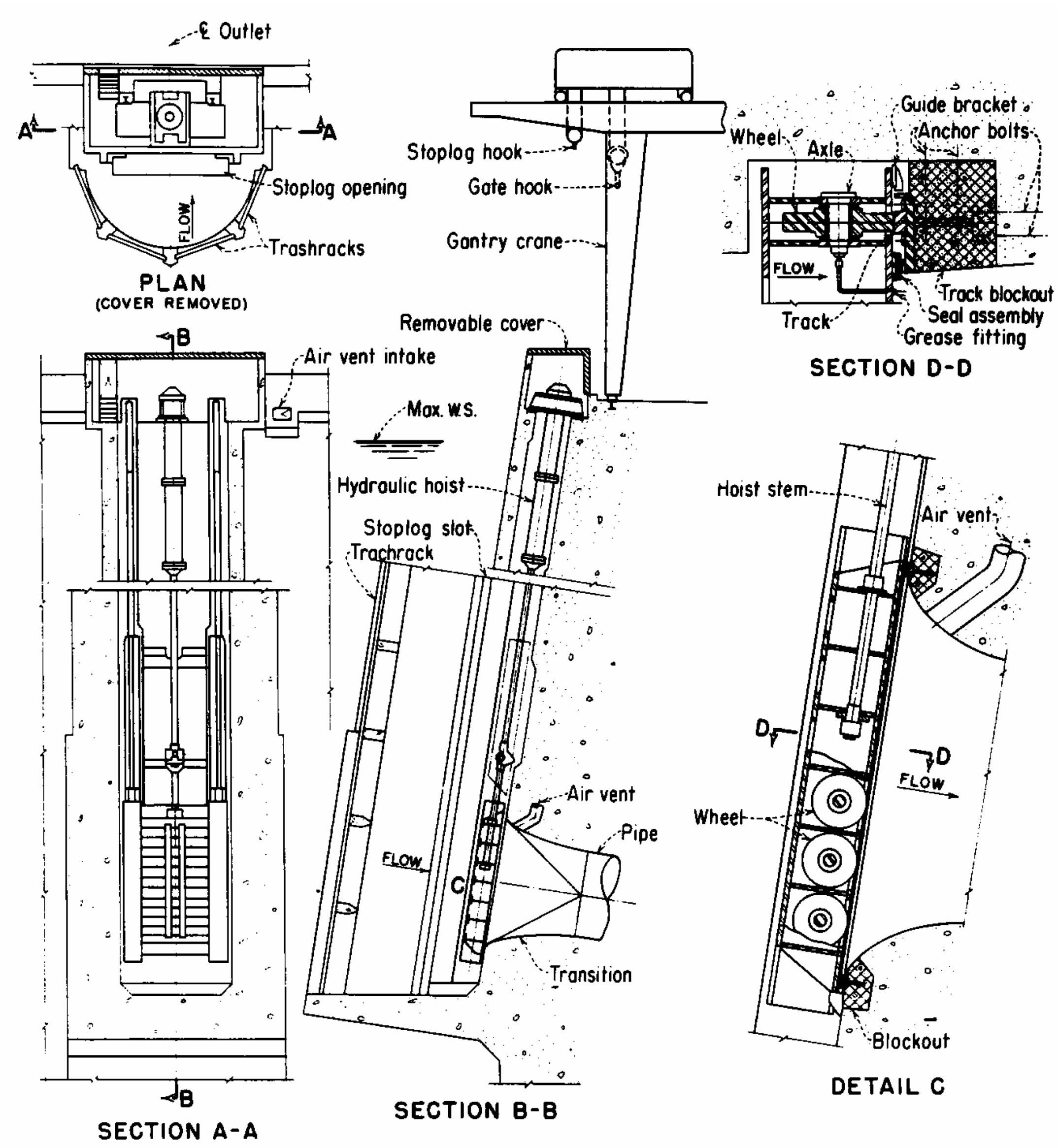


Figure 19.—Wheel-mounted gate (fixed wheel gate).

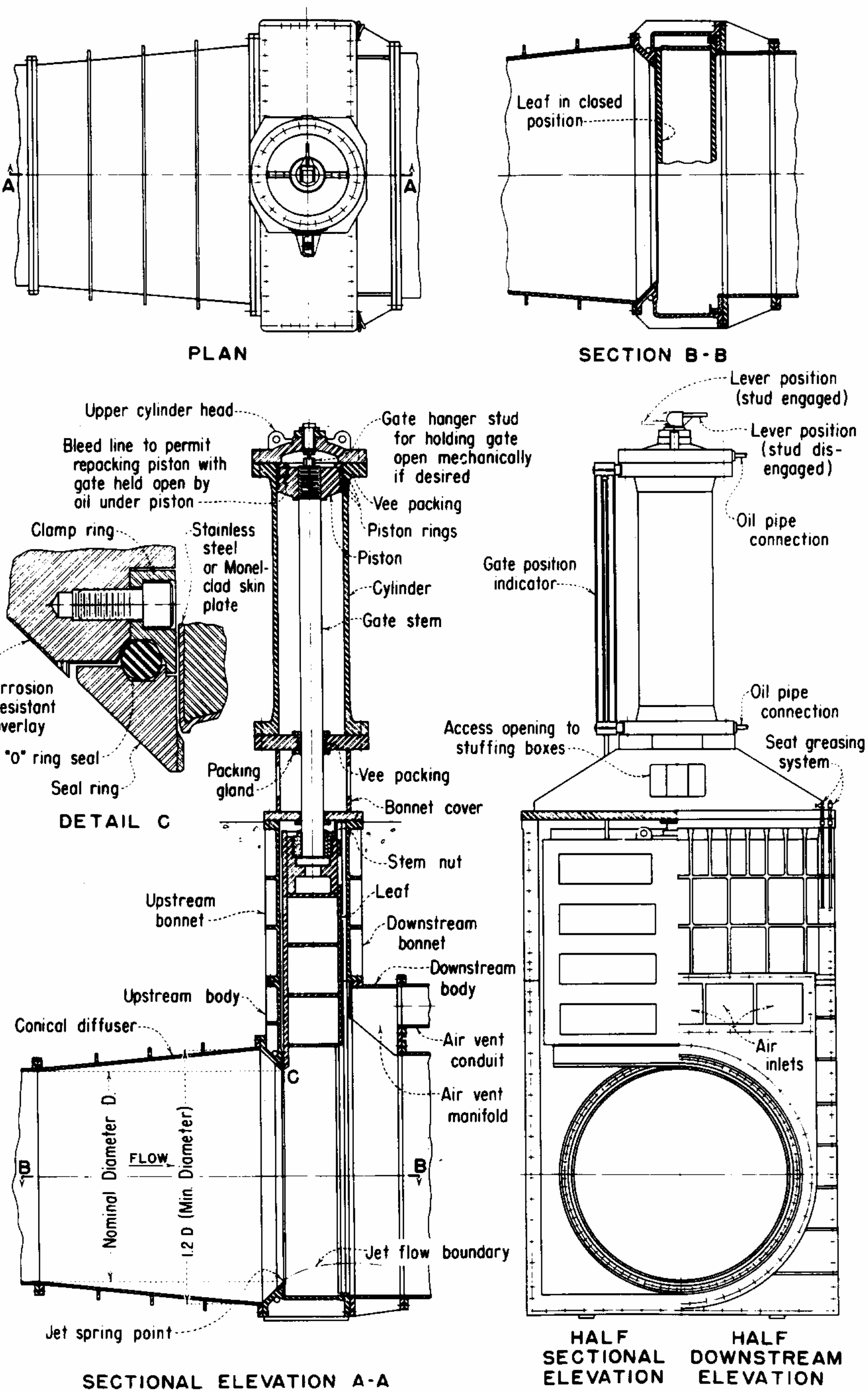


Figure 20.—Jet flow gate.

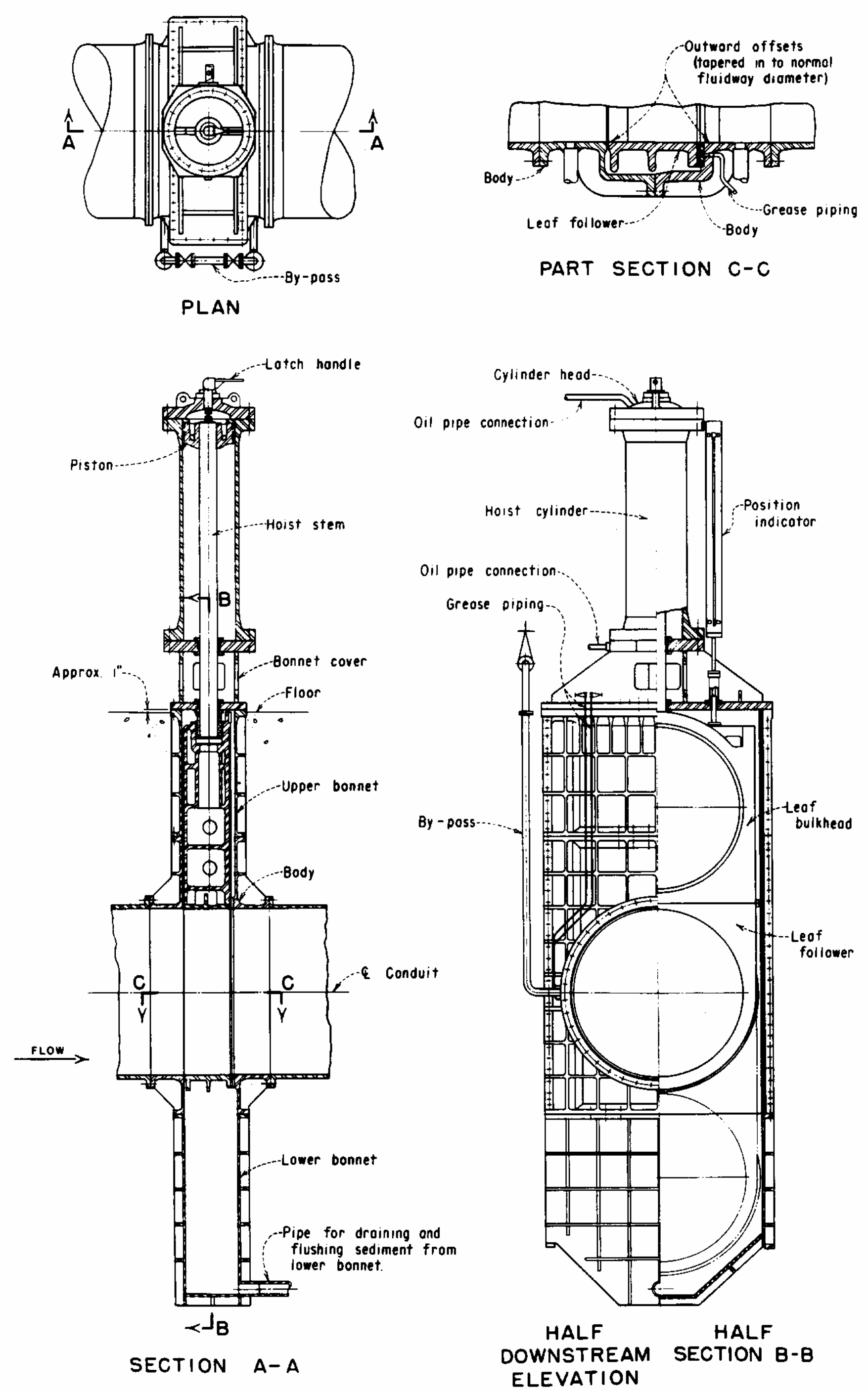


Figure 21.—Ring-follower gate.

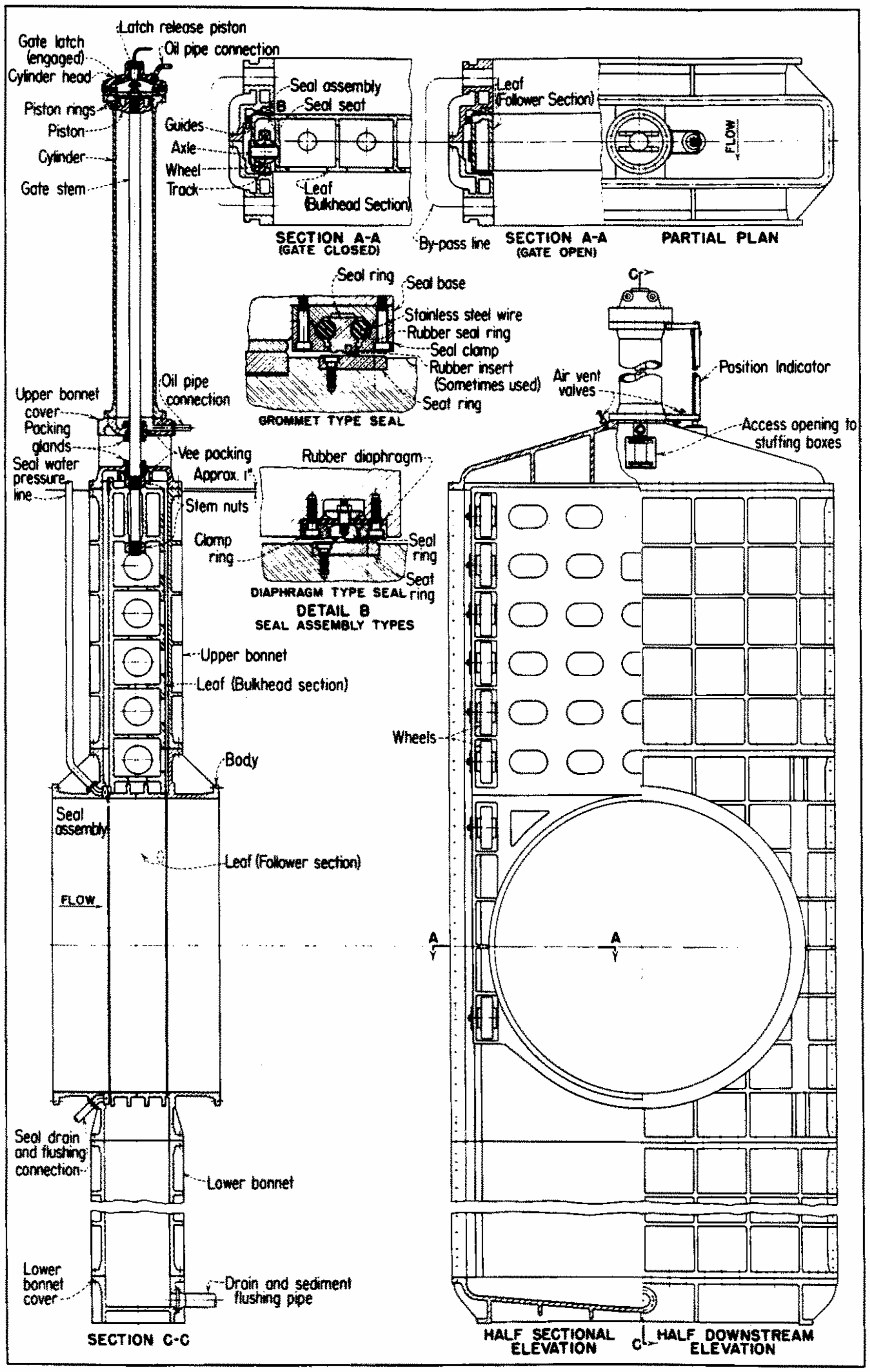


Figure 22.—Ring seal gate (hydraulically operated).

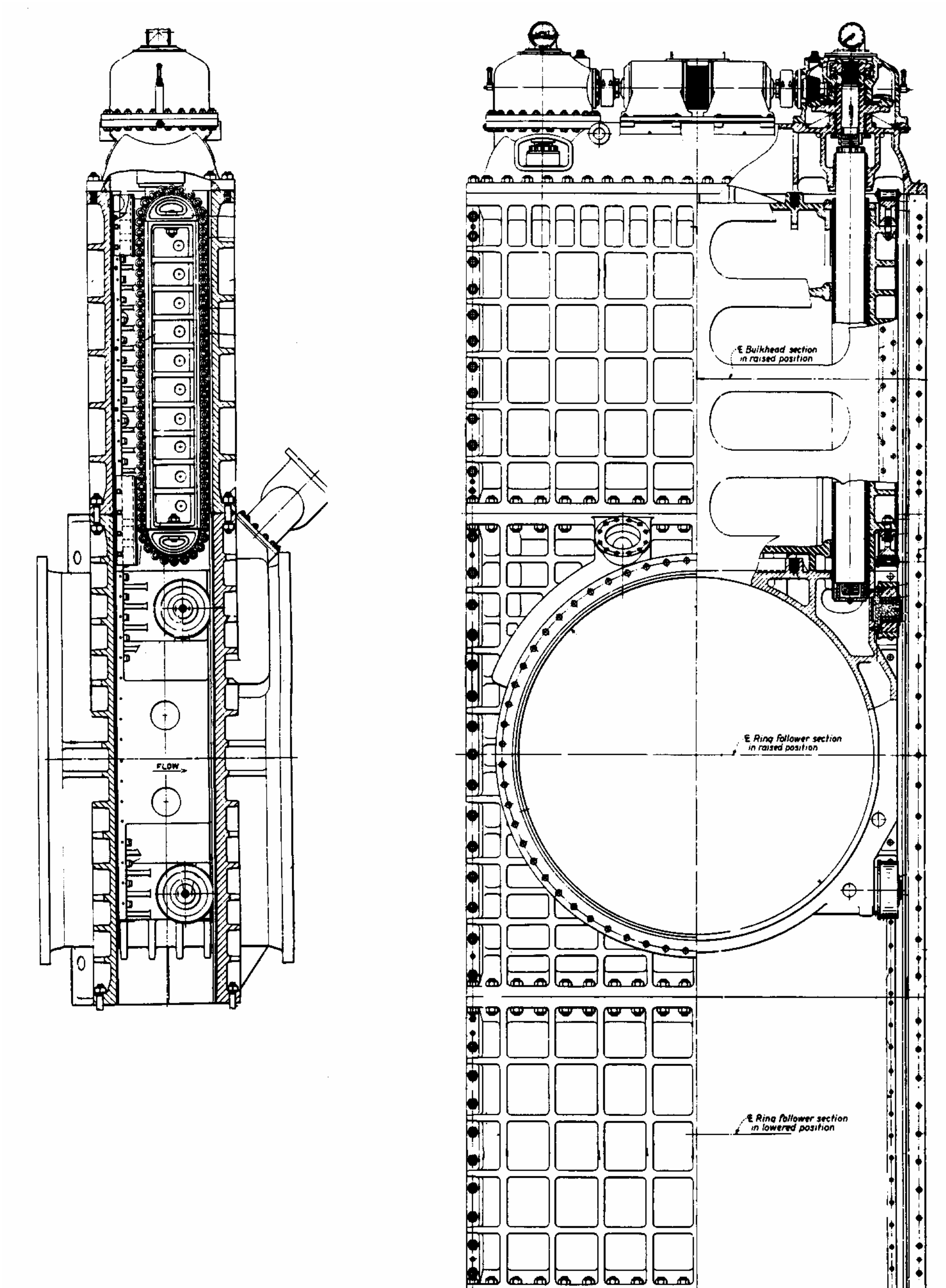


Figure 23.—Ring seal gate (mechanically operated).

7. *Bulkhead Gates and Stop Logs*. Bulkhead gates and stop logs are installed under balanced, no flow conditions, and are used to allow the unwatering of a waterway such as a outlet pipe, penstock, or turbine draft tube. In the case of outlet pipes and penstocks, they are placed as far upstream as possible to allow the complete unwatering of the waterway and provide access to gates or valves in the waterway. Bulkhead gates and modern stop logs are both constructed of structural steel with rubber seals and are virtually identical in appearance. Stop logs are differentiated from bulkhead gates in that they employ more than two sections and when all the sections are installed, extend above the reservoir surface. Bulkhead gates are made up of one or two sections and only cover the entrance to the waterway. Bulkhead gates and stop logs are usually installed with a gantry or mobile crane. Figures 24 and 25 show typical bulkhead gate and stop log installations.

Valves

Valves, like gates, can regulate flow or act as a guard valves to penstocks and outlet conduits. This section will describe the most common valve types in use in Reclamation facilities.

1. *Tube Valves*. Tube valves are used primarily as regulating valves in outlet conduits. The tube valve is essentially a needle valve with the downstream needle omitted to eliminate the cavitation damage experienced with normal needle valves. A hollow cylinder or tube is actuated by a mechanical operator to seal against a valve seat on the downstream end of the valve. Like a needle valve the fluid way converges at the outlet. A tube valve is shown in figure 26.

2. *Hollow-Jet Valves*. Hollow-jet valves are used as regulating valves and are similar in construction to a tube valve. The closure member of the hollow-jet valve is the needle which moves upstream to seal against its valve seat. The fluid way is not converging so that the discharge is in the shape of a hollow jet. The hollow-jet valve can be operated either hydraulically or mechanically. Figures 27 and 28 are examples of hollow-jet valves.

3. *Butterfly Valves*. Butterfly valves are most commonly used as guard valves on penstocks and outlet conduits. They are normally used for flow regulation only if the head differential across the leaf is small. The butterfly valve consists of a cylindrical or conical shaped body with a circular leaf, mounted on a horizontal or vertical shaft, perpendicular to the fluidway. An external actuator, usually hydraulic, rotates the leaf 90° to fully open or close the valve. A butterfly valve is shown in figure 29.

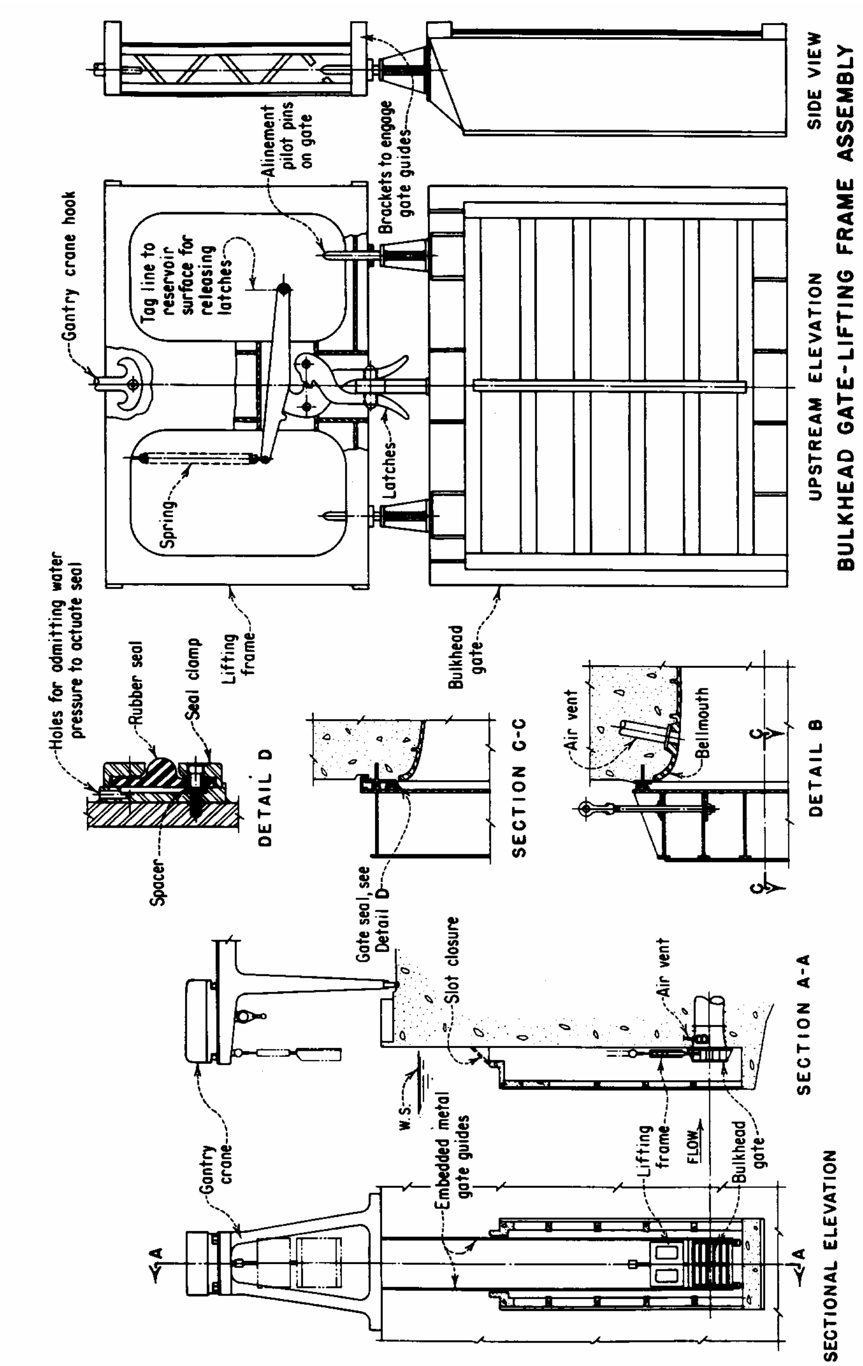


Figure 24.—Bulkhead gate.

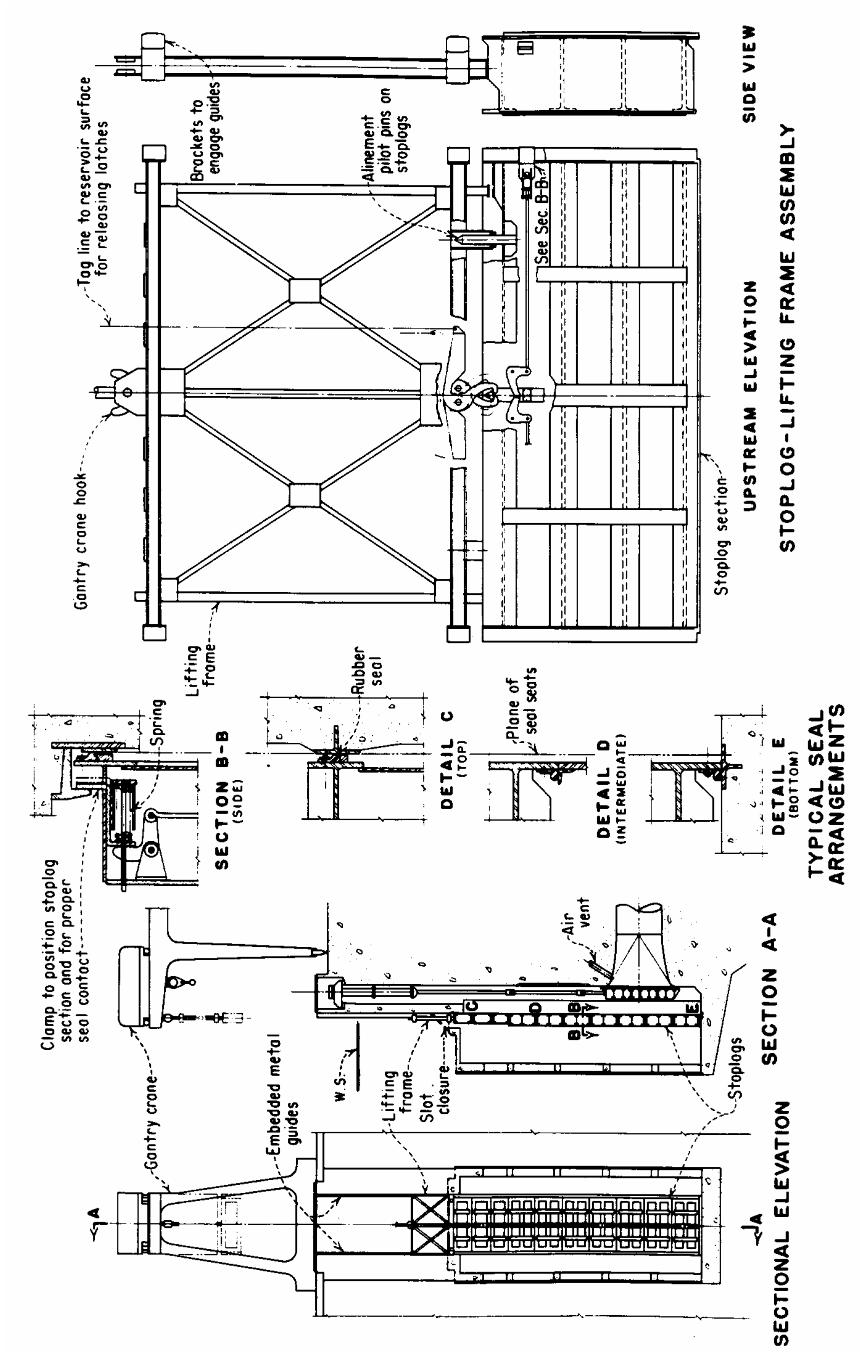


Figure 25.—Stop logs.

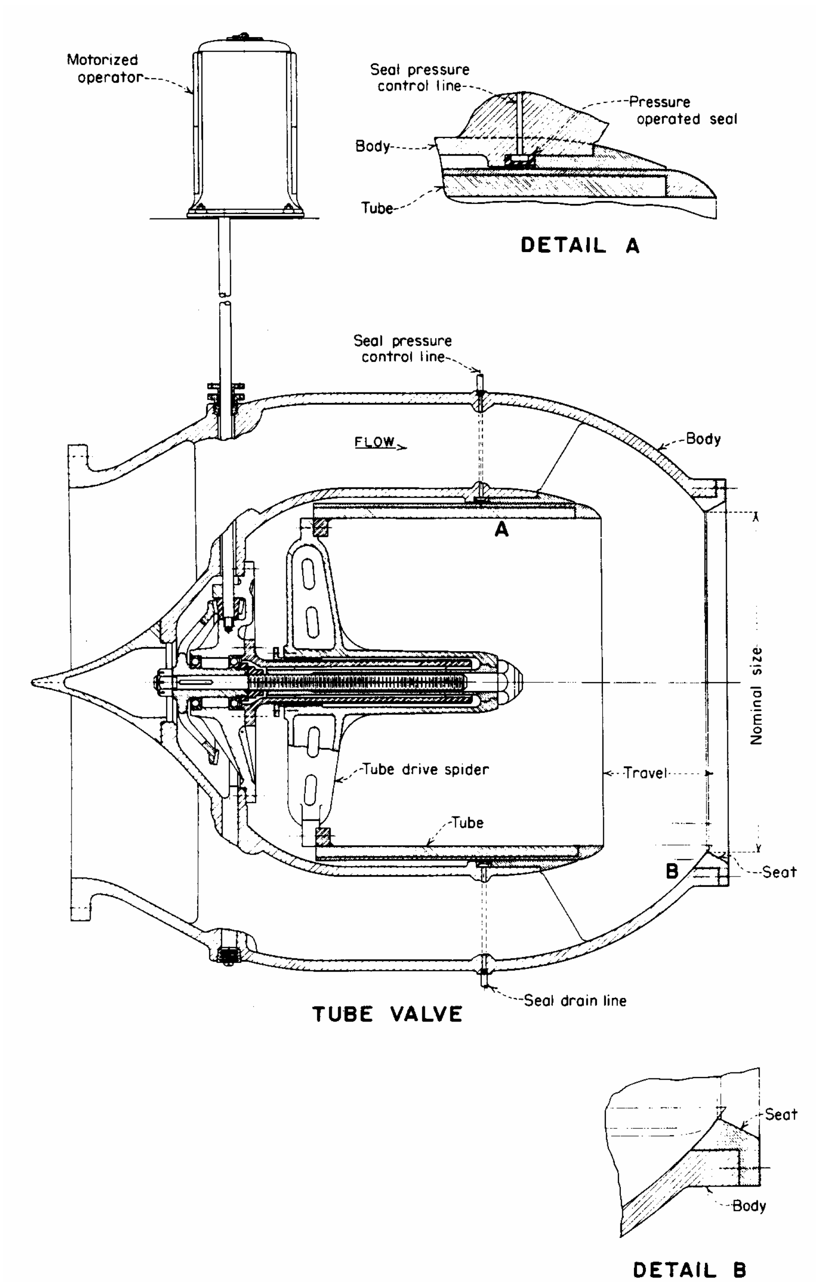


Figure 26.—Tube valve.

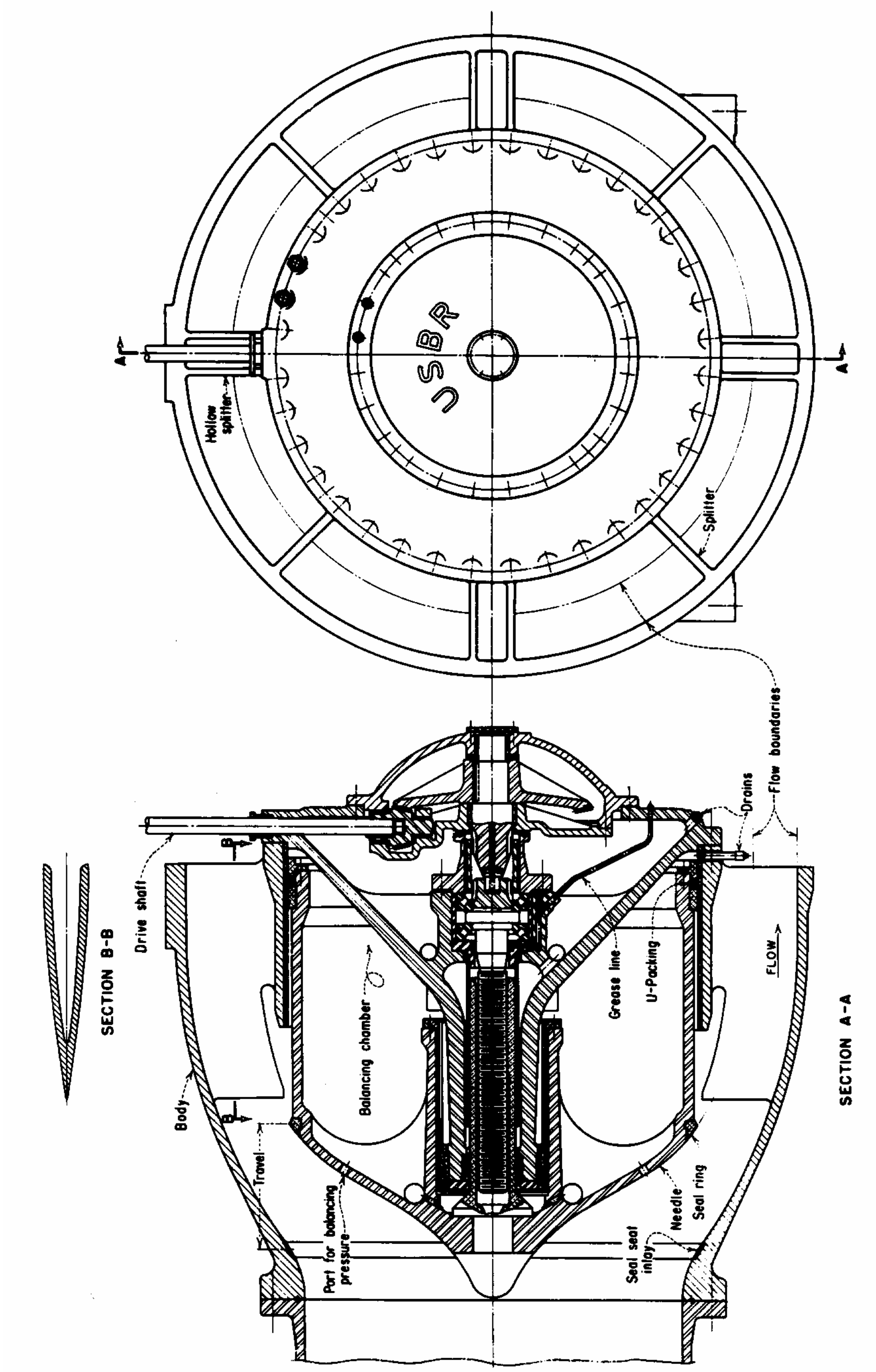


Figure 27.—Hollow jet valve (hydraulically operated).

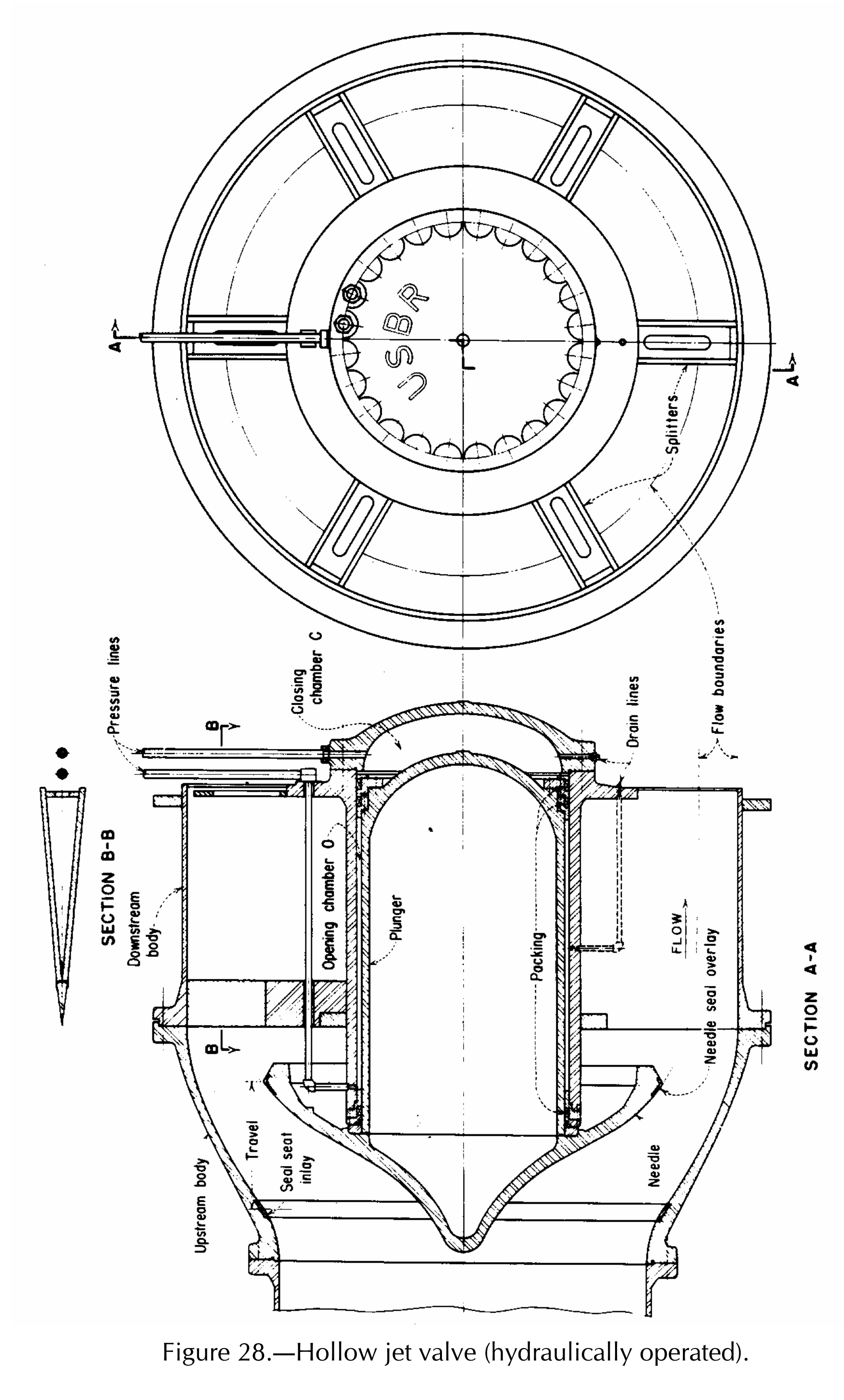


Figure 28.—Hollow jet valve (hydraulically operated).

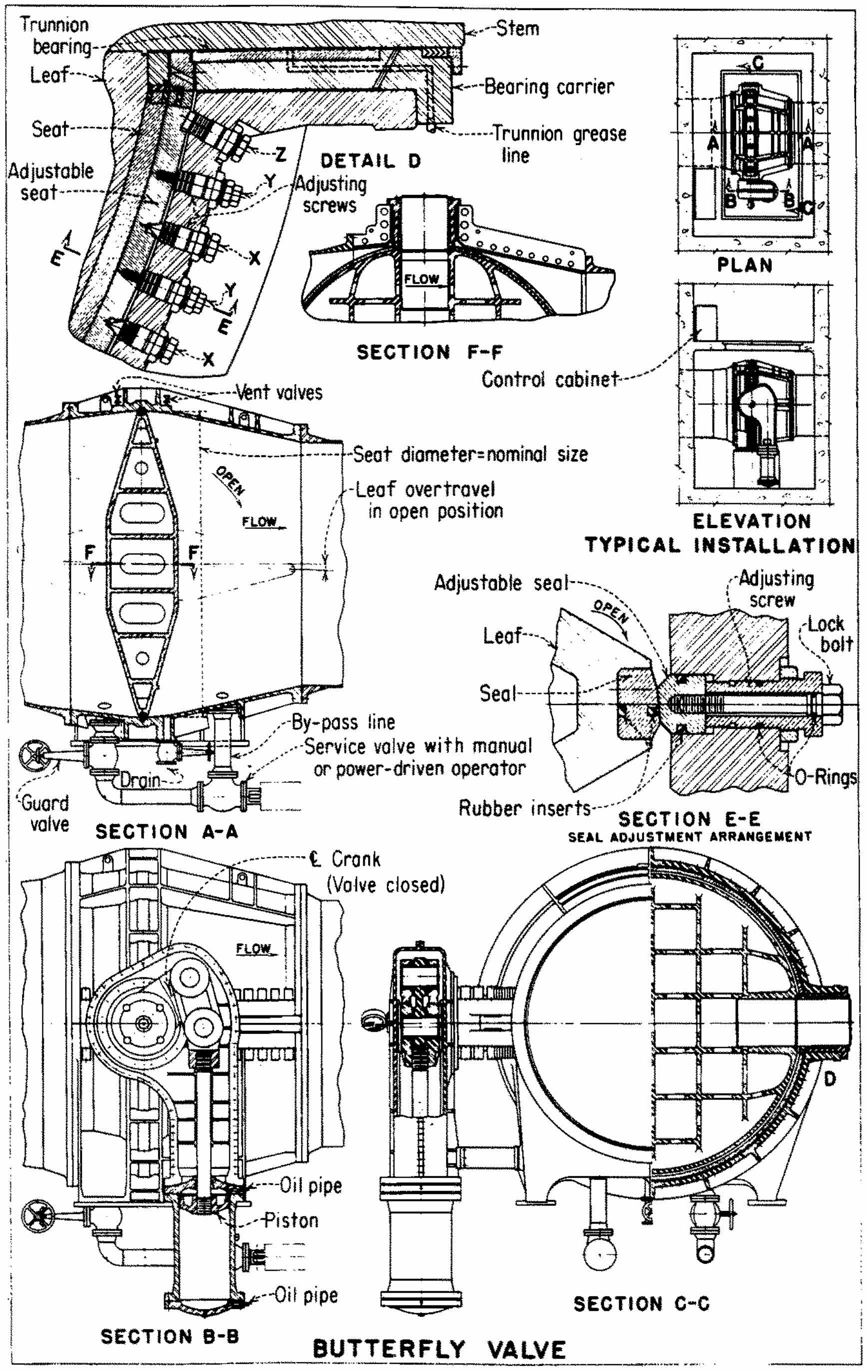


Figure 29.—Butterfly valve.

Valve and Gate Operators

1. *Threaded Stem Hoist*. Basically a threaded stem type hoist consists of a steel, Acme-threaded stem mated to a bronze stem nut. Depending on the application, the stem or the stem nut may be rigidly attached to the gate. In a rising stem type gate, the nut is rotated and the stem rises with the gate. In some cases the stem is rotated and the gate rises with the stem nut. In most cases, the hoist is electric motor driven through a system of gears. Ring-seal gates and some jet-flow gates use threaded stem type hoists with twin stems. Threaded stem hoists are shown in figures 30 and 31.

2. *Chain and Sprocket Hoist*. Chain and sprocket hoists are used to raise or lower large gates which are used infrequently. The hoists are powered by an electric motor which drives a reduction unit with two output shafts. The output shafts each drive a hoist unit with reduction gearing, drive sprocket, idler sprocket, and sprocket chain. One end of each chain is attached to the gate and the other to a counter weight. A typical chain and sprocket hoist is illustrated in figure 32.

3. *Wire Rope Hoist*. Wire rope hoists are most commonly used with radial gates. Wire rope hoists normally use two drums driven by an electric motor through reduction gearing similar to the chain and sprocket hoist. A wire rope hoist is shown in figure 33.

4. *Hydraulic Operators*. Hydraulic operators are used for a variety of gates and valves. Basically a hydraulic system consists of an oil reservoir, electric motor driven pump, directional, relief, check, flow control, and shutoff valves, filters, and the operator itself, usually a hydraulic cylinder. Many systems use two pumps in parallel to provide a backup should one fail. The operator may be driven in both directions or it may be powered open and allowed to close by gravity. Examples of hydraulic systems are shown in figures 34 and 35 and a hydraulic cylinder is shown in figure 36.

Guard Gate and Valve Closure Tests

Unbalanced tests of all guard gates and valves are required periodically to verify gate and valve dependability and determine maintenance requirements. While some gates and valves can only be tested under balanced conditions, most should be given a simulated emergency closure test under maximum flow, unbalanced conditions.

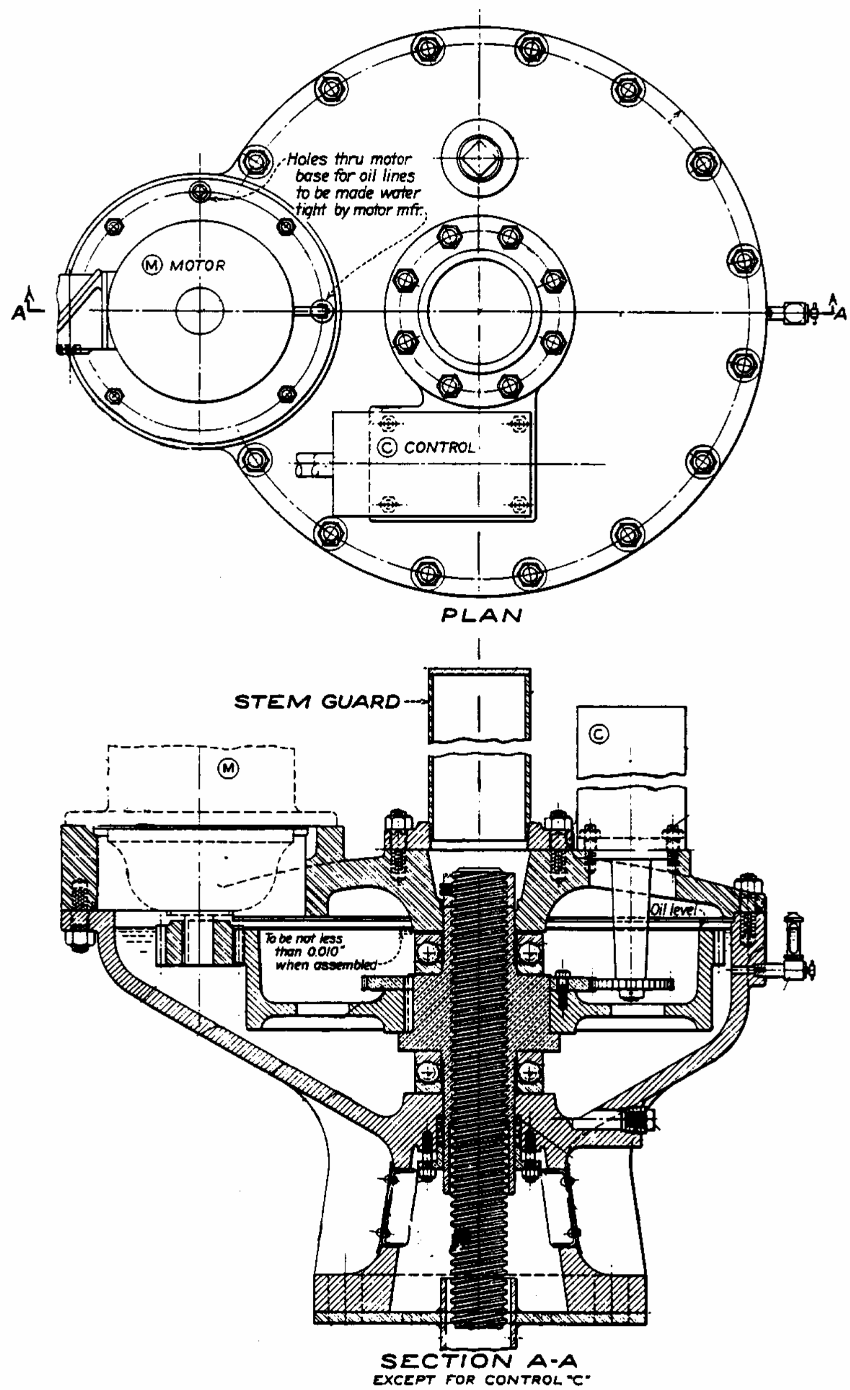


Figure 30.—Rising stem gate hoist.

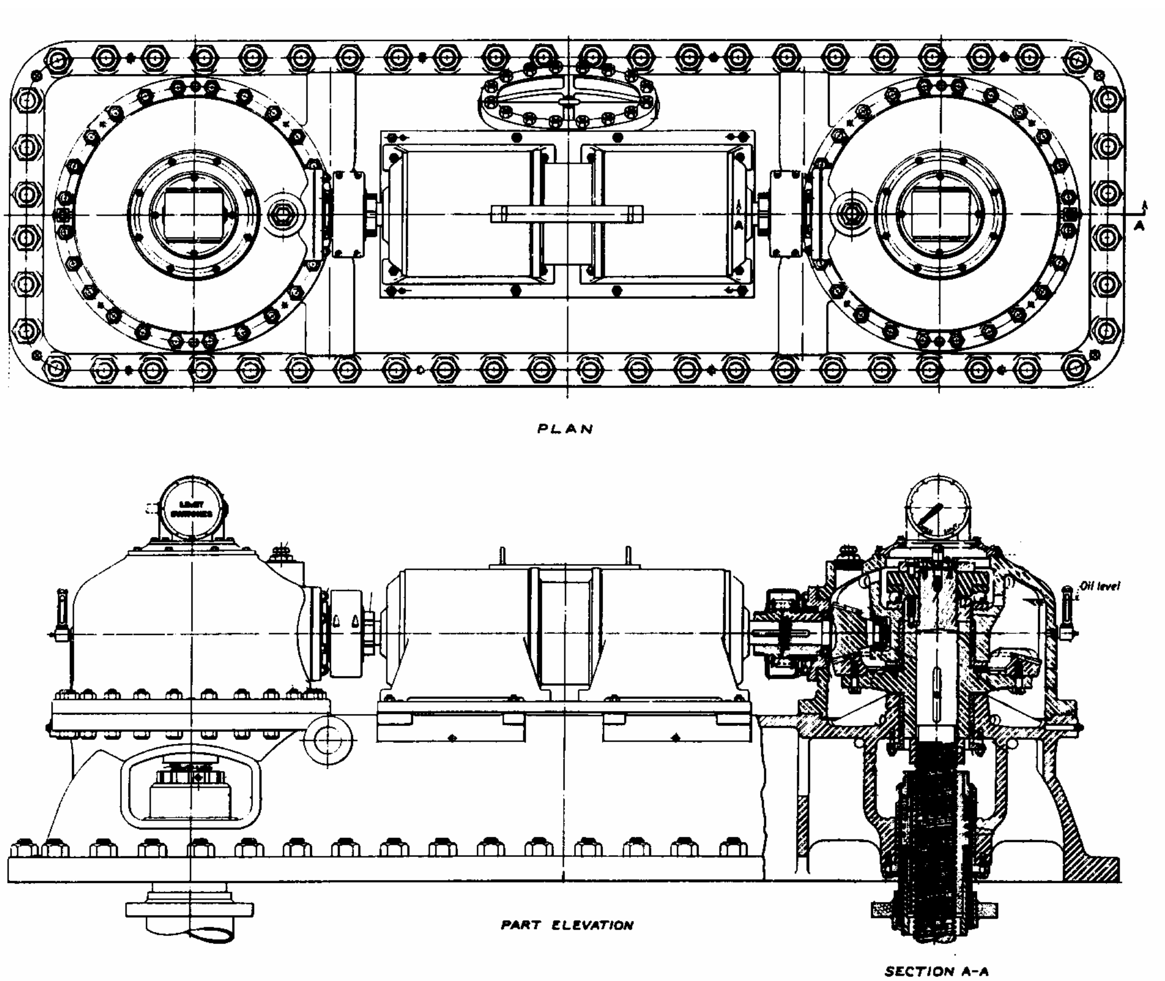


Figure 31.—Twin threaded stem gate hoist (non-rising stem).

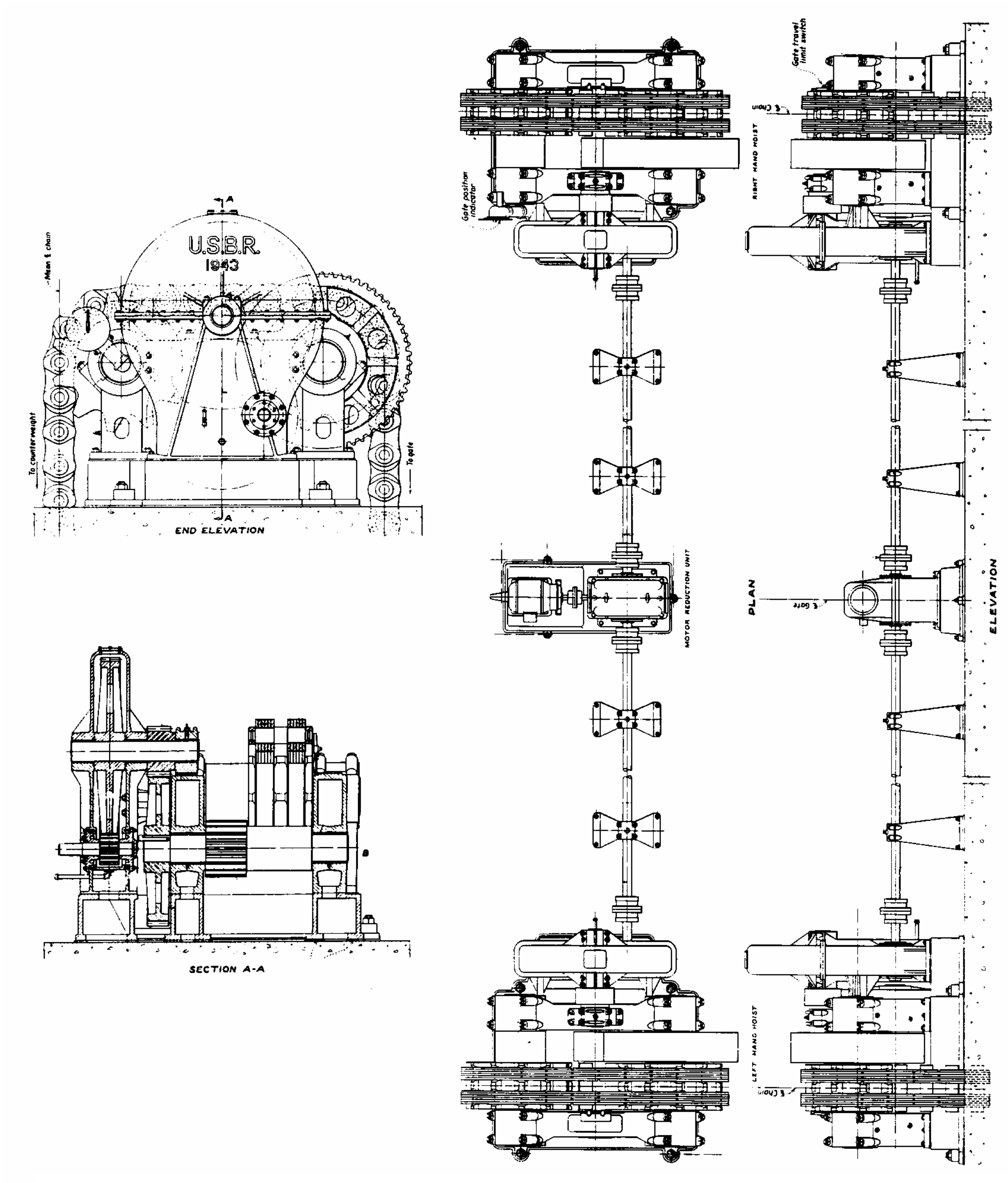


Figure 32.—Chain and sprocket hoist.

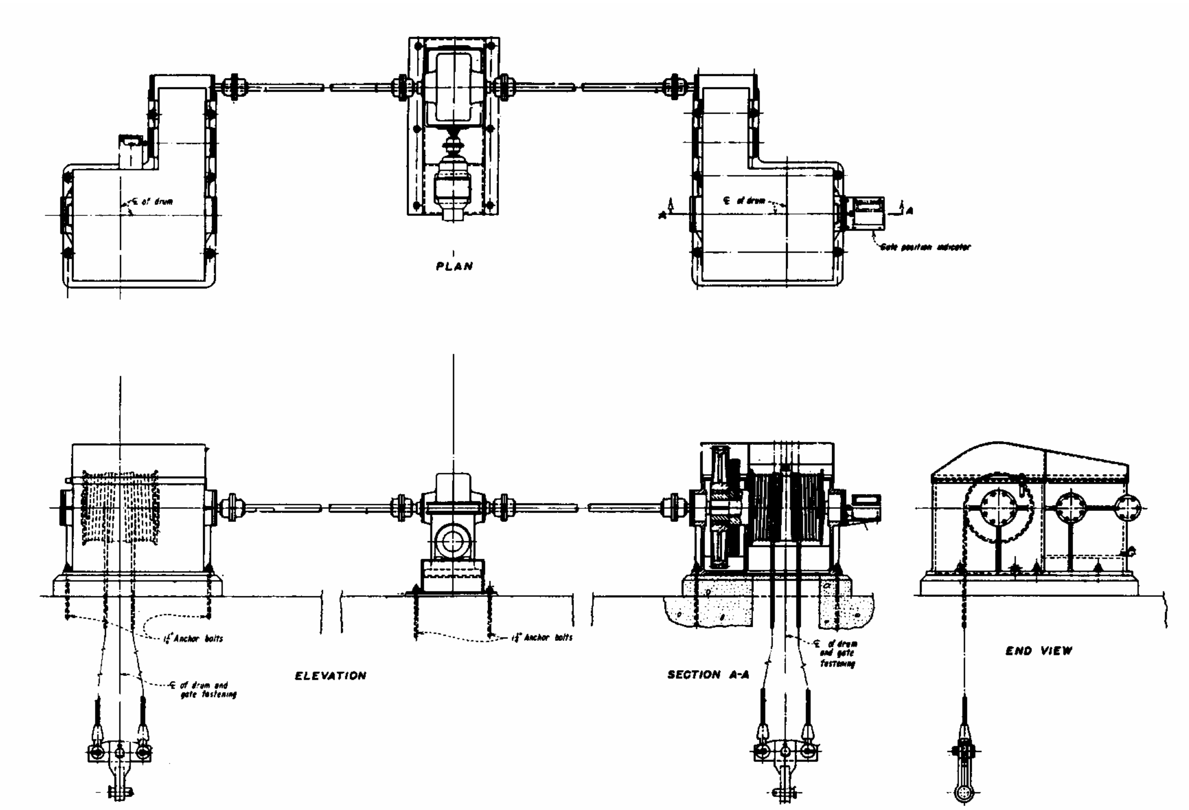


Figure 33.—Wire rope hoist.

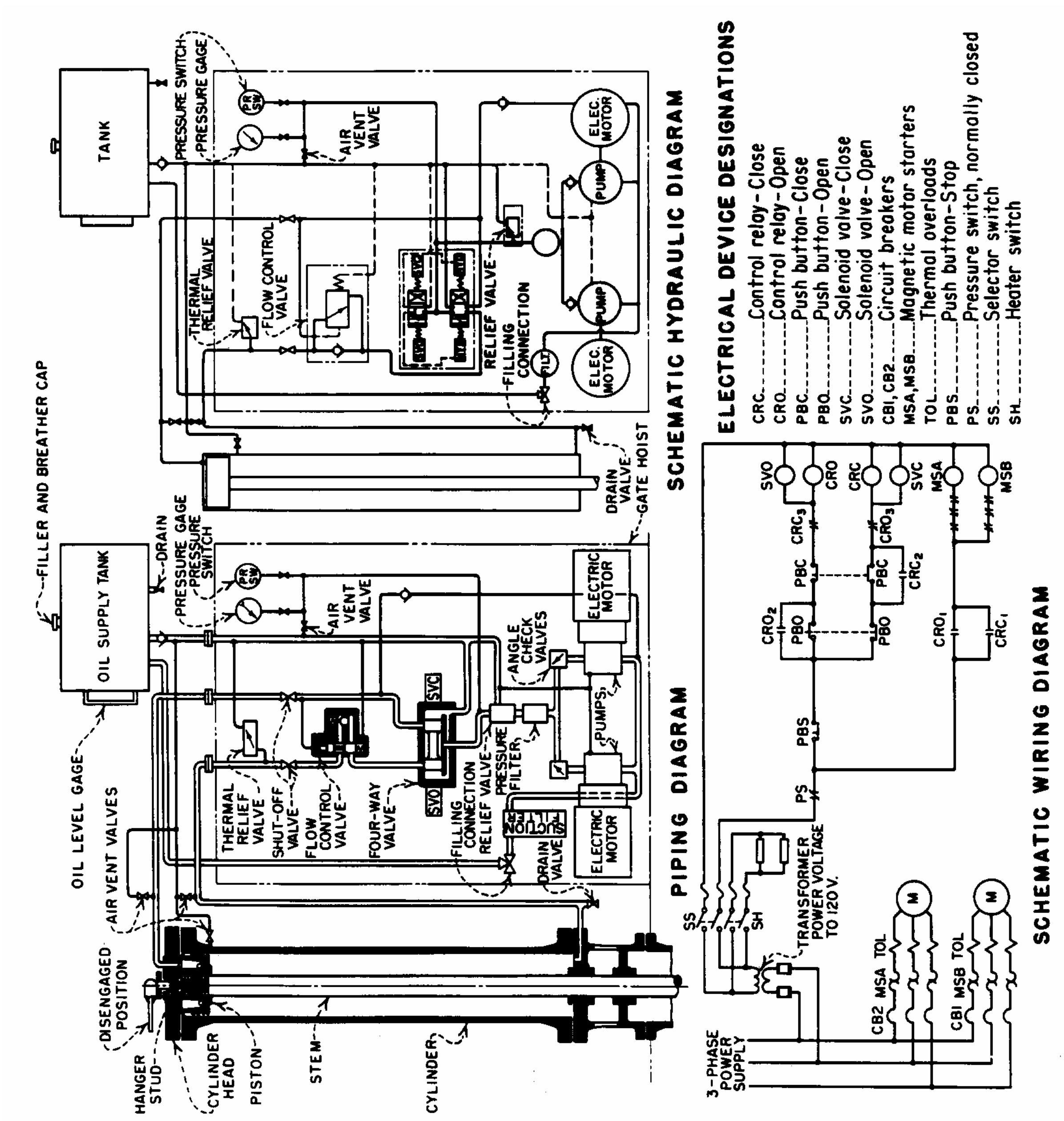


Figure 34.—Typical hydraulic hoist system.

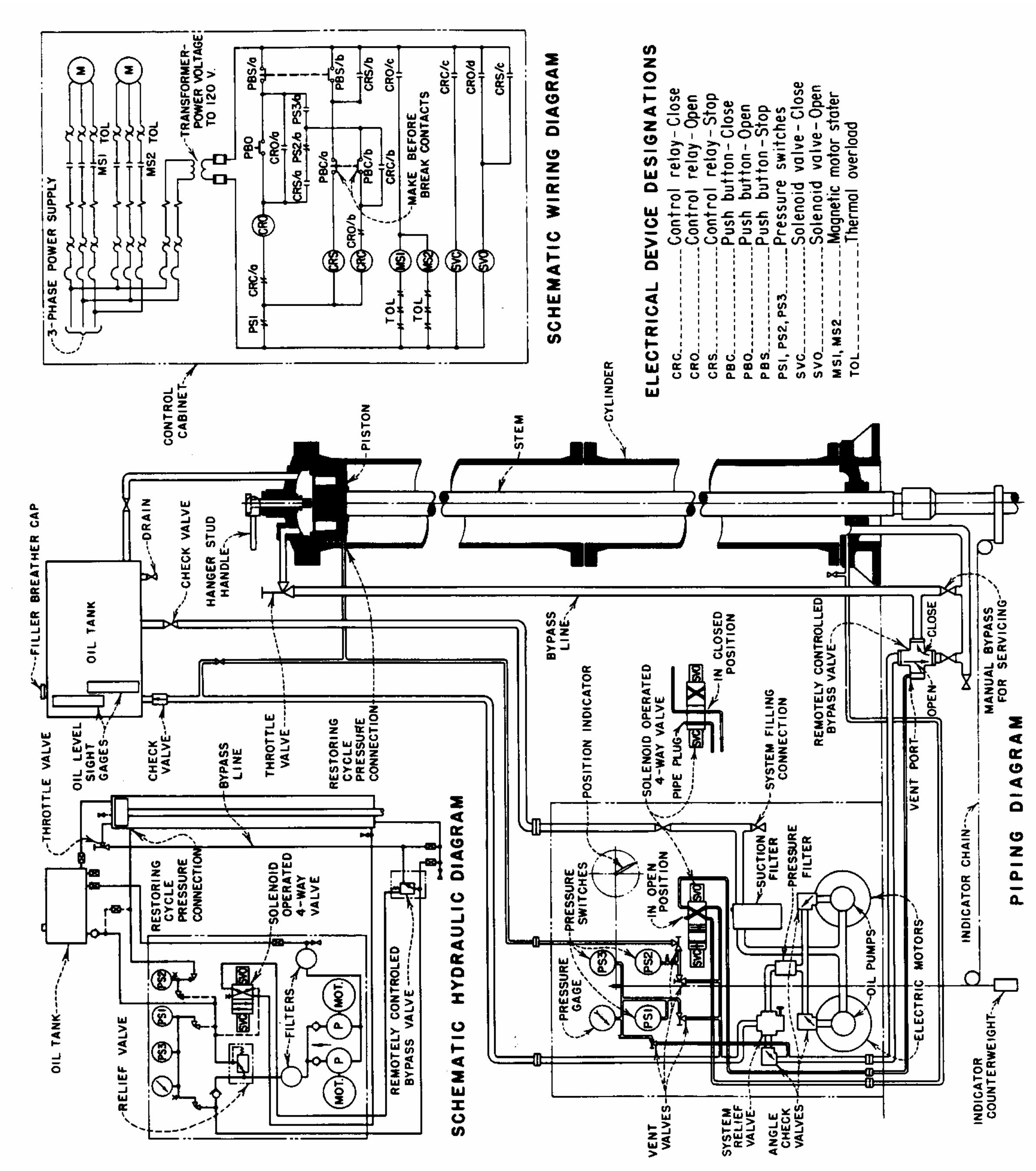


Figure 35.—Typical hydraulic hoist system (gravity closing gate).

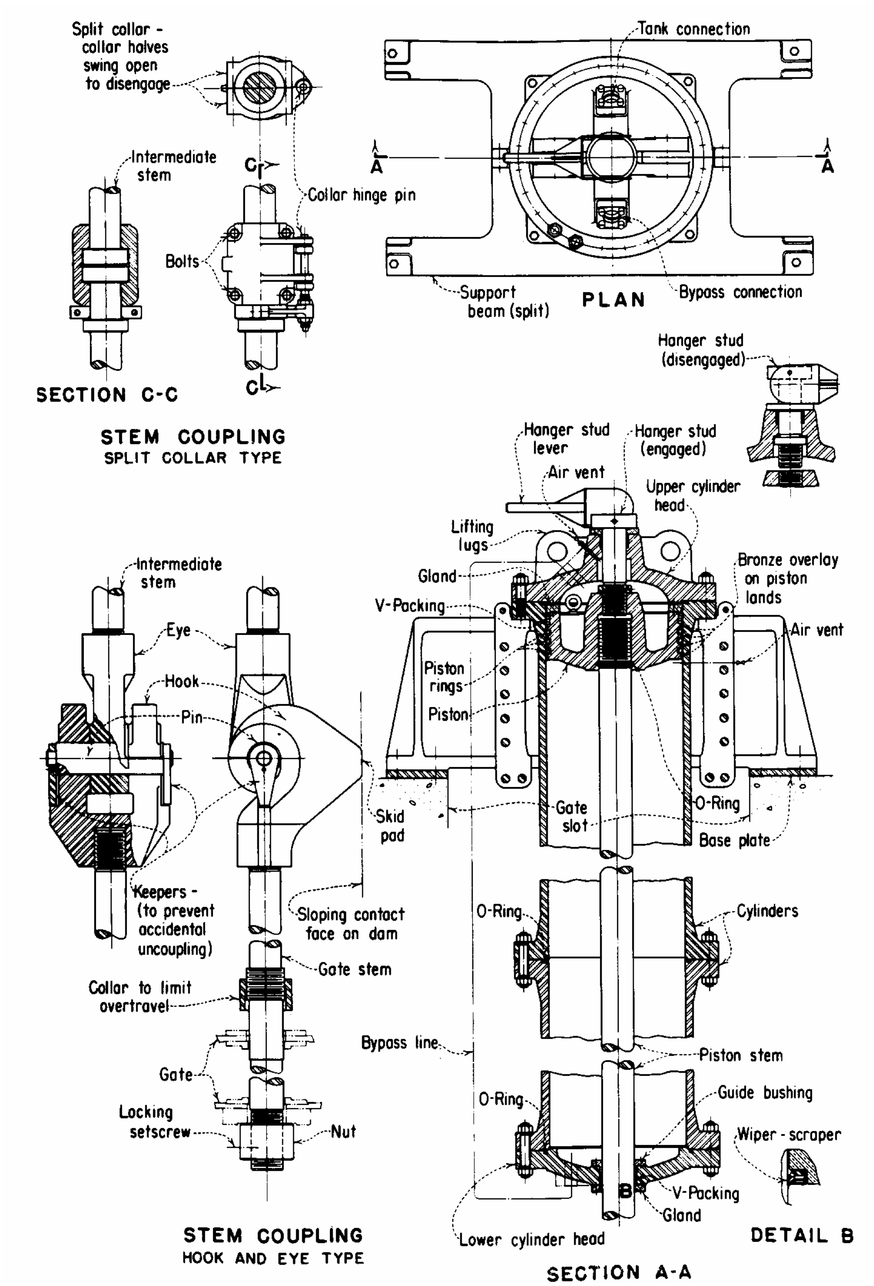


Figure 36.—Typical hydraulic hoist system (hydraulic cylinder).

The purpose of these tests is to ensure that the gates/valves will operate as intended under severe, but controlled, conditions. If the gate/valve fails to operate as intended during these tests the regulating gate/valve is still available to stop the flow. In an actual emergency situation, such as failure of regulating gate/valve or a ruptured pipe the guard gate/valve would be the only means of stopping flow.

The gates/valves requiring unbalanced tests are designed to close under full flow conditions with no damage, but it is essential that the correct test procedure be followed exactly. The test may require closing the gate/valve under unbalanced conditions or opening the gate/valve 10 percent of its total travel under unbalanced conditions. If there is any doubt about the validity of the test procedure or if a written procedure for a particular gate or valve is not available, contact the Hydroelectric Research and Technical Services Group, D-8450, immediately.

The unbalanced testing of gates or valves of outlet works is usually scheduled every 6 years to correspond to the Comprehensive Facility Review. The unbalanced testing of penstock guard gates or valves is usually scheduled to fit into the regular maintenance schedule of the powerplant. The scheduled interval for penstock gates or valves should not exceed 10 years.

Auxiliary Piping Systems

Auxiliary piping systems include domestic, fire protection, and cooling water systems, hydraulic and lubricating oil systems, and service air systems. In most cases oil systems require little maintenance other than repair of an occasional leak and routine oil testing and filtering. Due to corrosion, most water systems do require maintenance and eventually, replacement. The life of a water system will depend a great deal on the corrosiveness and mineral content of the water it carries.

Since determining the internal condition of water piping is very difficult, the first indication of a problem may be a leak or the failure of a valve or other component. Although a leak or valve failure may just be an isolated event, frequently it may be an indication of the condition of the entire system. By monitoring the condition of a piping system, maintenance and replacement can be scheduled, preventing an unscheduled outage. Partial disassembly of a piping system can provide a good indication of the condition of the entire system but it may damage the piping and valves. Nondestructive tests, such as radiographs or ultrasonic tests, can be used to determine the condition of a piping system. Radiographs will not only show pipe wall thickness but also the amount of scale buildup inside the pipe.

Service air systems may also suffer corrosion damage if excessive moisture is allowed into the system. Scale and rust particles can damage pneumatic tools and cause pneumatic cylinders to stick. If moisture in air piping is a problem, a moisture separator or an air dryer should be installed.

If a piping system fails prematurely because of a corrosion problem, it may be beneficial to replace the piping with a nonmetallic material. Pipe constructed of fiberglass and PVC (polyvinyl chloride) as well as other plastics have been used successfully in corrosive environments. Before switching to one of these materials, give careful consideration to their temperature and pressure limitations. If PVC or fiberglass is used, the installation instructions should be followed carefully. Pipe hanger requirements and joining procedures are significantly different from steel pipe. Fiberglass and plastic piping should not be used in compressed air systems.

Inspection Checklist

Penstocks and Outlet Pipes	**Inspection Interval**
1. Supports	A, NS
2. Expansion Joints	A, NS
3. Exterior	A, NS
4. Interior	A, NS

Gates and Valves

Abbreviations in parenthesis refer to the types of gates or valves a particular inspection item refers to.

FW - Fixed Wheel Gate	RG - Radial Gate	CG - Coaster Gate
JF - Jet Flow Gate	BV - Butterfly Valve	RS - Ring-Seal Gate
SG - Slide Gate	HJ - Hollow Jet Valve	RF - Ring-Follower Gate
TV - Tube Valve	BH - Bulkhead Gates or Stop Logs	

5. General Inspection (FW, CG, RS, RF, BH, JF, SG, RG, BV, HJ, TV)	A, NS
6. Seals and Seal Seats (FW, CG, RS, RF, BH, JF, SG, RG, BV, HJ, TV)	A, NS
7. Gate Frames and Tracks (FW, CG)	NS
8. Roller and Wheel Assemblies (FW, CG, RS)	A, NS
9. Pivot Pins and Hinges (RG)	A
10. Gate Frames and Bonnets (RS, RF, JF, SG)	A, NS
11. Gate Leaf, Skin Plates, and Structural Members (FW, CG, RS, RF, BH, JF, SG, RG, BV)	A, NS
12. Valve Body (BV, HJ, TV) and Valve Needle or Tube (HJ, TV)	A, NS

Gate and Valve Operators and Hoists

13.	Threaded Stem Hoist and Mechanical Operators (FW, CG, RS, RF, JF, SG, HJ, TV)	A, NS
14.	Chain Hoists (FW, CG, RG)	A, NS
15.	Wire Rope Hoists (FW, CG, BH, RG)	A, NS
16.	Hydraulic Hoists (FW, CG, RS, RF, JF, SG, BV, HJ)	A, NS

Outlet Works Guard Gate and Valve Closure Tests

17.	Balanced Closure Tests (FW, CG, RS, RF, SG, RG, BV)	A
18.	Unbalanced Tests (FW, CG, RS, RF, SG, RG, BV)	6Y

Auxiliary Piping Systems

19.	Pipe and Fittings - Exterior Surface	A
20.	Pipe and Fittings - Interior Surface	NS
21.	Gate Valves, Globe Valves, Plug Valves, etc.	A, NS
22.	Check Valves	NS
23.	Pressure Regulating and Pressure Relief Valves	A, NS

Notes:

A - Annual
NS - Not Scheduled (Extraordinary maintenance. Usually 5 year or longer intervals)
6Y - Six Year

Discharge Pipes

1. Supports

Annual. Check concrete supports for cracks, spalling or signs of movement. Check lubrication of sliding supports and clean exposed bearing surfaces. Make sure sliding surfaces are not obstructed.

2. Expansion Joints

Annual. Check leakage past packing and tighten as necessary. Sliding surfaces should be clean of rust and scale. Clean as required.

Not Scheduled. Remove old packing, thoroughly clean packing area and sliding surfaces and install new packing.

3. Exterior

Annual. Inspect surface for deterioration of paint and for corrosion paying particular attention to rivets, bolts, and welds. Prepare corroded or deteriorated surfaces by sandblasting or other acceptable means and repaint. Steel pipe where it emerges from concrete is subject to galvanic corrosion. These areas should be repaired by thoroughly cleaning and sandblasting, and painting with a zinc rich primer. Look for leakage from gasketed joints such as mandoors or at drain or fill lines.

4. Interior

Annual. Inspect surface for paint deterioration, corrosion, and cavitation damage paying particular attention to rivet heads, welded and bolted joints. Check condition of tie rods and supports at bifurcations. Prepare corroded or deteriorated surfaces by sandblasting or other acceptable means and repaint with an appropriate paint.

Not Scheduled. Sandblast and paint entire interior surface when condition of paint has reached the point that spot repairs are no longer adequate.

Gates and Valves

5. General Inspection
   (FW, CG, RS, RF, BH, JF, SG, RG, BV, HJ, TV)

Annual. Inspect exposed and accessible components for corrosion, deterioration of paint, or any other damage. Unwater penstock or water conduit and inspect downstream portion of gate or valve. Where guard gates are available, inspect upstream portion as well. If possible, operate gate through it full range of travel.

Not Scheduled. Install stop logs or bulkhead gates to inspect portions of gates or valves normally inaccessible. Remove or disassemble gate or valve as necessary to replace or renew seals or guides, to sandblast and repaint, or to repair any other damage.

6. Seals and Seal Seats
   (FW, CG, RS, RF, BH, JF, SG, RG, BV, HJ, TV)

Annual. Check for excessive leakage. Adjust seals or schedule maintenance as required. Leakage, especially through high pressure gates or valves, can cause further damage if not corrected. Where accessible, check rubber seals for cracking or other signs of deterioration and bronze seals for wear, cavitation erosion, or galling.

Not Scheduled. Unwater as required and check for damaged or missing seals, seal retainers, and bolts. Check that water actuated seals are free to move and that water lines and ports are clear. Check seal seats, wallplates, gate sills, and adjacent concrete for wear or other damage. Look for signs of misalignment such as uneven wear on the seals or seal seats.

7. Gate Frames and Tracks
   (FW, CG)

Not Scheduled. A thorough inspection of the tracks and gate frames in most cases will require the installation of bulkhead gates or stop logs or the use of divers or a remote controlled underwater vehicle. The tracks for the rollers or wheels should be checked for deformation, corrosion, and missing clamps or bolts. The gate frame should be checked for deformation, corrosion and cavitation damage and for any missing bolts.

8. Roller and Wheel Assemblies
   (FW, CG, RS)

Annual. Lubricate wheels and rollers of gates with manual grease fittings.

Not Scheduled. Removal or disassembly of the gate is usually required for inspection of roller and wheel assemblies. Roller assemblies should be checked for any damaged rollers, pins or links. Rollers and wheels should be checked for free movement and for flat spots or other indications that the rollers or wheels have been sliding and not rolling. Antifriction bearings (roller or ball bearings) should be checked for free rotation, adequate lubrication, corrosion, and replaced as necessary. Bronze bushings should be checked for scoring or adequate lubrication. Bearing seals should be replaced if there is any sign of damage. The bearing journal should be checked for scoring, corrosion or any other damage. The bearing journal of self lubricated bushings can sometimes corrode due to a electrolytic reaction from the graphite in the bushing. If this is noted the bushings should be replaced with a non-graphite, self lubricated bushing or a plain bronze bushing with some type of lubrication system.

9. Pivot Pins and Hinges
   (RG)

Annual. Check general condition of pivot pin or hinge, looking for bent or damaged parts. Check that pivot pins are properly lubricated. Inspect concrete adjacent to anchors or pivot pins for cracking or spalling.

10. Gate Frames and Bonnet
    (RS, RF, JF, SG)

Annual. If accessible, inspect interior of fluidway, checking for any cavitation erosion, corrosion, or other damage. Check bonnet cover for cracks or leaky gaskets. Check for excessive leakage past gate stem and position indicator rod packing and tighten as required. If equipped with a lower bonnet drain, flush silt from bottom of bonnet.

Not Scheduled. Disassemble gate and inspect for any cracks, corrosion, cavitation erosion, or any other damage. Sandblast or clean by acceptable method, and paint interior of bonnet as necessary.

11. Gate Leaf, Skin Plates, and Structural Members
    (FW, CG, RS, RF, BH, JF, SG, RG, BV)

Annual. Accessible portions should be checked for corrosion, cavitation erosion, missing or damaged bolts or rivets, or any other damage. Check flexible drain hoses of drum gates to ensure they are clear and unplugged.

Not Scheduled. Disassemble gate or install bulkhead gates and unwater to allow inspection of entire gate or gate leaf. Check bottom of the gate leaf or gate for cavitation erosion. Sandblast or clean by acceptable method, and paint as necessary. Check structural members for cracked welds, missing or damaged bolts or rivets, or any other damage. On drum gates and some radial gates, check interior of gate for leaks, plugged drain holes and general condition. Drum gate flexible drain hoses should be cleaned with a rotary drain cleaner.

12. Valve Body (BV, HJ, TV) and Valve Needle or Tube (HJ, TV)

Annual. Exterior of valve should be checked for leakage, cracks, and corrosion. If accessible, interior of valve should be checked for corrosion, cavitation erosion, scale buildup that may interfere with valve movement or sealing, and any other damage. Check lubrication to bearings and oil level of gear boxes.

Not Scheduled. Unwater water conduit or penstock or disassemble valve to allow inspection of all valve components. Check for parts damaged by cavitation erosion or corrosion. Check water and oil seals and replace as necessary. Polished surfaces of hydraulically operated hollow jet valves should checked for any damage and built up by welding or other process, remachined, and repolished if necessary. Check bearings, and bronze seal rings for wear or other damage and replace if necessary.

Gate and Valve Operators and Hoists

13. Threaded Stem Hoist and Mechanical Operators
    (FW, CG, RS, RF, JF, SG, CY, HJ, TV)

Annual. Inspect gear cases for leaks or other damage. Check motor coupling for misalignment. Check oil in gear boxes for water contamination and for proper level. Check grease coated gears, stems, and stem nuts for dirt or dust contamination of grease. Check gears, stem, and stem nut for wear, galling, or other damage. Grease bearings or other components equipped with grease fittings being careful not to overgrease and damage grease seals. During operational test, check for unusual or excessive vibration or noise.

Not Scheduled. Drain gear boxes and refill with new oil. Grease coated gears and stems should be cleaned and recoated with new grease. Disassemble as required to check condition of gears, bearings, or other components normally inaccessible.

14. Chain Hoists
    (FW, CG, RG)

Annual. Inspect chain for corrosion, and deformed chain links or pins. Check sprocket for damaged teeth. Apply appropriate lubricant to chain. Check oil in gear boxes for water contamination and for proper level. Check condition of grease for dirt or dust contamination on grease coated gears. Grease sheave, drum, and gear shaft bearings equipped with grease fittings being careful not to overgrease and damage grease seals. Check gears for uneven wear, galling, or signs of misalignment. Check brake shoes and brake drums for signs of overheating or other damage.

Not Scheduled. Drain gear boxes and refill with new oil. Grease coated gears should be cleaned and recoated with new grease. Disassemble as required to check condition of gears, bearings, or other components normally inaccessible.

15. Wire Rope Hoists
    (FW, CG, BH, RG)

Annual. Inspect wire rope for broken wires, worn or abraded wires, corrosion, and crushed or flattened strands. See Section 5, Cranes, Hoists, and Rigging Equipment for replacement requirements. Inspect rope drum and sheaves for wear and spooling characteristics of the drum. If possible apply lubricant to entire length of wire rope. Check oil in gear boxes for water contamination and for proper level. Grease sheave, drum, and gear shaft bearings equipped with grease fittings. Check gears for uneven wear, galling, or signs of misalignment. Check condition of brake shoes and brake drums for signs of overheating or other damage.

Not Scheduled. Drain gear boxes and refill with new oil. Grease coated gears should be cleaned and recoated with new grease.

16. Hydraulic Hoists
(FW, CG, RS, RF, JF, SG, CY, BV, HJ)

Annual. Check entire hydraulic system for leaks, including piping, valves, and packing. Drain accumulations of water and sediment from oil reservoir and lower end of hydraulic cylinders. Prior to scheduled maintenance, take oil sample after operating system for sufficient time to allow the oil and any to contaminants to mix. Oil sample should be checked for water content, viscosity, acidity, and solid contaminants. Based on results of oil tests, drain system, filter oil, and clean oil reservoir with lint free rags. Add oil to system if necessary to bring oil to proper level, making sure oil added is exactly the same type and viscosity as the oil in the system. Clean or replace oil filters. Calibrate pressure gauges and pressure switches. Check setting and operation of pressure relief valves. Operate gate or valve through a complete open - close cycle under balanced conditions, checking the opening or closing times, and noting any unusual or excessive noise or vibration. If there is a significant increase in either the opening or closing time, determine the reason for increase. Check surface condition of piston stem for rusting, scoring, or other condition that could impair operation or cause leakage. Check position indicators to ensure wire rope and sheaves or chains and sprockets move freely.

Not Scheduled. Remove cylinder head and inspect cylinder wall looking for signs of corrosion pitting or scoring. Check condition of stems and stem couplings, applying a coating of water proof grease to couplings normally submerged or exposed to moisture.

Guard Gate and Valve Closure Tests

17. Balanced Closure Tests
(FW, CG, RS, RF, SG, RG, BV)

Annual. Perform gate or valve closure test under balanced, no flow conditions following test procedure for particular gate or valve being tested. Test procedure should be for the specific gate or valve being tested and not a similar one. Contact the Hydroelectric Research and Technical Services Group, D-8450, if a procedure is not available or if there is any uncertainty about the procedure that is available.

18. Unbalanced Tests
(FW, CG, RS, RF, SG, RG)

Six Year. Perform gate or valve test following test procedure for the gate or valve being tested. Use caution when conducting this type of test. Test procedure should be for the specific gate or valve being tested and not a similar one. Contact the Hydroelectric Research and Technical Services Group, D-8450, if a procedure is not available or if there is any uncertainty about the procedure that is available.

Auxiliary Piping Systems

19. Pipe and Fittings - Exterior Surface

Annual. Visually inspect all threaded, welded, and flanged fittings checking for any leaks or corrosion. Replace or tighten fittings or pipe as required. Check pipe hangers and supports to make sure they are carrying their share of the load and that anchors are tight. Examine paint for cracking, chalking, or other deterioration. Remove corrosion by wire brushing, sandblasting, or other acceptable method and repaint.

20. Pipe and Fittings - Interior Surface

Not Scheduled. Partially disassemble piping or utilize a nondestructive test method to determine condition of interior surfaces. Measure pipe wall thickness and compare to original thickness.

21. Gate Valves, Globe Valves, Plug Valves, etc.

Annual. Check valve stem packing for leaks and tighten packing gland as required. Operate valve through its full range of movement several times. With valve closed under pressure, listen for leakage past valve and correct as required. Lubricate valve stems, plug valve seats, and other components as required with appropriate lubricant.

Not Scheduled. Disassemble valve and inspect condition of valve body, stem, and sealing surfaces and repair as required. Completely remove old valve stem packing and install new packing.

22. Check Valves

Not Scheduled. Check for leakage past valve while under full operating pressure. Disassemble and replace or regrind valve seats as required.

23. Pressure Regulating and Pressure Relief Valves

Annual. Check operation and setting of pressure regulating and pressure relief valves.

Not Scheduled. Disassemble valves and remove any scale buildup that interferes with the operation of the valve. Reassemble and check operation and settings of valves.

Section 4 – Air Compressors

General

Air compressors are a common piece of equipment found in most pumping plants and maintenance shops. There are a number of different types of compressors available, but the two most common types are the reciprocating and the rotary screw compressors.

Reciprocating Air Compressors

Reciprocating compressors have been available for many years in a variety of sizes and configurations and make up the majority of air compressors found in plants and maintenance shops. Reciprocating compressors are efficient and relatively simple to operate and maintain. Most reciprocating compressors can be completely overhauled with a minimum of tools and parts.

A reciprocating compressor compresses air in a cylinder, against a cylinder head, by a reciprocating piston. While all reciprocating compressors operate in basically the same manner, there are many variations in their construction. For example, a reciprocating compressor can be single or multi-cylinder, single or double acting, single or multistage, air or water cooled, and can have a horizontal, vertical, or angled cylinder arrangement. Other variations are possible depending on the application.

Single acting compressors utilize automotive type pistons, connected directly to the crankshaft by connecting rods, and compress air on one side of the piston only. Double-acting compressors have a double-acting piston, compressing air on both sides, driven by a piston rod which extends through a packing box. The piston rod is connected to a crosshead which is connected to the crankshaft by a connecting rod. Both single and double-acting compressors are available as single or multistage. Multistage compressors develop their final pressure in steps, by connecting the discharge of the first stage, through an intercooler, to the intake of the second stage. The intercooler removes the heat of compression of the first stage.

Rotary Screw Air Compressors

A rotary screw air compressor utilizes two meshing helical shaped rotors to compress the air. As the rotors turn, air is compressed by the advancing helix. The rotor may either be oil flooded or dry. Dry rotor compressors require the use of timing gears to maintain the proper clearance between the rotors. The oil in the oil flooded type compressor, lubricates and seals the rotors, and acts as a coolant to remove the heat of compression. The oil flooded type does not require timing gears as the oil film prevents contact of the rotors, but an air-oil separator is necessary to remove the oil suspended in the compressed air as it leaves the compressor.

Rotary screw compressors have fewer moving parts than reciprocating compressors, and provide a smooth, nearly pulse free air supply. Rotary screw compressors are usually supplied in a "package" requiring only connection to electrical power and to air system. Since there is little vibration they do not require the massive foundation a comparable reciprocating compressor would need. They are also very popular in trailer mounted, internal combustion engine driven portable compressors.

The construction of a rotary screw compressor is such that little maintenance can be accomplished in the field by plant personnel. The lubricating oil filtration system must be maintained regularly as the tight tolerances make clean oil an necessity. The air end (i.e. the rotors and their housing) of the rotary screw compressor has no sacrificial components such as the piston rings of the reciprocating type. Since the air end is constructed with such high precision and tight tolerances, in most cases, the entire air end must be replaced as a unit.

Accessories

Inlet Filters

Inlet filters prevent dust and other particulates from entering the compressor. All compressors, especially rotary screw compressors, are susceptible to wear or other damage from dirt particles. A clogged filter can cause a significant loss in compressor efficiency. To prevent damage and loss of efficiency, regular cleaning of filter elements or replacement of throw away elements is required.

Aftercoolers

Aftercoolers are installed on the discharge line to lower the compressed air's discharge temperature and to condense water from the air. Aftercoolers are usually installed with a separator and trap to handle the condensate.

Separators

Separators are used to remove entrained liquids from the compressed air. This is usually accomplished by changing the direction of movement of the liquid particles so that they are removed from the air either centrifugally or through impingement against a separator element. The most common types of separators are impingement, centrifugal, and cyclone types. Separators should be equipped with a trap or drain.

Traps

Traps collect liquid that has been removed from the air by separation or condensation and release it, either automatically or through a manual valve. Traps are installed with separators, filters, aftercoolers, receivers, and dryers. They should also be installed at the low points in distribution systems, especially on lines passing through a cold area. An in-line strainer is usually installed directly upstream of a trap to prevent sediment or other contamination from clogging the trap.

Dryers

Dryers are used when dryer air is required than can be provided by an aftercooler system. The most common are refrigerated dryers which condense the moisture from the air by reducing the air temperature. Deliquescent type dryers absorb moisture into a deliquescent material which must be periodically replaced. Desiccant dryers use porous moisture adsorbing materials that hold the moisture in the pores until they are regenerated by electric heat, air purging, or both.

Pressure Regulating Valves

Pressure regulating valves are used to supply small volumes of air to various pneumatic equipment at a pressure lower than the system pressure.

Pressure Relief Valves

As a safety precaution, a pressure relief valve is required in every compressed air system ahead of the first point that could conceivably act as an air flow restriction. This includes shutoff valves, check valves, and even in-line filters as they could clog. Receiver tanks should also have a relief valve installed on the tank with no restrictions between the tank and the valve. If there are no restrictions in the discharge line between the compressor and the receiver tank, the relief valve mounted on the receiver tank is sufficient to protect the system. The relief valve should be set to open at no higher than the maximum allowable working pressure of the receiver tank and periodically checked for proper operation. It should be noted that pressure regulators are not acceptable for protection against excessive system pressure as they do not vent air, but regulate pressure by restricting air flow.

Receiver Tanks

Receivers perform several functions in a compressed air system. The receiver dampens pulsations from reciprocating compressors, acts as a reservoir to take care of temporary demands in excess of compressor capacity, and prevents frequent loading and unloading of the compressor. The receiver may also act as a separator. Since the air is cooled and its velocity reduced, some of the moisture still in the air will condense and fall to the bottom of the receiver where it can be removed by a trap or manual valve.

Inspection Checklist

	General	Inspection Interval
1.	Foundation	A
2.	Frame	A
3.	Compressor Drive	W, A
4.	Cooling System	W, A
5.	Air Intake and Filter	W, M
6.	Piping and Valves	A
7.	Aftercoolers	NS
8.	Separators	NS
9.	Traps	W, A
10.	Dryers	A
11.	Pressure Regulating Valves	A
12.	Pressure Relief Valves	A
13.	Receiver Tanks	NS, W, A
14.	Gauges	W, A
15.	Pressure and Temperature Switches	M, A
16.	Unloader	M, A
17.	Bearings	NS, A
	Reciprocating Compressors	
18.	Lubrication	W, A
19.	Packing Gland	NS, A
20.	Crosshead	W, A
21.	Cylinder	NS
22.	Piston	NS
23.	Connecting Rod	NS
24.	Intake and Discharge Valves	NS

Rotary Screw Compressors

25.	Air End	NS
26.	Oil Reservoir and Separator	W, A
27.	Oil Filter	A

Notes:

A - Annual
M - Monthly
W - Weekly
NS - Not Scheduled (Extraordinary maintenance. Usually 5 year or longer intervals)

General

1. Foundation

Annual. Check foundation with level for settling. Examine concrete for cracks and spalling.

2. Frame

Annual. Examine metal for corrosion and cracks. Clean and paint as required.

3. Compressor Drive

Weekly. Check v-belts for slippage, chains for looseness, and shaft couplings for excessive runout or vibration. Dress or tighten v-belts as required. Tighten and lubricate chains as required. Tighten coupling bolts and lubricate coupling as required.

Annual. Check v-belts for signs of wear or aging and replace as needed. Check chain and sprocket for wear or distortion and replace as needed. Check shaft runout of direct coupled machines with dial indicator and check shaft alignment if runout is excessive.

4. Cooling System

Weekly. Check flow of water or coolant through compressor and aftercooler. Check for accumulation of dirt and lint on cooling fins of air cooled compressors.

Annual. Flush and clean all water lines and repair any leaks. Check for corrosion and scale buildup and clean as required. Thoroughly clean cooling fins of air cooled compressors.

5. Air Intake

Weekly. Check condition of filter and intake for obstructions.

Monthly. Remove intake filter and clean or replace. Filter may require cleaning more or less frequently depending on location of the intake.

6. Piping and Valves

Annual. Clean and repaint piping as required. Repack and reseat valves as required.

7. Aftercoolers

Not Scheduled. Check for leaks and for adequate water flow. Disassemble and check for internal corrosion and scale buildup. Clean as required.

8. Separators

Not Scheduled. Check for leaks. Disassemble and check for corrosion and scale buildup. Clean as required.

9. Traps

Weekly. Operate manual drains.

Annual. Check automatic traps for leaks and proper operation. Clean strainer and check for corrosion or scale buildup.

10. Dryers

Annual. Replace dryer elements as required on deliquescent dryers. Check operation of refrigerated and desiccant types.

11. Pressure Regulating Valves

Annual. Check operation and verify that regulating valves are providing correct pressure downstream from valve.

12. Pressure Relief Valves

Annual. Verify operation and setting.

13. Receiver Tanks

Weekly. Open the receiver drain valve and blow down until water is removed from tank. Check for leaks.

Annual. If equipped with inspection door, open and clean all rust and sludge from interior of tank. Inspect interior of tank for corrosion or other damage and repaint as required. Make thorough inspection of exterior of tank paying close attention to joints, seams, and fittings.

Not Scheduled. All receiver tanks are to be inspected in accordance with the National Board Inspection Code. The inspection interval shall not exceed 5 years. The inspection should be performed by a qualified inspector as outlined in the National Board Inspection Code or in accordance with Reclamation's FIST Volume 2-9, "Inspection of Unfired Pressure Vessels".

14. Gauges

Weekly. Check operation of gauge. Look for loose or stuck pointer. If there is any doubt about the accuracy of gauge remove and check calibration or replace with new gauge.

Annual. Remove gauge and calibrate. Make any necessary repairs or replace with new gauge if gauge is not repairable.

15. Pressure and Temperature Switches

Monthly. See that pressure switches cut in and out at proper pressures. Check setting of temperature switches.

Annual. Check and clean switch contacts. Check switch calibration and set points. Clean and adjust moving parts.

16. Unloader

Monthly. Check that compressor is not being loaded until operating speed is reached in starting and that it unloads at the proper pressure.

Annual. Inspect valves and air lines for leaks and valves for proper seating. Lap valves if required. Examine solenoid for deteriorated insulation or loose connections.

17. Bearings

Weekly. Check antifriction bearing for excessive vibration or noise and schedule replacement as required. Check for adequate lubrication.

Not Scheduled. Disassemble compressor and inspect condition of all bushings and babbitt-lined bearings. Repair or replace as required.

Reciprocating Compressors

18. Lubrication

Weekly. Check that oil or grease cups are full and that crank case oil is at proper level. Replace or add the correct lubricant to bring to proper levels in crankcase or oil reservoir. Check oil feed rate to cylinder. Check forced oil systems for proper operation. Note any leaks and repair if excessive.

Annual. Clean oil or grease cups and piping. Check condition of lubricant and change if required. Repair any leaks.

19. Packing Gland

Weekly. Check for excessive leakage and for scoring on piston rod. Adjust packing as necessary.

Annual. Replace packing as necessary.

20. Crosshead

Weekly. If visible, check fit and lubrication.

Annual. Check bearing shoes for scoring and wear, and fit to crosshead. Shim shoes if necessary to obtain proper fit. Check pin and bushing for wear and replace or refit as required.

21. Cylinder

Not Scheduled. Check cylinder walls for wear and scoring. Measure inside diameters at top, bottom, and middle in two directions, 90 degrees apart. If cylinder is out-of-round or oversized, rebore cylinder.

22. Piston

Not Scheduled. Check piston for wear. Check clearance with micrometer. Examine rings for tightness and fit. Replace if necessary. Check piston rod for trueness and scoring or wear. Renew or replace as required.

23. Connecting Rod

Not Scheduled. Check for distortion or bending. Check bearing bolts and nuts for damage and replace as required.

24. Intake and Discharge Valves

Not Scheduled. Inspect valves and seats for scoring and proper seating. Clean any deposits off of seats and valve plates being very careful not to scratch the surfaces. Lap valve seats if there are any imperfections. Deposits on the valves indicate a dirty intake, the wrong type or excessive oil, or a leaking valve or valve gasket.

Rotary Screw Compressors

25. Air End

Not Scheduled. Check condition of rotors and bearings. Replace if worn or if compressor efficiency has decreased noticeably.

26. Oil Reservoir and Separator

Monthly. Drain condensation from bottom of oil reservoir.

Annual. Check condition of separator element and service or replace if oil consumption is excessive.

27. Oil Filter

Annual. Replace or clean oil filter as required.

Section 5 – Cranes, Hoists, Rigging Equipment, and Elevators

Cranes and Hoists

At the time of publication of this documentation, a new FIST volume on the inspection and maintenance of cranes is being developed which will assist maintenance staff in this area.

Due to the potential for injury to personnel and damage to equipment, the inspection and maintenance of cranes and hoists is very important. A preventive maintenance and inspection program based on Government and Reclamation regulations, manufacturer's recommendations and applicable industry standards is required for all cranes, hoists, or other lifting devices. This program should be well documented with detailed records of the inspections and maintenance performed on the equipment.

Section 19 of Reclamation Safety and Health Standards lists the requirements for the operation and maintenance of hoisting equipment for Reclamation forces. The Occupational Safety and Health Administration (OSHA) and the American National Standards Institute (ANSI) publish the following regulations and standards that are also applicable in setting up an inspection and maintenance program for cranes and hoists:

OSHA Regulations

- 1910.179 “Overhead and Gantry Cranes”
- 1910.180 “Crawler, Locomotive and Truck Cranes”
- 1926.550 “Cranes and Derricks”

ANSI/ASME Standards

- ANSI/ASME B30.2 “Overhead and Gantry Cranes”
- ANSI/ASME B30.5 “Mobile and Locomotive Cranes”
- ANSI/ASME B30.7 “Base-Mounted Drum Hoists”
- ANSI/ASME B30.11 “Monorails and Underhung Cranes”
- ANSI/ASME B30.16 “Overhead Hoists (Underhung)”
- ANSI/ASME B30.17 ”Overhead and Gantry Cranes (Top Running Bridge, Single Girder, Underhung Hoist)”
- ANSI/ASME B30.20 “Below-the-Hook Lifting Devices”
- ANSI/ASME B30.21 “ Manually Lever Operated Hoists”
- ANSI/ASME B30.23 “ Personnel Lifting Systems”

If there is a difference between any provisions of these standards and regulations, state plans, or manufacturer's instructions, the more stringent provision will always prevail.

New vs. Existing Cranes

New cranes constructed, installed, inspected, tested operated and maintained shall conform to the requirements of the latest requirements of set standards and regulations. It is not the intent that older, existing cranes be retrofitted, however, when an item is being modified, its requirements shall be reviewed relative to the latest requirements. If the performance differs substantially, the need to meet the current requirement shall be evaluated by a qualified person. Cranes are required to be compliant with the accepted standard used at the time of its installation.

Mobile and Locomotive Cranes; Portal, Tower, and Pillar Cranes; Floating Cranes and Derricks; Material and Personnel Hoists; Manlifts, Draglines, A-Frame Trucks, and Similar Machines

This chapter summarizes maintenance, inspection and testing recommendations for common overhead and gantry cranes, hoists, rigging, wire rope and slings. Crane inspections are required at regular intervals as define in detail in the Reclamation Safety and Health Standards, OSHA 1910, ANSI B30, manufacturer's recommendations and the rigging standards. The operation and maintenance requirements for cranes, rigging and other accessories vary somewhat depending on the type of crane, hoisting equipment or component that requires testing. Due to the extreme variation in types of crane and hoisting equipment available and the infrequency that some of these types would be found in pumping plant facilities, this bulletin will not describe maintenance requirements and techniques for less common equipment. Included in this list are mobile and locomotive cranes; portal, tower, and pillar cranes; floating cranes and derricks; material and personnel hoists; manlifts, draglines, A-frame trucks and similar machines. For specific requirements and regulations regarding this equipment, the user should reference Reclamation's Safety and Health Standards, OSHA 1910, the related ANSI/ASME standard as described in Section 5.1, and the manufacturer's instructions for that piece of equipment.

Inspections

For a more complete description of inspection techniques, requirements and frequency, refer to the pertinent document stated above for the type of equipment at your site.

Inspections must be conducted by "designated personnel". These are people who are selected or assigned by the employer as being qualified to perform these specific duties.

Inspection procedure for cranes in regular service is divided into three general classifications based upon the intervals at which inspections should be performed. The intervals in turn are dependent upon the nature of the critical components of the crane and the degree of their exposure to wear, deterioration, or malfunction. The three general classifications of inspections are designated as "initial," "frequent," and "periodic."

1) *Initial Inspection*. Prior to use all new, altered, modified or repaired cranes shall be inspected by a designated person.

2) *Frequent Inspection*. A visual inspection by the user or other designated person with records not required to be maintained.

    a. Normal Service – monthly
    b. Heavy service – weekly to monthly
    c. Severe service – daily

The Bureau of Reclamation requires daily inspections or inspections prior to each shift. (Reference; Reclamation Safety and Health Standards)

3) *Periodic Inspection*. Visual inspection by a designated person requiring a record of the inspection as of apparent condition.

    a. Normal Service – annually
    b. Heavy service – annually
    c. Severe service – quarterly

The Bureau of Reclamation requires annual inspections. (Reference; Reclamation Safety and Health Standards)

The following table better defines these requirements.

Crane and hoist equipment inspection criteria

When to inspect	Type of inspection	Notes
Before initial use – new cranes	Initial inspection	Performed by manufacturer. "Initial use" refers to the first time Reclamation takes possession of and assembles a crane or whenever a non-Reclamation-owned crane is brought onto a jobsite and set up for use.
Before initial use – altered cranes	Initial inspection	A qualified person must conduct this inspection. "Altered" is defined as any change to the original manufacturer's design configuration, that is, replacement of weight handling equipment, parts, or components with other parts or components.
Daily or before every operation (shift)	Frequent inspection	
Annually or as required by manufacturer (if more frequent)	Periodic inspection	If the hoisting equipment has not been in service, inspect prior to operation. However, do not use the equipment if you have not inspected it in more than 12 months.
Before using a crane which is not in use on a regular basis and which has been idle for more than 1 month but less than 6 months	Frequent inspection	Also inspect running ropes
Before using a crane that is not used on a regular basis and that has been idle for more than 6 months.	Periodic and Frequent Inspection	Also inspect running ropes.
Standby cranes, at least semi-annually	Frequent inspection	Standby cranes are those not used regularly but are available, on a standby basis, for emergencies (e.g., emergency operation and maintenance work); requirements for frequent inspections of standby cranes are in addition to the requirements for a periodic inspection.

*Reclamation Safety and Health Standards, Revised 2001.

Inspection Reports

Inspection reports should be dated, comparable and kept on file. A electronic recordkeeping system may be used. If a computer system is used, and maintenance records are not retained in the crane file, the crane file should state where the electronic maintenance records are kept.

Frequent Inspections.—A written inspection report is not required.

Periodic Inspections.—An inspection report should be completed to record data obtained during the inspection.

Overhead and Gantry Cranes

General Requirements and Maintenance

This section applies to overhead and gantry cranes; semigantry, cantilever, and wall cranes; storage bridge cranes; and all other cranes that have trolleys and similar travel characteristics.

Modifications.—Modifications, additions, or major repairs shall not be made except by the manufacturer, with his written approval, or by the approval of a professional engineer. Any crane that has been modified or rerated such that it load-supporting components, capacity or operation has been modified shall be retested in accordance with the testing portion of this section. The new rated load shall be shown on the crane.

Markings.—The rated load of the crane should be marked on each side of crane. If the crane has more than one hoist, each hoist shall have its rated load marked on its load block. Markings shall be legible from the ground or floor.

Outdoor Cranes.—New outdoor storage cranes require automatic rail clamps and a wind indicating device.

General Construction.—Crane installations and equipment must be designed by the manufacturer or a professional engineer. Crane runways and supporting structures shall be designed to withstand the loads and forces imposed by the crane. A minimum clearance of 3 inches overhead and 2 inches laterally shall be provided and maintained between the crane and any obstructions.

***Crane Rails and Supports*.—**

Frequent Inspections.—Check for abnormal vibration or skewing in the crane structure or bracing when operating.

Periodic Inspections.—Check crane rails for alinement and level. Look for dips, cleanness; grease or oil. Bridge rails should be straight. Inspect welds if welded clips or welded rail is used. Check that expansion gaps in splice joints are even spaced and not so large as to cause vertical movement when the wheel passes over it. Look for wear patterns on the rail. Clean rails if significantly dirty. Check concrete rail supports for cracking or spalling and steel supports for corrosion and loose bolts or rivets. Repair concrete as required. Tighten loose bolts and rivets. Check that rail stops are securely fastened.

***Hoist, Trolley, and Bridge Framework*.—**

Frequent Inspections.—Nothing Required.

Periodic Inspections.—Check all framework for deformation, cracks, and corrosion, paying close attention to load bearing members and welded joints. Look for structural problems, especially in the corners and on long spans. Check for evidence of skewing. Skewing will occur between endtruck cross members and bridge girders, and can sometimes be seen on the inside corners. Check column anchorage and supports for deformed bolts or concrete cracks in the foundation. Check bolts and rivets for tightness. Clean and repaint as required.

***Cabs*.—**Access shall be by fixed ladder, stair, or platform requiring no step over any gap exceeding 12 inches. Out door cabs should be enclosed. All cab glazing shall be safety glass. All cabs shall have an emergency means of egress. A portable fire extinguisher is required to be installed in every cab. Carbon tetrachloride extinguishers are not allowed.

Frequent Inspections.—Tools, oil cans, extra fuses, and other articles shall be stored in the tool box and should not lie loose in or about the cab. Check for adequate cab lighting.

Periodic Inspections.—Check for broken windows or doors. Check guard rails and doors. Check bolts and rivets for tightness. Check welded joints for cracks. Look for corrosion of steel member. Clean and paint as required.

Footwalks and Ladders.—Footwalks shall be rigid with an antislip type walking surface. Wooden footwalks are acceptable. Ladders, toeboards, and handrails shall be permanent, securely fastened in place and be OSHA compliant. Ladders shall extend from the ground or floor to the cab platform or footwalk. If headroom is sufficient, a footwalk shall be included on the drive side along the entire length of the bridge of all cranes having a trolley running on top of the girders.

Frequent Inspections.—Check that footwalks are clean of trash, debris and oil.

Periodic Inspections.—Check hand rails and ladders. Check bolts and rivets for tightness. Check ladder rungs and stairs for significant wear of antislip surfaces. Check welded joints for cracks. Check that toeboards are secure. Look for corrosion of steel member. Clean and paint as required.

Stops, Bumpers, Rail Sweeps, and Guards.—Stops shall be provided at the limits of trolley travel and shall be fastened to resist forces applied when contacted by the bumpers.

All power-operated bridges and trolleys are required to have bumpers. They should be energy-absorbing (or –dissipating) and designed specifically for stopping the bridge or trolley even with loss of power. Bumpers shall be so equipped as to minimize parts falling from the crane in case of breakage or age.

Rail sweeps are required in front of the leading wheels on both ends of the trolley end truck. Their purpose is to clear the rail of objects on the bridge which, if caught between the wheel and rail, could damage or derail the wheel. Clearance between the top surface of the rail and the bottom of the sweep should not exceed 3/16". Rail sweeps should extend below the top of the rail. Side clearance should be equal to the crane float plus 3/16".

Guards are required over all exposed moving parts, such as gears, set screws, keys, drive chains and sprocket, which present a hazard under normal operating conditions. Guards are required to be substantially constructed so that they can not deform and make contact with moving parts or live electrical parts. A guard should be provided between exposed bridge conductors and hoisting ropes if it is possible that they could come into contact. Guards are also required if hoisting ropes run near enough to other parts to make chafing or fouling possible.

Frequent Inspections.—Nothing required.

Periodic Inspections.—Inspect stops and bumpers for wear, cracks, corrosion, or distortion. Check for looseness and proper positioning. Check for leaking of hydraulic bumpers and fill to proper level. Check rubber or plastic bumpers for cracks or other damage. Replace or repair as required. Adjust rail sweeps if required. Verify that all guards are in place and securely fastened.

Braking System.—

Hoist Brakes.—Each hoist unit is required to have at least one, self setting (holding) brake that applies directly to the motor shaft or some part of the gear train. Hoist holding brakes shall apply automatically when power to the brake is removed. Also hoist holding brakes shall be provided with brake adjusters to adjust for lining wear. Brakes should not overheat under general service conditions.

Each hoist unit (except specifically designed worm gear hoists) is required to have at least one control brake to prevent overspeed. Braking means can be electrical, mechanical, hydraulic or worm-gear. Brakes should not overheat under general service conditions.

Trolley and Bridge Brakes.—Each power-driven bridge and trolley unit of the crane shall be equipped with either a braking means or have frictional characteristics that will provide stopping and holding. Brakes should not overheat under general service conditions.

Brakes may be mechanical, electrical, pneumatic, hydraulic or gravitational. They shall be adjustable to compensate for wear. Foot-operated brakes shall require not more than 70 lbs to apply and be equipped with means for positive release when force is taken off the pedal.

Brake pedals, latches, and levers should allow release with less force than was used to apply the brake.

When provided, a parking brake shall:

- Be applied either automatically or manually
- Impede horizontal motion as required by ANSI/ASME standards
- Not prohibit the use of a drift point in the control circuitry

When provided, a service brake shall:

- Be applied manually by the operator
- Stop trolley or bridge travel as required by ANSI/ASME standards

When provided, a drag brake shall provide a continuous retarding torque without external control.

When provided, an emergency brake shall:

- Be applied when initiated by the operator, or automatically upon loss of power
- Stop trolley or bridge travel as required by ANSI/ASME standards
- Impede horizontal motion as required by ANSI/ASME standards

Frequent Inspections.—Check operation of bridge and trolley brakes and look for leaks in hydraulic lines. Before proceeding with a lift, lift load a few inches and check that hoist brakes are holding.

Periodic Inspections.—Check brake lining for excessive wear and oil contamination. Inspect for signs of heating. Check linings of shoes and pads for asbestos. Check brake drums for scoring. Check for smooth drums and uneven wear patterns. Measure clearance and shoe thickness. Check operating mechanisms for wear or damage, adequate lubrication, and proper adjustment. Repair or replace parts as required. Check operation of load control braking system. Verify that hoist brakes will hold load with loss of power. Clean brake dust and dirt from brakes. Always wear a dust mask for this work.

Electrical Equipment.—Control voltage shall be less than 600V AC or DC. Pendent control voltage shall not exceed 150V AC or 300 V for DC. Wiring and equipment shall comply with the requirements of the National Electric Code.

Pendant control stations shall be constructed to prevent electrical shock. Where multiple conductor cable is used, the station's electrical conductors will be provided with some type of strain support.

All electrical equipment shall be located or enclosed so that, under normal operating conditions, contact with energized parts can not occur. Electrical equipment shall be protected from dirt, grease, oil, and moisture.

Controllers.—Cranes that are not equipped with spring-return controllers or momentary contact pushbuttons shall be provided with a device which will disconnect all motors from the line on power failure and will not permit any motor to restart until the controller handle is brought to the "off" position or a reset is operated.

For cab cranes, the lever-operated manual controller and switch shall be provided with a spring-return and off-point detent or latch. With floor-operated cranes, the controllers, if rope operated, shall also automatically return to the off position when released by the operator. Push buttons on pendant stations shall return to the off position when pressure is releases. Radio or remote-operated cranes shall function so that on loss of control signal for any crane motion, the crane motion shall stop.

Arrangements of cab, pendent and radio controls should conform to the requirements of ANSI/ASME B30.2.

All controls and switches should be labeled as to their function.

Frequent Inspections.—Check control levers and pushbuttons for misdjustment, free movement and for any obstruction that could interfere with proper operation. Check that the controller returns to the off position when the lever is released. Check for excessive wear and contamination by lubricants or other foreign matter. Controls shall be kept clean and function labels kept legible.

Periodic Inspections.—Check controller contacts for signs of pitting or any other deterioration. Examine the controller for burned contacts or signs of overheating. Check for excessive wear or looseness of control levers. Vacuum and clean the controller if contaminated with dust and dirt. Lubricate moving parts as needed. Check strain relief on pendent. Check that required control markings are displayed and legible.

Resistors.—Resistors shall have openings to provide adequate ventilation. They shall be made to prevent molten metal from falling on the operator or from the crane. If enclosed, they shall be installed so that the accumulation of combustible matter is minimized.

Frequent Inspections.—Nothing required.

Periodic Inspections.—Visually examine resistor tubes for cracks, loose bands and connections and broken resistance wire. Clean resistor banks if dirty.

Switches.—The power to the runway conductors shall have a switch or circuit breaker accessible from the floor and lockable in the open position. On cranes with cabs, an enclosed switch or breaker, with provisions for locking in the open position, shall be provided in the leads from the runway conductor. A means of opening the switch or breaker shall be located within easy reach of the operator.

On floor, remote, or pulpit-operated cranes, the device of the enclosed type shall be provided in the leads from the runway conductors. It shall be able to be locked in the open position.

Hoists shall have an upper limit switch to prevent travel of the load block beyond the limit of travel. On wire rope hoists, if a geared or other limit switch or device that operates in relation to drum turns is used, an additional limit switch that operates independent of drum rotations shall be provided.

Plants where the load block may enter pits or hatchways below the floor should be provided with a lower limit switch.

Frequent Inspections.—Check operation of hoist upper limit switches, without load, by carefully inching into limit switch.

Periodic Inspections.—Check operation of hoist upper, lower and travel limit switches, check electrical contacts for signs of pitting or any other deterioration. Check levers and cams for adequate lubrication and excessive wear.

Bridge and Trolley Conductors and Collectors.—Conductors of the open type, mounted on the crane runway beams or overhead, shall be located or guarded so that personnel cannot under normal operating conditions, inadvertently come in contract with the energized conductors.

Frequent Inspections.—Nothing required.

Periodic Inspections.—Check the contact surfaces of open conductors and collectors for signs of arcing damage, pitting and corrosion. Check condition of insulators. Clean as required. Check that festoon type conductor cable moves freely with bridge and trolley movement. Check the condition of insulation and for kinking in cable.

Hoisting Equipment.—

Drums and Sheaves.—Rope drums shall be grooved, unless provided differently by the manufacturer for a special application. The grooves shall be free of surface defects and form a close-fitting saddle for the size of rope used.

Sheave grooves shall be smooth and free from surface defects that might damage the rope. Sheaves in the bottom block shall be equipped with guards that will prevent the ropes from fouling when the block is lying on the ground and the ropes are loose. All running sheaves shall be equipped with means for lubrication.

Frequent Inspections.—Nothing required

Periodic Inspections.—Visually inspect drums and sheaves for cracks or other damage. Check bearings for wear and proper lubrication. Check grooves of drums and sheaves for wear with a sheave gauge. Repair or replace as required.

Wire Rope or Load Chain.—Hoisting ropes shall be as recommended for the crane service. For hoists and overhead cranes, the wire rope design factor is 5:1.

Socketing shall be done in a manner recommended by the rope or fitting manufacturer or a qualified person.

Ropes shall be secured to the drum as follows:

(1) No less than two wraps of rope shall remain on the drum at each anchorage of the hoisting drum when the hook is in its extreme low position unless a lower-limit device is provided, in which case no less than one wrap shall remain.

(2) The rope end shall be anchored by a clamp attached to the drum, or by a socket arrangement specified by the crane or rope manufacturer. Rope clamps shall be tightened to the recommended manufacturer's torque.

(3) Eye splices shall be made in recommended manner. Rope thimbles should be used in the eye.

(4) Wire rope clips shall be drop-forged steel of the single-saddle(U-bolt) or double saddle type.

(5) Swaged or compressed fittings shall be applied as recommended by the rope, crane or fitting manufacturer or qualified person.

(6) Rope having an independent wire-rope or wire-stranded core, or other temperature resistant core shall be used whenever the rope is exposed to ambient temperatures greater than 180 degrees.

(7) Replacement rope shall be the same size, grade, and construction as the original rope furnished by the crane manufacturer, unless otherwise recommended by a rope or crane manufacturer or qualified person due to actual working condition requirements.

Frequent Inspections.—Visually inspect at the start of each shift prior to the crane being used, for visual damage, such as:

(1) Distortion of the rope, such as kinking, crushing, unstranding, birdcaging, main strand displacement, or core protusion.

(2) General corrosion

(3) Broken or cut strands

(4) Number, distribution and type of visible broken wires

When damage is discovered, the rope shall either be removed or given a detailed inspection as required in the periodic inspection below.

Check wire rope to ensure there is no slack in drum or load block and that reeving is proper.

Check load chains for worn or damaged links. Check that the chain feeds into and away from sprockets smoothly. If the chain binds, jumps, or is noisy, it shall be checked to ensure that it is clean, and properly lubricated. If the trouble persists, the chain and mating parts shall be inspected for wear, distortion, or other damage.

The chain shall be examined visually for gouges, nicks, weld spatter, corrosion and distorted links. The chain shall be slackened and the adjacent links moved to one side to inspect for wear at the contact points.

Monthly Inspections.—For in-service overhead and gantry cranes, a monthly documented rope inspection is required. Similarly, overhead and gantry cranes with load chains shall also have a monthly inspection conducted. A monthly inspection is not required if a periodic inspection of running and standing rope is accomplished the same month.

Visually inspect running ropes for any condition that could result in an appreciable loss of strength. Some conditions to look for are:

(1) Reduction of rope diameter below nominal diameter.

(2) A number of broken outside wires and the degree of distribution or concentration of broken wires.

(3) Worn outside wires

(4) Corroded or broken wires at end connections

(5) Corroded, cracked, bent, worn, or improperly applied end connections

(6) Severe kinking, crushing, cutting, or unstranding

Welded link and roller type chain inspection shall should checking for excessive wear, twist, or distorted links which interfere with the chains proper function, or stretching beyond the manufacturer's recommendations Also inspection the end connections.

Periodic Inspections.—Periodic wire rope and load chain inspections should be performed in conjunction with the overall crane periodic inspection. Check wire rope for:

(1) Items listed for frequent wire rope inspection
(2) Improper and insufficient rope lubrication
(3) Evidence of heat damage

Additional care should be taken when inspecting sections where rapid deterioration may take place, such as a section in contact with saddles and sheaves, and sections of rope at or near terminal ends. Refer to the Rigging Manual or the rope manufacturer for recommendations for replacement of the wire rope. Clean and apply lubrication, if required, according to manufacturer's recommendations.

Check welded link load chains for:

(1) Link wear that is less than 90 percent of the original bar diameter

(2) Nicking, cracking, or corrosion of a link that, when ground out to a smooth surface, leaves less than 90 percent of the original bar diameter

(3) Stiffening or poor hinging of the linkage

(4) Distortion by bending or kinking of 15 % of any overall link dimension

(5) Evidence of heat damage

(6) Elongation in excess of the manufacturer's recommended allowable

(7) Worn, nicked, or corroded fittings

Check roller type load chain for:

(1) Elongation following the hoist manufacturer's instructions.
(2) Chain Twist. Replace the chain if the twist in any 5 feet section exceeds 15 degrees.
(3) Pins turned from their original position
(4) Rollers that do not run free with light finger pressure
(5) Points that cannot be flexed by easy hand pressure
(6) Corrosion, pitting, or discoloration of the chain
(7) Gouges, nicks, or weld splatter

A more thorough inspection of the last five items is achieved if the chain is removed from the hoist and cleaned in an acid-free solvent prior to inspection. Refer to the Rigging Manual or the chain's manufacturer for guidelines on the replacement of the chain. Clean and apply lubrication, if required, according to manufacturer's recommendations.

Equalizers.—If the load is supported by more than one part of rope, the tension shall be equalized. Equalizer sheaves shall be lubricated at the same time as other drums and sheaves.

Hooks.—Hooks shall meet the manufacturer's recommendations and not be overloaded. Swivel hooks should rotate freely. Latch-equipped hooks shall be used unless the application makes the use of the latch impractical or unnecessary.

Frequent Inspections.—Visually inspect hook for cracks nicks, gouges, or chemical damage, or deformation. Check hook latch operation and hook attachment and securing means. Check that swivel hooks are free to rotate. Hooks having any of the following deficiencies shall be removed from service:

(1) Cracks, nicks, and gouges.

(2) A increase in throat opening of more than 15 percent(or as recommended by the manufacturer).

(3) A bend or twist of more than 10 degrees from the plane of the unbent hook.

(4) Wear exceeding 10 percent of the original sectional dimension of the hook or its load pin.

(5) Inoperable hook latch or a hook with a latch that does not close the full throat opening.

Periodic Inspections.—Visual inspection similar to that required in the frequent inspection. Annual NDT tests such as magnetic particle, die penetrant, or other nondestructive test are not normally required but are recommended for hooks that are submitted to severe or heavy service. Lubricate swivel and sheave bearings as required.

Maintenance.—All cranes are required to have a preventive maintenance program. As a minimum, manufacturer's recommendations shall be followed. Replacement parts shall be at least equal to the original manufacturer's specifications. Before maintenance is accomplished, where adjustments and repairs are required, the following precautions shall be taken.

(1) The crane shall be run to a location where it will cause the least interference and is most accessible.

(2) All controllers shall be checked to assure that they are in the off position.

(3) If the equipment is electrically powered, the main or emergency disconnect or switch shall be opened and locked in the open position. Facility specific lock-out/tag-out procedures shall be strictly followed. If the crane is hydraulic or air powered, effective isolation of the energy source and lock-out/tag-out procedures shall be conducted. Hydraulic and air pressure shall be relieved.

(4) Effective warning signs, guards and barriers shall be installed where overhead maintenance work creates a hazard or where interference with another crane or another crane's electrical conductors could occur.

(5) Only trained personnel shall work on energized equipment when adjustments and test are required.

(6) After maintenance work is completed and before returning to service,

    (a) Guards shall be reinstalled
    (b) Safety devices shall be reactivated
    (c) Replaced parts, tools, rags and debris shall be removed.

All hazardous conditions and discrepancies disclosed by inspection or operation shall be corrected before resuming normal operation. Adjustments or replacements of parts shall be made to assure the correct function of all operating mechanisms, limit switches, control systems, brakes and motors. The hook, rope, load chain, etc. shall be inspected and repaired or replaced as required.

A controlled lubrication plan is required to prevent under- or over-lubrication. Lubrication frequency and lubrication types used in motors, bearings, gear boxes wire rope and other lubrication points shall be specified by the responsible engineer inspector, or maintenance organization and adhere to the manufacturer's recommendations.

Sheave bearings including equalizing sheaves, shall be individually lubricated on a regular schedule. Load blocks that are immersed in water shall have special provisions to prevent lubricant loss. Lubrication frequency and type should be carefully evaluated.

Hoist ropes, except for stainless steel rope (consult manufacturer) shall be lubricated. Again, when ropes are immersed in water, the type of lubricant and frequency shall be adjusted to reduce the loss of lubricant to water.

***Testing*.—**

Operational Tests.—Before initial use, new, reinstalled, altered, repaired, or modified cranes shall be tested by a designated person to ensure that the crane is in good operational condition. Tests shall include:

(1) Lifting and lowering
(2) Trolley travel
(3) Bridge travel
(4) Limit switches

Operational testing of altered, repaired, and modified cranes may be limited to the functions affected by the alteration, repair or modification as determined by a qualified person.

Reclamation requires an annual operational test unless the equipment has been out of service, in which case it may be deferred until the next crane operation.

Load Tests.—Scheduled load-tests are not routinely required. Management may implement a periodic load-testing program. The frequency and capacity of such periodic tests shall be set by management. For example, Reclamation requires a load test before any lift where the load is expected to be at least 75% of the rated capacity. The test remains valid for 5 years, and must be at least 100 percent of rated capacity but not greater than 110%. (Reclamation Safety and Health Standards, Section 19).

Before initial use, new, reinstalled, altered, repaired, or modified cranes shall be load tested as determined by a qualified person. Overhead and gantry cranes may be load-tested between 100% and 110%.

The replacement of load rope and chain is specifically excluded from this load test; however, an operational test is required.

Load tests shall be performed only after inspection and maintenance of the crane are confirmed as current and any outstanding problems have been addressed. This is usually a good time to also check load limiting devices for accuracy of settings.

If a load test is conducted, the person conducting the test shall prepare a written report on the test. This report shall be signed, dated and kept on file.

Safe Operating Practices.—Cranes shall be operated only by qualified designated persons; trainees under direct supervision of a designated person, and maintenance and test personnel when necessary. Operators of cab-operated cranes and pulpit operated cranes shall be required to pass a written or oral examination and shall meet specified physical requirements as outlined in Reclamation's Safety and Health Standards.

All controls shall be tested by the operator before beginning a new shift. The operator shall test the brakes each time a load approaching the rated load is handled. The brakes shall be tested by raising the load a few inches and applying the brakes.

The operator shall be familiar with the crane and its proper care.

Contact with runway stops or other cranes should be made with extreme caution and care.

Before any maintenance work is performed on the crane, the operator shall lock and tag the main disconnect in the deenergized position.

Before leaving a cab-operated crane, the operator shall land any attached load, place controllers in the off position, and open the main disconnect of the crane. The operator should not leave his position at the controls while the load is suspended.

The operator shall not close the main disconnect until certain that no worker is on or adjacent to the crane. The operator shall be sure that all controllers are in the off position before closing the main disconnect.

If power goes off during operation, the operator shall immediately place all controllers in the off position.

A warning signal shall be sounded prior to starting the bridge and when the load or hook approaches near or over people.

Standard hand signals shall be used. Radio communication should be used where hand signals are insufficient. The crane operator and signal person shall always maintain communication.

Outdoor cranes shall be secured after use.

If a wind-indication device is present and alarms, all crane operation shall be discontinued and the crane prepared and stored for excessive wind conditions.

The crane shall not be loaded beyond its rated load except for test purposes.

The hoist rope or chain shall be free from all kinks or twists and shall not be wrapped around the load. Multiple part lines shall not be twisted around each other.

The load shall be attached to the block hook by means of slings or other approved devices.

Care shall be taken to make certain that the sling clears all obstacles. The load should not contact any obstructions.

The load shall be well secured and properly balanced in the sling or lifting device before it is lifted. The hook should be centered over the center of gravity of the load in such a manner as to prevent swinging.

The hoist rope should be checked to verify that it is seated in the drum grooves and sheaves, especially if there has been a slack condition.

Avoid sudden acceleration or deceleration of the load.

Cranes shall not be used for side pulls, except when specifically authorized by a qualified person.

When practical, tag lines shall be used to control loads.

Personnel shall not ride the load or hook.

The operator shall avoid carrying loads over people.

The load shall not be lowered below the point where less than two full wraps of rope remain on the drum.

When two or more cranes are used to lift a load, one qualified responsible person shall be in charge of the operation.

Critical Lifts.—Reclamation designates critical lifts are those that are determined to be:

(1) Lifts made when the load weight is 75 percent or more than the rated capacity of the crane or hoisting device

(2) Lifts made with more than one crane

(3) Hoisting personnel with a crane

(4) Any lift that the crane or hoist operator believes to be critical.

ANSI/ASME has less stringent requirements. Refer to the appropriate reference for your critical lift criteria.

Ropes, Slings, Chains, and Rigging Hardware

Section 18 of Reclamation Safety and Health Standards provides information on ropes, slings, chains and accessories and their safe use. It is based on safety regulations set forth in OSHA 1910.184 “Slings” and OSHA 1926.251 “Rigging Equipment for Material Handling” (Construction). The *Rigging Manual* published by the Construction Safety Association of Ontario, 21 Voyager Court South, Etobicoke, Ontario, Canada M9W 5M7 has been designated as the Reclamation Rigging Manual. This publication provides information on safe rigging, load capacities of slings and other rigging equipment, and the inspection of wire rope and slings. The Rigging Manual should be used as a guide in determining whether rigging practices are safe and in conformance with industry-wide practices and while its use is recommended, it is advisory in nature and intended to complement the safety requirements of Section 18 and Appendix D and E of Reclamation Safety and Health Standards. ANSI/ ASME B30.9 "Slings" and ANSI/ASME B30.10 “Hooks” may also be helpful in the use and inspection of rigging.

Rigging equipment shall be inspected prior to use on each shift and as necessary during its use to ensure that it is safe. Defective equipment that is repairable should immediately be clearly marked as unsafe and removed from service. Repairs should be made by the manufacturer or in accordance with the manufacturer's written instructions. Repaired equipment shall be tested at twice their rated safe working load. Defective equipment that is not repairable should be cut in half or otherwise rendered unusable to ensure it will not be used. Capacity charts should be consulted, and all variables, such as sling angle, should be considered, to assure that the rigging hardware's rated capacity is not exceeded by the load being lifted.

Slings shall not be used with loads in excess of the rated capacities shown in the rigging tables and in accordance with the manufacturer’s recommendations.

Inspections

Sling inspection is divided into three inspection classifications based upon the (a) frequency of sling use; (b) severity of service conditions and (c) nature of lifts and (d) historical experience of the service life of slings in similar conditions. The three general classifications of inspections are as defined.

Initial Inspections.—Prior to use all new, altered, modified or repaired slings shall be inspected by a designated person.

Frequent Inspections.—Visual inspection by the user or other designated person with records not required to be maintained.

a. Normal Service – monthly

b. Severe service – daily to weekly The Bureau of Reclamation requires inspection “prior to each shift.”

c. Special or infrequent service – as recommended by a qualified person before and after each occurrence

Periodic Inspections.—Visual inspection by a designated person requiring a record of the inspection as of apparent condition.

a. Normal Service – annually

b. Severed service – monthly to quarterly

c. Special or infrequent service – as recommended by a qualified person before the first occurrence and as direct by him for any subsequent occurrences.

Under no condition shall inspection intervals be greater than once every 12 months.

Damaged or defective slings shall be immediately removed from service. Attachments should not be repaired but instead replaced.

Periodic load testing of slings is not recommended.

Operating Practices

Proper operating practices and guidelines applicable to all types of slings are as follows:

(1) Slings having suitable characteristics for the type of load, hitch, and environment shall be selected.

(2) The weight of the load shall be with the rated load (working load limit) of the sling.

(3) Slings shall not be shortened or lengthened by knotting, twisting, or other methods not approved by the sling manufacturer.

(4) Slings that appear to be damaged shall not be used unless they are inspected and accepted as usable in accordance with the periodic inspection requirements stated.

(5) The sling shall be hitched or rigged in a manner providing control of the load.

(6) Sharp corners in contact with the sling should be padded with material of sufficient strength to minimize damage to the sling.

(7) Portions of the human body should be kept from between the sling and the load and from between the sling and the crane/hoist hook.

(8) Personnel should stand clear of the suspended load.

(9) Personnel should not ride the sling.

(10) Shock loading is prohibited.

(11) Slings should not be pulled from under a load when the load is resting on the sling.

(12) Slings should be stored in an area where they will not be subjected to mechanical damage, corrosive action, moisture, extreme heat, or kinking.

(13) Twisting and kinking the legs (branches) shall be avoided.

(14) The load applied to the hook should be centered in the bowl of the hooks to prevent point loading on the hook, unless the hook is designed for point loading.

(15) During lifting, with or without load, personnel shall be alert for possible snagging.

(16) In a basket hitch, the load should be balanced to prevent slippage.

(17) The sling's legs (branches) should contain or support the load so that the load remains under control.

(18) Slings should be long enough so that the rated load is adequate when the angle of the legs (branches) is taken into consideration.

(19) Slings should not be dragged on the floor or over an abrasive surface.

Alloy Steel Chain Slings.—Chain for alloy steel chain slings shall conform to the requirements of ASTM A391/A391M.

Rated Load.—Refer to the Bureau of Reclamation Safety and Health Standards, the Rigging Manual or the chain's manufacturer for guidelines on sizing and safe work load of the chain.

Proof Testing.—When specified by the purchaser, new slings shall be proof loaded by the manufacturer. Before use, each repaired, or reconditioned alloy steel chain sling, including all welded components in the sling assembly shall be proof tested by the sling manufacturer or repairing agency to twice the rated capacity. Refer to the Bureau of Reclamation Safety and Health Standards, the Rigging Manual or the chain's manufacturer for guidelines for other proof testing criteria.

Sling Identification.—Alloy steel chain slings shall have permanently affixed durable identification stating manufacturer, grade and size, number of legs, rated load and angle, and reach. Repaired or worn sling shall be labeled to reflect any reduced capacity.

Environment.—Alloy steel chains shall be permanently removed from service if heated above 1000˚F and capacities reduced if exposed above 600˚F. The chain manufacturer should be consulted when chain slings are to be used in temperatures of -40˚F or below.

The sling manufacturer should be consulted before slings are used around chemicals; especially caustic, acid or oxidizing environments.

Attachments.—Hooks, rings, oblong and pear shaped links, coupling links or other attachments shall have a rated capacity at least equal to that of the alloy steel chain which they are used or the sling shall not be used in excess of the rated capacity of the weakest component. All welded components in the sling shall be proof-load tested as components or as part of the sling assembly. Makeshift or job made links or fasteners formed from bolts or rods shall not be used. Where used, handles shall be welded to the master link or hook before heat treating. (This prohibits welding on chain slings in the field.)

Hook characteristics shall meet the requirements of ANSI/ASME B30.10.

Repairs.—Any hazardous condition disclosed by the inspection requirements shall be corrected before use is resumed. Repairs shall be made only by the chain manufacturer or qualified personnel.

Frequent Inspections.—Inspect for defects and damage. Any found deficiencies shall cause the sling to be set aside for periodic inspection. Chain and attachments should display no sign of wear, nicks, cracks, breaks, gouges, stretch, bends, weld splatter, discoloration from excessive temperature, or excessive throat opening of hooks. Chain links and attachments shall hinge freely with adjacent links. Latches on hooks, if present, should hinge freely and seat properly without distortion.

Periodic Inspections.—Perform a complete link-by-link inspection of the sling. The inspection shall include all items described in the frequent inspection and in addition:
Each link and attachment shall be individually examined, taking care to expose the inner-link surfaces of the chain and chain attachment. Refer to the Bureau of Reclamation Safety and Health Standards, the Rigging Manual or the chain's manufacturer for guidelines on the replacement of the chain.

Operating Practices.—

(1) Multiple-leg (branch) chain slings shall be selected according to Bureau of Reclamation Safety and Health Standards, the Rigging Manual or the chain's manufacturer for guidelines. Operation at other angles shall be limited to rated loads of the next lower angle given in the table or calculated trigonometrically so as to not introduce into the leg (branch) itself a working load in direct tension greater than that permitted.

(2) When used in a choker hitch arrangement, slings shall be selected to prevent the load developed on any portion of the sling from exceeding the rated load of the chain sling components.

Wire Rope Slings.—Wire rope slings are made from various grades and types of wire rope. Rated loads of wire rope slings shall be specified by the manufacturer, with a design factor of at least 5. Rotation-resistant wire rope shall not be used for slings.

Minimum Sling Length.—Cable laid, wire and braided slings, sling grommets and endless slings shall have a minimum length as defined in OSHA 1920.184.

Rated Load.—Refer to the Bureau of Reclamation Safety and Health Standards, the Rigging Manual or the wire rope manufacturer for guidelines on sizing and safe work load of the rope.

Proof Testing.—Job made or repaired slings require proof testing. Refer to the Bureau of Reclamation Safety and Health Standards, the Rigging Manual or the wire rope manufacturer for proof testing criteria.

Sling Identification.—Wire rope slings shall be labeled with a permanent tag or other identification method. The tag, or other identification method, shall state the manufacturer's name and rated load. The load test date and periodic inspection due date is also beneficial.

Environment.—Fiber core wire rope slings of all grades shall not be exposed to temperatures in excess of 180˚F or less than -40˚F. Wire rope slings of any grade shall be used only between 400˚F and -60˚F.

The sling manufacturer should be consulted before slings are used around chemicals; especially caustic, acid or oxidizing environments.

End Attachments.—All welded load-bearing components (welded before or after assembly) in the sling shall have a design factor of 5:1 and shall be proof tested by the manufacturer or the manufacturer's agent to twice their rated load. Welding of handles or any other accessories to end attachments, except covers to thimbles, shall be performed prior to assembly of the sling. Eyes in wire rope slings shall not be formed using knots.

Hook characteristics shall meet the requirements of ANSI/ASME B30.10.

Wire Rope Clips and Hooks.—Wire rope clamps (clips) shall not be used to fabricate wire rope slings except when the application of the sling prevents the use of a prefabricated sling or when the specific application is designed by a qualified person. When used, slings fabricated using wire rope clamps shall be derated to 80 percent of the rated wire rope load capacity to account for the efficiency of the clamps. Wire rope clamps must be installed in accordance with the manufacturer's recommendations. The nuts on the clamps must be checked periodically and retorqued to the recommended value. Slings made with wire rope clips should not be used as a choker hitch.

Wire rope wedge sockets shall not be used to fabricate wire rope slings.

Slings with eyes formed by folding back the rope (not a Flemish eye loop) and secured with one or more metal sleeves pressed (not forging) over the wire rope junction are prohibited.

Repairs and Replacement.—Slings shall be made only from new wire rope. Thimbles should be used unless their use makes the sling impractical.

Wire rope slings shall be removed from service if any of the following conditions exist:

(1) For strand-laid and single-part slings, ten randomly distributed broken wires in one rope lay or five broken wires in one strand in one rope lay

(2) Broken wires in braided and cable-laid slings

(3) Severe localized abrasion or scraping of one-third the original diameter of outside individual wires

(4) Kinking, crushing, birdcaging, or any other damage resulting in distortion of the rope structure

(5) Evidence of heat damage

(6) End attachments that are cracked, deformed, or worn to the extent that the strength of the sling is substantially affected

(7) Severe corrosion of the rope or end attachments

(8) Hooks that have been opened more than 15 percent of the normal throat opening measured at the narrowest point or twisted more than 10° from the plane of the unbent hook

Because many variable factors are involved, no precise inspection criteria can be given for determining the exact time for replacement of a sling. In this respect, safety depends largely on the use of good judgment by a qualified person.

Frequent Inspections.—All slings shall be visually inspected each day by the person using the sling. Slings should be inspected for:

(1) Distortion of rope in the sling such as kinking, crushing, unstranding, birdcaging, main strand displacement, or core protrusion. If loss of rope diameter in short rope lengths or unevenness of other strands is observed, the sling or slings should be replaced

(2) General corrosion

(3) Broken or cut strands

(4) Number, distribution and type of visible broken wires (ten randomly distributed broken wire in one rope lay or five broken wires in one strand in one rope lay).

Periodic Inspections.—A wire rope sling periodic inspection shall be performed by a designated person on a regular basis. Inspection shall be of the entire length of each sling including splices, end attachments, and fittings. Deterioration that would result in loss of original strength shall be observed and a determination made whether further use of the sling would constitute a hazard.

Replacement.—Refer to the Bureau of Reclamation Safety and Health Standards, the Rigging Manual or the wire rope manufacturer for guidelines on when to replace the wire rope.

Operating Practices.—

(1) Multiple-leg slings shall be selected so as not to introduce a working load in direct tension in any leg greater than that permitted. Triple and quadruple leg sling rating should be considered the same as a double-sling rating. If rigging techniques, verified by a qualified rigger, ensure the load is evenly distributed, then full use of three legs is allowed. Special rigging techniques verified by a qualified engineer shall be required to prove a load is evenly distributed over four or more sling legs.

(2) In a choker hitch, slings shall be long enough so that the choker fitting chokes on the wire rope body and never on the fitting.

(3) Slings shall not be inspected by passing bare hands over the wire rope body. Broken wires, if present, may injure the hands.

(4) Fiber core wire rope should not be subjected to degreasing or a solvent because it will damage the core.

(5) Single-leg slings with hand-tucked splices can be unlaid by rotation. Care should be taken to minimize rotation.

(6) An object engaging the eye of a loop eye sling should not be greater in width than one-half the length of the loop eye.

Metal Mesh Sling.—The use of metal mesh slings in power and pumping facilities is limited. Refer to the ANSI/ASME 30.9, the Rigging Manual or the sling manufacturer for guidelines if this type of sling is used.

Natural and Synthetic Fiber Rope Slings.—Slings manufactured from conventional three-strand natural or synthetic fiber rope are not recommended for use in lifting service. Refer to the ANSI/ASME 30.9, Bureau of Reclamation Safety and Health Standards, the Rigging Manual or the sling manufacturer if this type of sling is used.

Synthetic Webbing Slings.—

Marking (Sling Identification).—Synthetic web slings shall be labeled (a sewn-on leather tag is recommended). The label shall state the following:

- Manufacturer's name or trademark
- Manufacturer's code or stock number
- Rated loads for the types of hitches used
- Type of synthetic web material

An additional tag, sticker, or other identifier shall be added by the user to indicate when the next periodic inspection is required.

If the synthetic web sling is to be used for critical lifts, the tag or other identification means shall be used to indicate that a proof test has been performed.

Design Factor.—The design factor for synthetic web slings shall be a minimum of 5.

Rated Load.—A synthetic web sling shall not be used at a load greater than shown on its tag.

Environment.—High radiation or chemically active environments can destroy the strength of synthetic web slings. Sling materials can be susceptible to caustics and acids. The manufacturer should be consulted before slings are used in chemically active environments. Specific environmental limits are as follows:

(1) Nylon and polyester slings shall not be used at temperatures in excess of 180 F.

(2) Synthetic web slings that incorporate aluminum fittings shall not be used where fumes, vapors, sprays, mists, or liquids of caustics or acids are present.

(3) Nylon web slings shall not be used where fumes, vapors, sprays, mists or liquids of acids or phenolics are present.

(4) Polyester web slings shall not be used where fumes, vapors, sprays, mists, or liquids or caustics are present.

(5) Synthetic web slings are not recommended where extensive exposure to sunlight or ultraviolet light is experienced. Most synthetic web slings are especially susceptible to damage by ultraviolet light. Synthetic slings require storage away from exposure to sunlight. Slings that have had long-term exposure to sunlight should be removed from service.

Inspections.—

Initial Inspections.—Before any new or repaired synthetic web sling is used, it shall be inspected to ensure that the correct sling is being used as well as to determine that it has proper identification.

Frequent Inspections.—This inspection should be made by the person handling the sling each day the sling is used.

Periodic Inspections.—A periodic inspection shall be performed by a qualified inspector on a regular basis with frequency of inspection based on the frequency of sling use, severity of service conditions, and the nature of the lifts being made.

The periodic inspection shall be made at least annually and shall be documented.

Removal Criteria.—Synthetic web slings shall be removed from service if damage such as the following is visible:

(1) Acid, phenolic, or caustic attack
(2) Melting or charring on any part of the sling
(3) Holes, tears, cuts, or snags
(4) Broken or worn stitching in load-bearing splices
(5) Excessive abrasive wear
(6) Knots in any part of the sling
(7) Excessive pitting or corrosion, or cracked, distorted or broken fittings
(8) Other visible indications that cause doubt as to the strength of the sling, such as loss of color that may indicate the potential for ultraviolet light damage

Repairs.—Synthetic web slings shall be repaired only by a sling manufacturer or a qualified repair agent. Proof testing is required to twice the rated load for all repaired slings.

Additional Operating Practices.—The following operating practices are applicable to the use of synthetic web slings:

(1) The sling's legs should contain or support the load from the sides above the center of gravity when a basket hitch is used.

(2) In a choker hitch, slings shall be long enough so the choker fitting chokes on the webbing and never on the other fitting.

(3) Nylon and polyester slings shall not be used at temperatures in excess of 180 °F or below -40 °F.

(4) Nylon and polyester web slings lose strength from extensive exposure to sunlight or ultraviolet light. Possible strength loss may be indicated by loss of color in the pick threads or outer jacket. If the user suspects sunlight or ultraviolet light damage the sling shall be taken out of service pending inspection by a qualified person.

(5) Hard or brittle spots in the fabric of synthetic slings may indicate a substantial reduction in strength as a result of damage from chemicals or excessive heat.

Rigging Hardware (Eyebolts, Shackles, etc.)

This section provides a summarization of some of the more important requirements for the use of rigging hardware for lifting service and includes shackles, rings, wire rope clamps (clips), eyebolts, turnbuckles, and rigging hooks.

Shackles and Rings.—

General.—Shackles are manufactured in two configurations for use in rigging: anchor shackle and chain shackle. Both are available with screw pins, round pins, or safety bolts.

Shackles are sized by the diameter of steel in the bow section rather than the pin size.

Rings should be forged steel and weldless. Welded rings are not recommended but may be used if designed by a qualified engineer and subjected to weld nondestructive testing (NDT).

Marking and Tagging.—Each shackle body shall be permanently and legibly marked by the manufacturer. Marking will be raised or stamped letters on the side of the shackle bow with an identifying manufacturer’s name or trademark, shackle size, and safe working load (SWL).

Shackle pins shall be unmarked.

Inspections.—Inspection criteria for shackles and rings are as follows:

Before each use, shackles shall be inspected to the following criteria.

(1) Shackle pins shall fit freely without binding.
(2) The pin shall show no sign of deformation.
(3) The shackle shall have no defect that will interfere with serviceability.
(4) Before each use, rings shall be visually inspected for damage, corrosion, wear, cracks, twists, and opening.

Operation.—Operating practices and guidelines for the use of shackles are as follows:

(1) The shackle pin shall never be replaced with a bolt; only a properly fitted pin shall be used. Bolts are not intended to take the load that is normally applied to the pin.

(2) Shackles shall not be used if the pin cannot be completely seated.

(3) Shackles shall never be pulled at an angle because the capacity will be tremendously reduced. Centralize whatever is being hoisted on the pin by suitable washers or spacers.

(4) Screw pin shackles shall not be used if the pin can roll under load and unscrew.

Wire Rope Clamps.—

General.—Clamps (also called clips) shall meet or exceed the requirements of Federal Specification FF-C-450, “Clamps, Wire Rope.” Clamps shall be legibly and permanently marked with size and the manufacturer’s identifying mark.

For application information see the Bureau of Reclamation Safety and Health Standards, the Rigging Manual or the manufacturer for guidelines.

Inspections.—Inspection criteria for wire rope clamps follow:

(1) Before use, clamps shall be visually inspected for damage, corrosion, wear, and cracks.

(2) Verify that the clamp components are marked as noted above.

(3) Ensure that the assembled clamp contains the same size, type, and class parts.

***Eyebolts*.—**

Manufacturer Installed Eyebolts.—Eyebolts designed for and permanently installed by the manufacturer on existing engineered equipment are considered part of the engineered equipment. They may not meet all requirements specified for rigging hardware. Eyebolts permanently installed on engineered equipment are acceptable for their intended use as long as they pass visual inspection before use.

It is important to know how the manufacturer of engineered equipment intends permanently installed eyebolts to be used. Eyebolts installed by the manufacturer to lift only parts of the engineered equipment are not suitable for lifting the completely assembled piece of equipment. When questions arise regarding the use of manufacturer-installed eyebolts, the equipment manufacturer or qualified engineer should be consulted.

Eyebolts for Rigging.—

(1) Only shouldered eyebolts (Type 2) shall be used for rigging hardware, except when prohibited by the configuration of the item to which the eyebolt is attached. Where nonshouldered eyebolts (Type 1) are required, they shall be used only in vertical pulls or in rigging systems that are designed, analyzed, and approved by a qualified person.

(2) Eyebolt marking:

  (a) Carbon Steel Eyebolts. Each eyebolt shall have the manufacturer's name or identification mark forged in raised characters on the surface of the eyebolt.

  (b) Alloy Steel Eyebolts. Each eyebolt shall have the symbol “A” (denoting alloy steel) and the manufacturer's name or identification mark forged in raised characters on the surface of the eyebolt.

(3) Eyebolts shall have a minimum design factor of 5, based on ultimate strength.

(4) Carbon steel eyebolts shall be made of forged carbon steel. Alloy steel eyebolts are forged, quenched, and tempered with improved toughness properties, intended primarily for low-temperature applications.

(5) Nuts, washers, and drilled plates shall not be used or assembled to make shouldered eyebolts. Wire type and/or welded eyebolts shall not be used in lifting operations.

(6) Shoulders shall seat uniformly and snugly against the surface on which they bear.

(7) Size 7/8-inch eyebolts should not be used because a 7/8-9 UNC thread may be threaded into a 1-8 UNC tapped hole but will fail when loaded.

Inspections.—Inspection criteria for eyebolts are as follows:

(1) A careful visual inspection of each eyebolt immediately before use is mandatory. Eyebolts that are cracked, bent, or have damaged threads shall be discarded.

(2) The shank of the eyebolt shall not be undercut and shall be smoothly radiused into the plane of the shoulder.

(3) For sizing and safe work loads see the Bureau of Reclamation Safety and Health Standards, the Rigging Manual or the manufacturer for guidelines.

Operation.—Operating practices and guidelines for eyebolts are as follows:

(1) The size of the hole shall be checked for the proper size of eyebolt before installation. The condition of the threads in the hole shall be checked to ensure that the eyebolt will secure and that the shoulder can be brought to a snug and uniformly engaged seat.

(2) When installed, the shoulder of the eyebolt must be flush with the surface (Fig 10-8). When eyebolts cannot be properly seated and aligned with each other, a steel washer or spacer not to exceed one thread pitch may be required to put the plane of the eye in the direction of the load when the shoulder is seated. Proper thread engagement must be maintained. Use a washer with approximately the same diameter as the eyebolt shoulder and the smallest inside diameter that will fit the eyebolt shank.

(3) Angular loading of eyebolts should be avoided. Angular loading occurs in any lift in which the lifting force is applied at an angle to the centerline of the eyebolt shank.

(4) When more than one eyebolt is used in conjunction with multiple-leg rigging, spreader bars, lifting yokes, or lifting beams should be used to eliminate angular loading. Where spreaders, yokes, or beams cannot be used, shouldered eyebolts may be used for angular lifting.

(5) To keep bending forces on the eyebolt to a minimum, the load shall always be applied in the plane of the eye, never in the other direction.

(6) If the hook will not go completely into the eyebolt, use a shackle to avoid loading the hook tip.

(7) Slings shall not be reeved through an eyebolt or reeved through a pair of eyebolts. Only one leg should be attached to each eyebolt.

Hooks.—Rigging hooks are used as part of rigging tackle, such as sling assemblies, or with below-the-hook lifting devices. See Section 5, 'Overhead and Gantry Cranes,' "Hooks," for load hooks on hoists or cranes. Many styles of rigging hooks are available. Some rigging hooks (e.g., grab hooks and sorting hooks) are designed to carry the load near the point as well as in the bowl or saddle of the hook. Maximum safe working loads normally apply only when the load is in the bowl or saddle. Rigging hooks shall be used within the limits specified by the manufacturer. Forged alloy steel hooks generally make the best rigging hooks.

The manufacturer's identification shall be forged or die-stamped on the hook. Loads for rigging hooks shall be equal to or exceed the rated load of the chain, wire rope, or other suspension member to which it is attached. Where this is not feasible, special precautions shall be taken to ensure that the rated load limit of the hook is not exceeded. Welding on hooks, except by the hook manufacturer, is not allowed. Never repair, alter, rework, or reshape a hook by welding, heating, burning, or bending.

Requirements and guidelines for rigging hooks are as follows:

(1) Rigging hooks shall meet or exceed the requirements of ANSI/ASME B30.10, *Hooks*, Chapter 10-2, "Hooks, Miscellaneous."

(2) Throat latches shall be used, unless application makes the use of the latch impractical or unnecessary.

(3) The SWL for a hook used in the manner for which it is intended shall be equal to or exceed the rated load of the chain, wire rope, or other suspension member to which it is attached.

(4) The designated SWL applies only when the load is applied in the bowl or saddle of the hook.

(5) The manufacturer's identification shall be forged or die-stamped on the hook.

Inspections.—Inspection criteria for rigging hooks are as follows:

(1) Rigging hooks that are not permanently installed in a sling assembly shall be visually inspected for the following deficiencies before use:

   (a) Distortions such as bending, or twisting exceeding 10 degrees from the plane of the unbent hook

   (b) Increased throat opening exceeding 15 percent

   (c) Wear exceeding 10 percent of the original dimension

   (d) Cracks, severe nicks, or gouges

   (e) Damage, engagement, or malfunction of latch

(2) Rigging hooks shall be inspected as a part of the slings to which they are attached.

(3) The non destructive testing of rigging hooks is not routinely required. Rigging hook non destructive tests may be required by a critical-lift procedure.

Shop Fabricated Lifting Devices and Rigging Hardware

All lifting devices and rigging hardware shall be designed with a 5:1 factor of safety and in accordance with any applicable ANSI standard. All job-made or repaired wire rope slings and steel chains require marking and proof testing prior to use.

Below-the-Hook Lifting Devices

There are four types of below-the-hook lifters as defined by ASME B30.20, *Below-the-Hook Lifting Devices*. They are arranged in groups as follows:

Group I: Structural and Mechanical Lifting Devices

Structural Lifter – A lifter consisting of an assembly of rigid parts designed to hold and attach a load to a hoisting device.

Mechanical Lifting Device-– A mechanism composed of two or more rigid parts that move with respect to each other for attaching a load to a hoisting device.

***Group II: Vacuum Lifting Device*-–** A below-the-hook lifting device using a holding force by means of vacuum.

***Group III: Magnet, lifting, close proximity operated* –** A lifting magnet used in such a fashion that the operator manually positions the magnet on the load and manually guides the magnet and load during a lift.

***Group IV: Magnet, lifting, remotely operated* –** A lifting magnet that does not require the operator or other personnel to be in close proximity to the magnet or its load while the magnet is in use.

This section provides the requirements for Group I, structural and mechanical below-the-hook lifting devices. The majority of below-the-hook lifting devices used at power and pumping plants include, but are not limited to, supporting lifting devices, indentation-type pressure lifting devices, friction-type pressure lifting devices, spreader bars, lifting jigs, lifting yokes, and load test fixtures. Slings and rigging hardware that may be components in a below-the-hook lifting device are covered in previous sections of this bulletin.

The use of vacuum and magnetic lifting devices is very limited at pumping plants and is not covered in this bulletin.

Structural and mechanical lifting devices are often one-of-a-kind designs.

Design

All specialized devices should be designed and certified for use by a engineer competent in the field and in accordance to the provisions of ASME B30.20. Lifting devices designed for a specific operation should not be used for any other operation unless approved by a competent engineer.

Marking.—

a. The rated capacity of each lifting device shall be marked on the main structure where it is visible and legible. If the lifting device comprises several items, each detachable from the assembly, each lifting device shall be marked with its rated capacity. At a minimum, a nameplate, name tag, or other permanent marker shall be affixed displaying the following data:

   1. Manufacturer's name (contractor's name if fabricated onsite)
   2. Lifting device weight (if over 100 lb)
   3. Serial number (if applicable)
   4. Rated capacity.

b. A rerated lifting device shall be relabeled with the new rated capacity.

Modifications

Any modification or rerating of below-the-hook lifting devices requires documented analysis by a qualified engineer or the manufacturer of the lifting device. Any rerated or modified lifting device requires a new load test. A rerated lifting device also must be appropriately relabeled with the new rated load capacity.

Operations

Below-the-hook lifting devices shall be operated only by qualified personnel.

Inspections

Initial Inspections.—Before initial use, all new, modified, or repaired lifting devices shall be inspected by a designated person to ensure compliance with the provisions of ASME B30.20, *Below-the-Hook Lifting Devices.*

Frequent Inspections.—The user shall inspect for the following deficiencies on each shift or before use. In addition, visual observations should be conducted during regular service for any damage or evidence of malfunction that appears between regular inspections. Deficiencies shall be carefully examined to determine whether they constitute a hazard:

- Structural deformation, cracks, or excessive wear on any part of the lifter
- Loose or missing guards, fasteners, covers, stops, or nameplates
- All functional operating mechanisms and automatic hold and release

- Mechanisms for misadjustments that interfere with operations.
- All load-carrying portions of the device for deformation, cracks, and excessive wear.

Periodic Inspections.—A complete inspection of lifting devices shall be performed by a qualified inspector at 12-month intervals for normal service, 6-month intervals for heavy service, and 3-month intervals for severe service. Fixtures not in use do not require periodic inspection, but the inspection must be performed before use. Any deficiencies shall be examined and a determination made as to whether they constitute a hazard. These inspections shall include the requirements of "Frequent Inspections," noted above, and items such as the following, as applicable:

(1) Loose bolts or fasteners

(2) Cracked or worn gears, pulleys, sheaves, sprockets, bearings, chains, belts, and welds

(3) Excessive wear of linkages and other mechanical parts

(4) Excessive wear at hoist-hooking points and load-support clevises or pins

(5) Marking as required by ASME B30.20

(6) External evidence of damage to structure, motors, and controls.

(7) Lubricate bearings and bushings.

(8) Check that all pivot points and level indicators are free to move. For rarely used lifting devices, apply a protective coating to areas prone to corrosion.

(9) Clean and paint as required.

Inspection Records.—Dated inspection reports and records are to be made for each periodic inspection and any time the lifting device requires adjustment or repair. The most recent inspection records shall be retained in an equipment maintenance file.

Repairs.—Any deficiencies disclosed by the inspection shall be corrected before normal operation of the lifting device is resumed.

Testing.—Keep dated reports of operational tests, rated load tests, and manufacturers' certification, as applicable, so long as the device is available for use.

Before initial use, load test and inspect all new, altered, modified, or repaired lifting devices. Rated load tests shall be done under the direction of a qualified person. A written report furnished by such person confirms the load rating of the lifter. The load rating should not be more than 80 percent of the maximum load sustained during the test. Test loads shall not be more than 110 percent of the rated load unless otherwise recommended be the manufacturer.

At the option of the organization, a manufacturer's certification may be used in lieu of a rated load test only if all the following criteria apply:

(1) The lifter is manufactured by a reputable manufacturer that customarily manufactures structural and/or mechanical lift devices.

(2) The lifter is a standard ready-made item in the manufacturer's normal inventory. (One-of-a-kind items shall be load tested.)

(3) The manufacturer furnishes a written statement, signed and stamped by a registered professional engineer, certifying its structural and operational integrity and that it conforms to the specific requirements of ASME B30.20, "Below-The-Hook Lifting Devices."

Elevators

At the time of publication of this documentation, a new FIST volume on the inspection and maintenance of elevators is being developed which will assist maintenance staff in this area.

Section 19 of Reclamation Safety and Health Standards lists requirements for the installation and maintenance of elevators and other personnel hoists. Passenger and freight elevators are to be inspected and tested in accordance with ANSI A17.1, "Safety Code for Elevators and Escalators," and ANSI A17.2, "Inspector's Manual for Elevators and Escalators." The inspector shall meet the qualification requirements of ASME/ANSI QEI-1, "Standard for the Qualification of Elevator Inspectors," and shall be certified by an organization accredited by the American Society of Mechanical Engineers (ASME) in accordance with the requirements of ASME/ANSI QEI-1. If the state or other organization is responsible for elevator inspections, the inspector shall be an employee of that organization or authorized by that organization. Periodic maintenance should be in accordance to the elevator manufacturer's recommendations and any recommendations of the elevator inspector.

Routine and Periodic Inspections

Semiannual.—Perform routine inspections and tests in accordance with ANSI A17.1, Part X, Section 1001 on all electric passenger and freight elevators.

Annual.—Perform periodic inspections and tests in accordance with ANSI A17.1, Part X, Section 1002 on all electric and hydraulic passenger and freight elevators.

Section 6 – Annunciators

General

Annunciators provide essential plant condition status information to O&M personnel. Two aspects must be considered: (1) correct operation of the annunciator itself and (2) integrity of the alarm devices and interconnected wiring. Annunciator operation is easily tested using the "Test" button provided on most annunciators and is considered an "operations" activity.

Verifying integrity of the alarm devices and interconnecting wiring requires a "functional test" of these circuits. Functional testing is accomplished by (1) resetting the annunciator, (2) closing (or opening) contacts at the alarm device, and (3) verifying that the correct annunciator window is activated. It is recommended that the alarm device actually be triggered, where possible, for best assurance; however, it may be necessary to simulate contact operation with a "jumper" (or lifted lead) when device activation is not possible.

Caution: Operating the alarm device may trigger unwanted control or protection actions as well as annunciation.

Know what "should happen" by consulting up-to-date drawings before triggering alarms.

Annual functional testing of annunciators is recommended for best assurance of integrity. However, this may be considered too extensive for time and resource limitations. In these cases, functional testing of those alarm points that indicate impending shutdown or failure that could be mitigated by operator action is still recommended.

Functional testing of annunciators is also recommended after a major outage or after modifications that affect wiring and cabling in the plant.

Maintenance Schedule for Annunciators

Maintenance or test	Recommended interval
Operational test	Each shift – staffed plants Each visit – unstaffed plants
Functional test	Annually

Section 7 – Arresters

General

Lightning or surge arresters provide protection for important equipment from high-energy surges. These arresters are static devices which require fairly infrequent maintenance. Most maintenance must take place while the associated circuit is de-energized. However, crucial visual inspections and infrared scans can take place while energized.

Maintenance Schedule for Arresters

Maintenance or test	Recommended interval	Reference
Review equipment rating	5 years	North American Electric Reliability Council (NERC) Planning Standard
Visual inspection with binoculars	Quarterly to semi-annually	Reclamation Recommended Practice
Clean porcelain and check connections	3-6 years Ambient dependent	Manufacturer's Instruction Books
Doble test (power frequency dielectric loss, direct current [DC] insulation resistance, power factor)	3-6 years Ambient dependent	Doble Test Data Reference Book, NFPA 70B
Infrared scan	Annually	NFPA 70B 18-17

Section 8 – Batteries and Battery Chargers

General

Battery systems provide "last resort" power for performing communication, alarm, control, and protective functions when other sources of power fail. Battery system maintenance should have highest priority. Computerized, on-line battery monitoring systems can greatly reduce maintenance required on battery systems and actually improve battery reliability and increase battery life. Reclamation has had positive experience with these systems, and they should be considered to supplement a maintenance program.

Battery chargers, important to the health and readiness of battery systems, require regular maintenance as well.

Maintenance Schedule – Flooded, Wet Cell, Lead Acid Batteries

Maintenance or test	Recommended interval	Reference
Visual inspection	Monthly	FIST Volume 3-6, Table 1
Battery float voltage	Shift, monthly, annually	FIST Volume 3-6, Table 1
Pilot cell float voltage	Monthly, quarterly	FIST Volume 3-6, Table 1
Specific gravity	Monthly, quarterly (pilot cell), annually (all cells)	FIST Volume 3-6, Table 1
Temperature	Monthly (pilot cell), quarterly (10 percent of all cells)	FIST Volume 3-6, Table 1
Connection resistance	Annually	FIST Volume 3-6, Table 1
Capacity testing	5-year, annually if capacity less than 90 percent	FIST Volume 3-6 IEEE 450-1995
Safety equipment inspection	Monthly	FIST Volume 3-6 IEEE 450-1995
Infrared scan	Annually	NFPA 70B 18-17

Maintenance Schedule – Valve Regulated, Lead Acid (Gel Cel) Batteries

Maintenance or test	Recommended interval	Reference
Visual inspection	Monthly	FIST Volume 3-6, Table 3
Battery float voltage	Shift, monthly	FIST Volume 3-6, Table 3
Cell float voltage	Monthly, semi-annually	FIST Vol 3-6, Table 3
Temperature	Quarterly	FIST Volume 3-6, Table 3
Connection resistance	Quarterly (25 percent) Annually (100 percent)	FIST Volume 3-6, Table 3
Internal resistance	Quarterly	FIST Volume 3-6, Table 3
Capacity testing	Annually and semi-annually if capacity test less than 90 percent	FIST Volume 3-6, Table 3 IEEE 1188-1996
Safety equipment inspection	Monthly	FIST Volume 3-6, Table 3 IEEE 1188-1996
Infrared scan	Annually	NFPA 70B 18-17

Maintenance Schedule – Vented Nickel Cadmium Batteries

Maintenance or test	Recommended interval	Reference
Visual inspection	Monthly, annually	FIST Volume 3-6, Table 4
Battery float voltage	Shift, monthly, quarterly, semi-annually	FIST Volume 3-6, Table 4
Cell float voltage	Quarterly	FIST Volume 3-6, Table 4
Temperature	Quarterly (pilot cell)	FIST Vol 3-6, Table 4
Intercell connection retorque	Annually	FIST Volume 3-6, Table 4
Capacity testing	5-year, annually if capacity less than 90 percent	FIST Volume 3-6, Table 4 IEEE 1106-1995
Safety equipment inspection	Monthly	FIST Volume 3-6, Table 4 IEEE 1106-1995
Infrared scan	Annually	NFPA 70B 18-17

Maintenance Schedule – Battery Chargers

Maintenance or test	Recommended interval	Reference
Preventive maintenance	Dependent on charger type	FIST Volume 3-6
Infrared scan	Annually	NFPA 70B 18.17

Section 9 – Bushings

General

Bushings are critical components of circuit breakers and transformers. Bushing maintenance is usually conducted at the same time maintenance is performed on the circuit breaker or transformer, or at least during an outage on that equipment.

Maintenance Schedule for Bushings

Refer to the circuit breaker and transformer maintenance sections of this document for bushing maintenance requirements.

Section 10 – Buswork, Enclosures, and Insulators

General

Buswork conducts current from one part of the powerplant or switchyard to another. Buswork is usually constructed of flat or round copper or aluminum busbar and can be either isolated-phase or nonsegregated. Except for infrared scanning, bus maintenance must be conducted de-energized. Standoff buswork insulators provide isolation of “live” power circuits from ground and other circuits. Failure of insulators will cause a power system fault and a forced outage.

Maintenance Schedule for Buswork and Enclosures

Maintenance or test	Recommended interval	Reference
Review equipment ratings	5 years	NERC Planning Standard
External visual inspection Check and tighten connections Check and clean enclosures	Annually	NFPA 70B, 6-1.3 NFPA 70B, 21-4.3
High potential (to ground and between phases) or Doble "tip up"	1-6 years Ambient dependent	NFPA 70B, 21-5.6.2
Infrared scan	Annually	NFPA 70B, 21-5.2.2

Maintenance Schedule for Insulators

Maintenance or test	Recommended interval	Reference
Dielectric loss	5 years	Doble M2H Instruction Manual
Infrared scan	Annually	NFPA 70B, 18-17

Section 11 – Power Cables – Rated 5 Kilovolts (kV) and Above

General

High voltage cable conducts power between the powerplant and switchyard. The cable may be solid dielectric or oil-filled. In the case of critical circuits, periodic maintenance tests are justified during the life of the cable to determine whether or not there has been significant insulation deterioration due to operational or environmental conditions.

Direct current (DC) high potential tests effectively reduce in-service failures from faults of the cable or its accessories. When done properly, maintenance tests can detect cables that are approaching failure without accelerating the deterioration process. However, the insulated conductor industry has determined that DC testing of crosslinked polyethylene (XLPE) insulation systems after the initial 5 years is detrimental to the life of the insulation.[3]

[3] Association of Edison Illuminating Companies (AEIC) CS 5-94, "Specifications for Cross-Linked Polyethylene Insulated Shielded Power Cables Rated 5 through 46 kV," paragraph L-2.

Therefore, periodic direct-current maintenance tests are not recommended for XLPE cables. Other types of cable insulation are not subject to the same aging characteristics and, therefore, can be tested in accordance with manufacturer's recommendations and industry standards.

Except for infrared scanning, de-energize the cable circuit before maintenance. For assistance in determining appropriate test methods and voltage levels for a specific cable installation, please contact D-8450 at (303) 445-2300.

Maintenance Schedule for High-Voltage Cables

Maintenance or test	Recommended interval	Reference
Review equipment ratings	5 years	NERC Planning Standard
DC high potential test (stepped or ramped voltage method)	3-6 years[1]	FIST Volume 3-1 NFPA 70B IEEE 400
Oil tests (dissolved gas analysis [DGA], dielectric, acidity, color, interfacial tension, water content, power factor)	Annually	FIST Volume 3-5
Infrared scan	Annually	NFPA 70B, 18-17

[1] Except XLPE cables.

Section 12 – Coupling Capacitors

General

Coupling capacitors provide a path for communication frequency signals (traveling over the transmission line) to reach communication and relaying equipment without allowing power system frequency energy to pass. These are static devices requiring relatively little maintenance. Except for infrared scanning, maintenance must be conducted with equipment de-energized.

Maintenance Schedule for Coupling Capacitors

Maintenance or test	Recommended interval	Reference
Review equipment ratings	5 years	NERC Planning Standard
Power factor	2 years	Doble Reference Book on Cables and Accessories; Doble Power Factor Test Data Reference Book
Infrared scan	Annually	NFPA 70B, 18-17

Section 13 – Circuit Breakers

General

Circuit breakers interrupt electrical current to stop power flow both for switching operations and during fault conditions.

- Molded case circuit breakers are usually located in low voltage distribution panels and in control boards. These are typically 120-volts alternating current (Vac), 125-volts direct current (Vdc), 240-Vac, and 480-Vac breakers for control, protection, and auxiliary power. Molded case breakers in panel boards should not be loaded more than 80 percent of rating per NFPA 70B, 11-2.

- Low voltage air breakers are usually located in motor starter cabinets, motor control centers, station service switchgear, or similar enclosures. These are typically 480 Vac for auxiliary power.

- Medium voltage circuit breakers are generally located in station-service metal clad switchgear or in separate enclosures as unit breakers. Examples are 4160-Vac station service, 11.95-kV and 13.8-kV unit breakers. These breakers may be air, air blast, vacuum, or SF6.

- High voltage circuit breakers are located in separate breaker enclosures, either indoors or outdoors. These are oil, air-blast, or SF6 breakers. Examples are 115-kV and 230-kV breakers located in the switchyard.

- Extra high voltage (EHV) circuit breakers are not addressed in this bulletin. Reference the manufacturer's instruction books.

Most breaker maintenance (except infrared scanning) must be performed with equipment de-energized.

Molded Case Breaker Maintenance Schedule

Maintenance or test	Recommended interval	Reference
Review equipment ratings	5 years	NERC Planning Standard
Visual inspection	3-6 years	NFPA 70B, 11-8 and Appendix H
Mechanical operation by hand	3-6 years	NFPA 70B, 11-8 and Appendix H
Infrared scan	Annually	NFPA 70B 18-17

Low Voltage (Less Than [<] 600 Vac) Air Breaker Maintenance Schedule

Maintenance or test	Recommended interval	Reference
Review equipment ratings	5 years	NERC Planning Standard
Preventive maintenance	Per manufacturer's recommendations	Manufacturer's Instruction Book
Inspection and maintenance	1-3 years	NFPA 70B, Appendix H
Overcurrent and fault trip settings and testing	1-3 years per FIST 3-5 years per NFPA	FIST Volume 3-16 NFPA 70B 6.4 and 18-10.2
Infrared scan	Annually	NFPA 70B, 18-17.5

Medium Voltage (600-15,000 Vac) Air and Air Blast Breaker Maintenance Schedule

Maintenance or test	Recommended interval	Reference
Review equipment ratings	5 years	NERC Planning Standard
Preventive maintenance	Per manufacturer's instructions and per Appendix A	Manufacturer's Instruction Book FIST Volume 4-1B, Appendix A
Inspection and maintenance, lube, clean, adjust, align control mechanism	1-3 years	NFPA 70B, 6-4 and Appendix H
Overcurrent trip settings and testing	Annually or 2,000 operations (3-year maximum)	FIST Volume 3-16 NFPA 70B, 6-4
Contact resistance measurement	Per manufacturer's instructions	Manufacturer's Instruction Book
Breaker timing (Motion analyzer)	Annually or 2,000 operations	FIST Volume 3-16
High potential (to ground and between phases)	3-6 years	NFPA 70B, 18-5.3 and Appendix H
Power factor	3-6 years	NFPA 70B Doble Field Test Guide
Infrared scan	Annually	NFPA 70B, 18-17.5

Medium Voltage (600-15,000 Vac) Vacuum Breaker Maintenance Schedule

Maintenance or test	Recommended interval	Reference
Review equipment ratings	5 years	NERC Planning Standard
Preventive maintenance	Per Manufacturer's Instruction Book	Manufacturer's Instruction Book
Record meter readings, check temperature and pressure switch operation, calibrate gages	Annually	Manufacturer's Instruction Books Western Area Power Administration (WAPA) Standard Maintenance Guidelines, Chapter 13
Record operations counter	Biweekly	Manufacturer's Instruction Books
Check foundation, grounds, paint Check external screws, bolts, electrical terminals tight	Annually	Manufacturer's Instruction Books WAPA Standard Maintenance Guidelines, Chapter 13
Contact resistance measurement, motion analyzer, trip test	Annually	Manufacturer's Instruction Books WAPA Standard Maintenance Guidelines, Chapter 13
Power factor, AC high potential (including across open contacts[1])	5 years	Manufacturer's Instruction Books WAPA Standard Maintenance Guidelines, Chapter 13
Lube, clean, adjust, align control mechanisms	Annually	Manufacturer's Instruction Books WAPA Standard Maintenance Guidelines, Chapter 13

[1] Caution: Refer to manufacturer's instructions regarding safe distances to avoid X-radiation.

Medium and High Voltage SF6 Breaker Maintenance Schedule

Maintenance or test	Recommended interval	Reference
Review equipment ratings	5 years	NERC Planning Standard
Preventive maintenance	Per Manufacturer's Instruction Book	Manufacturer's Instruction Book
Record gas pressure and temperature, compare with tolerances	Biweekly	Manufacturer's Instruction Books
Record operations counter	Biweekly	Manufacturer's Instruction Books
Visual inspection	Biweekly, annually, 5 years	Manufacturer's Instruction Books
Check foundation, grounds, paint	5 years	Manufacturer's Instruction Books WAPA Standard Maintenance Guidelines, Chapter 13
Check external screws, bolts, electrical terminals tight	Annually	Manufacturer's Instruction Books
Contact resistance test, power factor insulation test, motion analyzer, trip test, moisture test on gas	5 years	WAPA Standard Maintenance Guidelines, Chapter 13
Verify operation and calibration of temperature and pressure switches and gages	5 years	WAPA Standard Maintenance Guidelines, Chapter 13
Check oil levels; carbon brush condition; heater operation, tightness of terminals, linkages, screws, bolts; latch, linkage, operating mechanism adjustments	5 years	Manufacturer's Instruction Books
Overhaul breaker with new seals, contacts, nozzles	10 to 15 years or 4,000 to 10,000 operations (more frequent if high current operation)	Manufacturer's Instruction Books
Overhaul disconnect, grounding, and breaking switches	15 years or 5,000 to 10,000 operations	Manufacturer's Instruction Books

High Voltage (Greater Than [>] 15,000 Vac) Oil Circuit Breaker Maintenance Schedule

Maintenance or test	Recommended interval	Reference
Review equipment ratings	5 years	NERC Planning Standard
Preventive maintenance	Per manufacturer's recommendations, FIST Volume 3-16, and Appendix A	Manufacturer's Instruction Books FIST Volume 3-16 FIST Volume 4-1B, Appendix A
Visual inspection	2 years	FIST Volume 3-16 Doble Reference Book on High Voltage Circuit Breakers NFPA 70B, 6-6
Breaker and bushing Doble test	3-5 years (6 months to 1 year for suspect bushings)	FIST Volume 3-2 FIST Volume 3-16 Doble Reference Book on High Voltage Circuit Breakers
Contact resistance	Per manufacturer's recommendations	Manufacturer's Instruction Book
Breaker timing (Motion analyzer)	3-5 years	FIST Volume 3-16
Bushing - visual inspection	Annually with binoculars and 3-5 years	Doble Bushing Field Test Guide IEEE P62-1995
Bushing - Doble with hot collar	3-5 years, more often if ambient condition requires	Doble Bushing Field Test Guide
Bushing - cleaning	3-5 years, more often if ambient condition requires	Reclamation Recommended Practice
Bushing - visual inspection for cracks and leaks	Quarterly	Reclamation Recommended Practice
Infrared scan	Annually	NFPA 70B, 18-17
Insulating oil - Doble test (power factor and dielectric strength) and dissolved gas analysis	3-5 years	FIST Volume 3-5 Doble Reference Book on Insulating Liquids and Gasses ANSI C57.104

Section 14 – Communication Equipment

This document does not define maintenance of communication equipment used in power system or pumping plant operation.

Refer to communication system operation and maintenance requirements included in these documents:

- Bureau of Reclamation Radio Communication Systems - Management and Use - Guidelines 07-01

- Department of the Interior - Departmental Manual - Radio Communications Handbook (377DM)

Information regarding operation and maintenance of Reclamation communication systems may be found at the Reclamation intranet site: http://intra.usbr.gov/telecom.

Section 15 – Control Circuits

General

Control circuits (usually 125 Vdc or 120 Vac) provide the path for all control functions for major equipment in the powerplant. Reliability of these circuits is paramount. Although tested during commissioning, these circuits can become compromised over time through various means:

- Modifications and construction work which unintentionally break circuit integrity or introduce wiring errors.

- Age and deterioration of wiring rendering the system nonfunctional.

- Connections that become loose.

- Failure of individual control and protection devices due to misuse, old age, or inadvertent damage.

Verifying the integrity of the control devices and interconnecting wiring requires a "functional test" of these circuits. Functional testing of control circuits may be considered completed in the course of normal plant operation. However, control circuits that rarely are used should be functionally tested on a periodic basis.

Maintenance Schedule for Control Circuits

Maintenance or test	Recommended interval	Reference
Functional test control circuits	3-6 years	NFPA 70B under specific equipment and Appendix H

Section 16 – CO_2 Systems

General

Carbon dioxide (CO_2) systems provide fire suppression for generator and large motor windings. These systems consist of CO_2 storage bottles or tanks, piping and valves, and electrical control systems.

Maintenance Schedule for CO_2 Systems

Caution: CO_2 is dangerous and costly to replace. Take care to avoid inadvertent CO_2 discharge during maintenance and testing.

Maintenance or test	Recommended interval	Reference
Weigh CO_2 bottles	Semi-annually	FIST Volume 5-2, 6.4.3
Check electrical controls	Monthly	FIST Volume 5-2, 6.4.3
Operate routing valves	Annually and after painting	FIST Volume 5-2, 6.4.3
Overall CO_2 system functional test	Annually	FIST Volume 5-2, 6.4.3
Cylinder discharge and hydrostatic test	12 years Any discharged cylinder not hydrostatically tested in past 5 years must be tested prior to refill.	FIST Volume 5-2, 6.4.3
Visually inspect and functional test CO_2 discharge warning beacons	Annually	NFPA 72. 7-3.1 NFPA 72 7-3.2

Section 17 – Cranes, Hoists, and Elevators

General

Cranes, hoists, and elevators are important to operation and maintenance of the facility. Proper maintenance of cranes and hoists will ensure they are ready for service which will reduce time and cost of maintaining other equipment. Maintaining elevators is important to the convenience and safety of staff, visitors, and the public. Also, elevators must be inspected periodically by a certified elevator inspector. Maintenance of these types of equipment is important to the safety of everyone.

Maintenance Schedule for Cranes, Hoists, and Elevators

Mechanical maintenance of cranes, hoists, and elevators is covered in section 5 of this bulletin. Only the electrical components are covered here.

Maintenance or test	Recommended interval	Reference
Inspect motors, controls, wiring	Annually	PO&M Bulletin No. 19

Section 18 – Electrical Drawings

General

Electrical drawings, especially control and protection schematics and wiring diagrams, are the most important references for ongoing O&M of a facility. Ideally, these drawings will be kept current with all modifications and replacements to plant equipment. Every effort must be made to keep key electrical drawings up to date to avoid risk to equipment and staff. Key electrical drawings should be accessible to all O&M personnel.

Maintenance Schedule for Electrical Drawings

Maintenance or test	Recommended interval
Key control and protection schematics	Current and available
Key wiring diagrams	Current and available
1-line, 3-lines, tripping, switching diagrams	Current and available
Relay data sheets	Current and available

Section 19 – Emergency Lighting

General

Reliable plant emergency lighting is essential for personnel safety.

Maintenance Schedule for Emergency Lighting

Maintenance or test	Recommended interval	Reference
Preventive maintenance	Per manufacturer's recommendation	Manufacturer's Instruction Book
Functional test	Monthly (30 seconds)	NFPA 101, Section 5.9.3
Functional test	Annually (1½ hours)	NFPA 101, Section 5.9.3

Section 20 – Exciters and Voltage Regulators

General

Exciters and voltage regulators comprise excitation systems which provide appropriate DC excitation for the field of generators and synchronous motors. Excitation systems may be rotating or static.

Maintenance Schedule for Exciters and Voltage Regulators

Some components of excitation systems (e.g., transformers, circuit breakers, protective relays, annunciators, and buswork) may require maintenance similar to that described in like sections of this document. However, excitation system manufacturer maintenance requirements supersede requirements specified in these sections.

Automatic voltage regulator performance testing ("alignment") is a specialty, requiring specialized training and unique equipment as well as knowledge of current power system stability requirements. It is recommended that qualified staff in the Hydroelectric Research and Technical Services Group (D-8450) perform these tests.

Maintenance or test	Recommended interval	Reference
Preventive maintenance	Per manufacturer's recommendations	Manufacturer's Instruction Book
Automatic voltage regulator (AVR) and power system stabilizer (PSS) performance testing (Contact the Controls Team of the Hydroelectric Research and Technical Services Group, D-8450, 303-445-2309)	5 years	Western System Coordinating Council Controls Working Group (WG) Recommendations Fiscal Year 1999 Government Performance and Results Act (GPRA) Goals NERC White Paper on Certification and Performance Measures for Interconnected Operation Services
Infrared Scan	Annually	Reclamation Recommended Practice

Section 21 – Fire Detection and Alarm Systems

General

Fire detection and alarm systems provide indication and warning of fire in the facility. They are crucial to safety of personnel and the public. Correct operation may also minimize damage to equipment by an early response. Regular maintenance of systems in unstaffed facilities is particularly important because O&M staff are not usually present to detect problems.

Maintenance Schedule for Fire Detection and Alarm Systems

Maintenance or test	Recommended interval	Reference
All circuits - functional test	Annually - staffed facility Quarterly - unstaffed facility	NFPA 72 7-3.1
Visual inspection of detection and control equipment (fuses, interfaces, lamps, LED's, primary power supply)	Annually - staffed facility Weekly - unstaffed facility	NFPA 72 7-3.1
Visual inspection - batteries	Monthly	NFPA 72 7-3.1
Lead acid battery 30-minute discharge and load voltage test	Monthly	NFPA 72 7-3.1
Ni Cad battery 30-minute discharge and load voltage test	Annually	NFPA 72 7-3.1
Other maintenance[1]	Per NFPA recommendations	NFPA 72 7

[1] NFPA 72 7 is revised regularly, and requirements change frequently. Reference the latest version of the standard for the latest requirements.

Section 22 – Fuses

General

Fuses provide power and control circuit protection by interrupting current under certain overload and fault conditions.

Maintenance Schedule for Fuses

Some fuse failures are self evident. Loss of meter indication or control circuit operation may indicate a blown (open) fuse. Other fuses that are critical to equipment operation may be monitored and their opening alarmed. However, some fuse operation cannot be detected remotely and should be assessed by regular maintenance. It may be as simple as looking for the "fuse operated" indicator on the fuse, or it may require checking with an ohmmeter. Failure to do so may result in more significant failure leading to an outage.

Maintenance or test	Recommended interval	Reference
Review equipment ratings	5 years	NERC Planning Standard
Visual inspection	3-6 months	NFPA 70B.13 and Appendix H
Remove and check	3-6 years	NFPA 70B.13 and Appendix H
Infrared scan	Annually	NFPA 70B.13 and NFPA 70B, 18-17 and Appendix H

Section 23 – Generators and Large Motors

General

Generators produce electrical energy from mechanical power transmitted from the turbine. Large motors drive pumps to move water. Generators and large motors included in this section are synchronous machines performing the primary function of the power or pumping plant. Small motors are covered in the section, "Motors."

References and Standards

Maintenance references and standards from which the recommendations are drawn are numerous:

- Manufacturers Instruction Books
- FIST Volume 3-1, Testing Solid Insulation of Electrical Equipment
- Power O&M Bulletin No. 19 - Maintenance Schedules and Records
- IEEE Std. 432-1992, Guide for Insulation Maintenance for Rotating Electric Machinery (5 hp to 10,000 hp).
- IEEE Std. 95-1997, Recommended Practice for Insulation Testing of Large AC Rotating Machinery with High Direct Voltage
- Conditions Rating Procedures/Condition Indicator for Hydropower Equipment, U.S. Army Corps of Engineers

- Handbook to Assess the Insulation Condition of Large Rotating Machines, Volume 16, Electric Power Research Institute (EPRI)
- Electric Generators, Power Plant Electrical Reference Series, Volume 1, EPRI
- Inspection of Large Synchronous Machines, I. Kerszenbaum
- Test Procedure for Synchronous Machines, IEEE 115-1983
- Guide for Operation and Maintenance of Hydrogenerators, IEEE Std. 492-1974

Maintenance Schedule for Generators and Large Motors

Maintenance or test	Recommended interval
Preventive maintenance and inspections	No standard recommended interval. Machine specific PM according to site operating conditions. Also, see Appendix B.
Stator winding - physical inspection	During 1-, 2½-, and 5-year warranty inspections; thereafter, during major maintenance outages but not to exceed 5 years.
Stator winding - high voltage DC ramp test	3 to 5 years and after prolonged maintenance outage.
Stator winding - insulation resistance polarization index (Megger)	Performed in lieu of HVDC ramp test
Stator winding - AC high potential test	At factory and as an acceptance test. Non-routine thereafter but may be used to verify insulation integrity before and/or after stator winding repair.
Stator winding - partial discharge measurements (corona probe/scope)	Benchmarked within first 5 years of operation then annually thereafter. Three- to six-month intervals if deterioration detected.
Stator winding - black out test	Nonroutine. Performed when deterioration is suspected.
Stator winding - ozone measurement	Nonroutine. Performed when deterioration detected.
Stator winding - wedge tightness measurements	During 1-, 2½-, and 5-year warranty inspections; thereafter, performed after rotor is removed (particularly if unit in operation for 20-25 years without re-wedging).
Stator winding - power factor measurements (Doble)	Nonroutine. May be performed in conjunction with other generator-condition tests.

Maintenance or test	Recommended interval
Stator core - physical inspection	During 1-, 2½-, and 5-year warranty inspections; thereafter, during major maintenance outages but not to exceed 5 years.
Stator core - core magnetizing test	Nonroutine. Should be performed prior to rewind or if core has been damaged.
Rotor - physical inspection	During major maintenance outages but not to exceed 5 years.
Rotor - insulation resistance polarization (Megger)	Annually or after maintenance outage.
Rotor - AC pole drop test	Nonroutine. Performed when deterioration is suspected.
Thrust and upper guide bearing insulation test	Annually per FIST Volume 5-11.

Section 24 – Ground Connections

General

Equipment grounding is an essential part of protecting staff and equipment from high potential caused by electrical faults. Equipment grounding conductors are subject to failure due to corrosion, loose connections, and mechanical damage. Grounding may also be compromised during equipment addition and removal or other construction-type activities. Periodically verifying grounding system integrity is an important maintenance activity.

Maintenance Schedule for Ground Connections

Maintenance or test	Recommended interval	Reference
Visual inspection, tighten connectors	Annually	PO&M Bulletin No. 19

Section 25 – Meters

General

Meters indicate, and sometimes record, electrical and mechanical quantities for operator information. Some meters also transmit stored data to Supervisory Control and Data Acquisition (SCADA) or other systems. Accuracy of meter indication is important to ensure correct power and water systems operation.

Maintenance Schedule for Meters

Maintenance or test	Recommended interval
Calibration	Annually

Section 26 – Motors (< 500 hp)

General

Motors of this type drive pumps, valves, gates, and fans. They are usually induction motors and are generally less than 500 hp but may be somewhat larger. Critical motors should routinely be tested.

Maintenance Schedule for Motors

Maintenance or test	Recommended interval	Reference
Insulation resistance (Megger)	Annually	FIST Volume 3-4, Section 2.2
Infrared scan	Annually	NFPA 70B, 18-17.5

Section 27 – Oil, Insulating

Insulating oil is associated with oil-filled cable, oil circuit breakers, and transformers. Refer to those sections of this document for oil maintenance and testing requirements.

Section 28 – Personal Protective Equipment

General

Personal protective equipment is used by maintenance workers to provide protection from hazardous electrical energy. Integrity of this equipment is paramount so maintenance should be scheduled and accomplished similar to equipment maintenance.

Maintenance Schedule for Personal Protective Equipment

Maintenance or test	Recommended interval	Reference
Review equipment ratings	5 years	NERC Planning Standard
Safety ground - visual inspection	Annually and before each use	NFPA 70E, 11-3.2 FIST Volume 5-1
Safety ground - millivolt drop test	Annually	NFPA 70E, 11-2 FIST Volume 5-1
Hot stick inspection and electrical test	Annually and before each use	PO&M 19, Section 11 FIST Volume 3-29, A.3
Gloves, sleeves, blankets tests	Annually	Per Manufacturer's Instruction Book NFPA 70E, 11-2

Section 29 – Potheads and Stress Cones

General

Potheads and stress cones provide mechanical support and electrical insulation for conductors like cable. Insulating capability of these devices is important to prevent a fault and resulting forced outage.

Maintenance Schedule for Potheads and Stress Cones

Maintenance or test	Recommended interval	Reference
Visual inspection for leaks, cracks	Annually	NFPA 70B, 8-2.4 and Appendix H
Doble AC loss measurement (hot collar)	3-6 years	FIST Volume 3-1 Doble Reference Book on Cables and Accessories
Infrared scan	Annually	NFPA 70B, 18-17

Section 30 – Regulator, Voltage

General

Voltage regulators are static devices operating at power system voltages and frequencies to maintain stable voltage. De-energization is required for some maintenance. (For excitation system type voltage regulators, see section 16 on exciters, earlier in this volume).

Maintenance Schedule for Voltage Regulators

Maintenance or test	Recommended interval	Reference
Doble power factor	5 years	Doble Power Factor Test Data Reference Book
Infrared scan	Annually	NFPA 70B, 18-17

Section 31 – Relays and Protection Circuits

General

Protective relays monitor critical electrical and mechanical quantities and initiate emergency shutdown whenever they detect out-of-limits conditions.

Protective relays must operate correctly when abnormal conditions require and must not operate at any other time.

Electrical protective relays are calibrated with settings derived from system fault and load studies. Initial settings are provided when relays are installed or replaced. However, electrical power systems change as new generation and transmission lines are added or modified. This may mean that relay settings are no longer appropriate. Outdated relay settings can be hazardous to personnel, to the integrity of the powerplant and power system, and to the equipment itself. Therefore, it is necessary to periodically conduct a fault and load study and review protective relay settings to ensure safe and reliable operation.

Fault and load studies and relay settings are provided by the Electrical Design Group (D-8440) at 303-445-2813. Field-initiated changes to relay settings should be verified by this group.

Protective relays currently in use in Reclamation include electro-mechanical, solid-state, and microprocessor-based packages. Calibration and maintenance recommendations differ from type to type because of their different design and operating features.

Calibration

This process usually includes removal of the relay from service to a test environment. Injecting current and/or voltage into the relay and observing the response according to the manufacture's test procedure verifies the recommended settings. Calibration of electro-mechanical relays is recommended fairly frequently since operating mechanisms can wear and get out of adjustment. Calibration of solid-state and micro-processor-based relays is recommended less frequently since there are fewer ways for them to get out of calibration.

Relay Functional Test

This process verifies that the protective outputs of the relay (e.g., contact closures) actually operate as intended. This can be accomplished as part of the calibration procedure in most cases, but relay functional testing should be verified according to the maintenance schedule.

Protective relays operate into protection circuits to accomplish the desired protective action. Similar to control circuits, protection circuit integrity may be compromised by construction, modifications, deterioration, or inadvertent damage. A compromised protection circuit may not provide the system and plant protection desired. Periodic functional testing is recommended to ensure the integrity of protection circuits.

Protection Circuit Functional Testing

This process verifies that the entire protective "trip path" from protective relay through circuit breakers (or other protective equipment) is intact and functional. This requires actually operating the entire circuit to verify correct operation of all components.

Protective circuit functional testing is accomplished as follows:

- ❑ Conduct a Job Hazard Analysis.
- ❑ Verify that testing will not disrupt normal operation or endanger staff or equipment.

- With lockout relays reset, initiate lockout relay trip with the protective device contact.[4]

- Verify the lockout relay actually tripped from the protective relay action. Verify that circuit breakers actually tripped (or other protective action occurred) from the lockout relay action.

- Activate the lockout relay from each protective device. After the first full test of lockout relay and breakers, it may be desirable to lift the trip bus from the lockout relay so as not to repeatedly trigger the lockout—a meter may be substituted.

Caution: Do not forget to reconnect the trip bus to the lockout relay when testing is complete.

Where functional testing of ALL protection circuits is unfeasible, testing of the most critical protection circuits and devices is still recommended.

Reclamation standard design for lockout relay and circuit breaker control circuits includes the use of the red position/coil status indicator light to monitor the continuity of the circuit through the trip coil. These lights should be lit when the lockout relay is in the "Reset" position or when the breaker is closed. If the light is not lit, this may indicate a problem with the coil integrity which should be addressed immediately.

Maintenance Schedule for Relays and Protection Circuits

Maintenance or test	Recommended interval	Reference
Fault/load study and recalculate settings	5 years	Reclamation Recommended Practice
Electro-mechanical relays Calibration and functional testing	Upon commissioning and every 2 years	Reclamation Recommended Practice
Solid-state relays Calibration and functional testing	Upon commissioning 1 year after commissioning 5 years	Reclamation Recommended Practice
Micro-processor relays Calibration and functional testing	Upon commissioning 1 year after commissioning	Reclamation Recommended Practice

[4] It is recommended that the protective device actually be operated where possible for best assurance. The ideal functional test is to actually change input quantities (e.g., instrument transformer secondary injection) to the protective device to thoroughly test the entire protection path. However, it may be necessary to simulate contact operation with a "jumper" when device activation is not possible.

Maintenance or test	Recommended interval	Reference
	8-10 years	
Protection circuit functional test	Annually	FIST Volume 3-8 Manufacturer's Instruction Books
Check red light lit for lockout relay and circuit breaker coil continuity	Daily[1]	Reclamation Recommended Practice
Lockout relays Cleaning and lubrication	5 years	Power Equipment Bulletin No. 6

[1] In staffed plants, in conjunction with daily operator control board checks. Otherwise, check each visit to the plant.

Section 32 – SCADA Systems

General

Supervisory Control and Data Acquisition (SCADA) systems are computer-based, real-time control systems for power and water operations. Since these systems are in operation continuously and are in many ways self-diagnosing, regular maintenance and testing is not necessary except as recommended by the manufacturer. However, circuits that are infrequently used may require periodic functional testing to ensure they will be operational when the need arises.

Security requirements affecting SCADA are dictated by documents such as Presidential Decision Directive 63: Critical Infrastructure Protection, May 22, 1998 and Office of Management and Budget (OMB) Circular A-130, Appendix III, Security of Federal Automated Resources, February 8, 1996. Periodic audits, Critical Infrastructure Protection Plans (CIPP), and regularly scheduled security training are important requirements of SCADA security.

Maintenance Schedule for SCADA Systems

Maintenance or test	Recommended interval	Reference
Preventive maintenance	Per manufacturer's recommendations	Manufacturer's Instruction Books
Functional test circuits	3-6 years	Reclamation Recommended Practice

Maintenance or test	Recommended interval	Reference
Failure mode tests	Annually	Reclamation Recommended Practice
Security - audit	3 years	OMB Circular A-130, Appendix III
Security - CIPP updated	2 years	Presidential Decision Directive 63
Security - training	Annually	Public Law (P.L.) 100-235, Computer Security Act of 1987
Uninterruptible power supply test	Annually	Reclamation Recommended Practice

Section 33 – Switches, Disconnect – Medium and High Voltage

General

When open, disconnect switches permit isolation of other power system components thus facilitating safety during maintenance procedures. Disconnect switches may be manually or motor operated and, in some cases, may integrate fuse protection. (See section 18 on fuses).

Maintenance Schedule for Disconnect Switches

Maintenance or test	Recommended interval	Reference
Review equipment ratings	5 years	NERC Planning Standard
Preventive maintenance	Per manufacturer's recommendations and per Appendix C	Manufacturer's Instruction Books and Appendix C
Visual inspection	Semi-annual	NFPA 70B, 6-7 and Appendix H FIST Volume 4-1B, Appendix C
Infrared scan	Annually	NFPA 70B, 18-17

Section 34 – Transducers

General

Transducers convert data collected in one format into electrical signals used by meters and computerized monitoring and control systems. Accuracy of transduced signals is important to alarm and control functions. Examples of transduced data include:

- Bearing oil level or temperature read by a meter or scanning equipment
- Megawatt or megavars as input to the SCADA system

Maintenance Schedule for Transducers

Maintenance or test	Recommended interval
Calibration	Annually

Section 35 – Transformers

General

Transformers convert electrical power from one voltage level to another. Transformer reliability is essential to the continued delivery of the facility's services.

References and Standards

Maintenance references and standards from which the recommendations are drawn are numerous:

- Manufacturers' Instruction Books
- Doble Transformer Maintenance and Test Guide
- IEEE Std. 62-1995
- FIST Volume 3-30, Transformer Maintenance
- NFPA 70B - Recommended Practices for Electrical Equipment Maintenance

Station/Distribution Transformers

General

Station and distribution transformers generally operate at relatively low voltages and power ratings. They provide step-down power to supply plant auxiliary loads—for example, a 480 - 240/120-Vac transformer that supplies power to auxiliary lighting panels.

Maintenance Schedule for Station and Distribution Transformers

Maintenance or test	Recommended interval	Reference
Review equipment ratings	5 years	NERC Planning Standard
Infrared scan	Annually	NFPA 70B, 18-17
Power factor test if oil-filled	3-6 years	FIST Volume 3-30
Dissolved gas analysis if oil-filled	Annually	Reclamation Recommended Practice

Instrument Transformers

General

Instrument transformers convert power-system level voltages and current to levels safe to feed meters and other low voltage and current devices. Voltage or potential transformers generally have output in the 240/120-Vac range, while current transformers have output in the 2.5- to 5-ampere range. Voltage transformers may be integral to other equipment or stand-alone. Typically, current transformers are integral to other equipment (circuit breakers, transformers) but occasionally may be stand-alone (e.g., 500-kV switchyard at Grand Coulee).

Over the course of time, instrument transformers (particularly current transformers) may become overburdened with the addition of more devices in the secondary circuit. This may lead to saturation during a fault which may cause the relay to misoperate. Periodically measuring secondary burden and comparing it to the transformer rating will indicate if this is a problem.

Instrument transformer secondary wiring should always be checked for integrity after any work that may have disrupted these circuits.

Maintenance Schedule for Instrument Transformers

Maintenance or test	Recommended interval	Reference
Review equipment ratings	5 years	NERC Planning Standard
Burden measurements	5 years	FIST Volume 3-8
Power factor test	5 years	Reclamation Recommended Practice
Visual inspection	Annually	Reclamation Recommended Practice
Infrared scan	Annually	NFPA 70B, 18-17

Power – Dry-Type Transformers

General

Dry-type power transformers are air cooled, having no liquid insulation. Typical applications include station service and excitation system transformers.

Maintenance Schedule for Dry-Type Power Transformers

Maintenance or test	Recommended interval	Reference
Review equipment ratings	5 years	NERC Planning Standard
Infrared scan	Annually	NFPA 70B, 18-17 Transformer FIST Volume 3-30
Temperature alarm check	Annually	NFPA 70B, 7-3 and Appendix H Transformer FIST Volume 3-30
Visual inspection/cleaning	Annually	NFPA 70B, 7-3 and Appendix H Transformer FIST Volume 3-0

Maintenance or test	Recommended interval	Reference
Check fan operation	Annually	NFPA 70B, 7-3 and Appendix H Transformer FIST Volume 3-30
Clean fans and filters	Annually	NFPA 70B, 7-3 and Appendix H Transformer FIST Volume 3-30
Turns ration test	3-6 years or if problems are suspected	NFPA 70B, Appendix H
Megger windings	3-6 years or when problem is suspected	NFPA 70B, Appendix H

Power – Oil-Filled Transformers

General

Oil filled transformers generally deliver power to and from the main units of the facility—for example, generator step-up transformers. These transformers are generally located outside the building in a transformer bay or in a switchyard. These transformers may be two-winding or more and include autotransformer

Maintenance Schedule for Oil-Filled Power Transformers

Maintenance or test	Recommended interval	Reference
Review equipment ratings	5 years	NERC Planning Standard
Preventive maintenance	Per manufacturer's recommendations	Mfr. Instruction Books
Transformer physical inspection	Annually	NFPA 70B, 7-2 and Appendix H Transformer FIST Volume 3-30
Bushings - visual inspection	Quarterly and 3-5 years	Doble Bushing Field Test Guide IEEE P62-1995

Maintenance or test	Recommended interval	Reference
		Transformer FIST Volume 3-30
Bushings - check oil level	Weekly	PO&M 19 Transformer FIST Volume 3-30
Bushings - cleaning	3-5 years	Transformer FIST Volume 3-30
Transformer and bushings - Doble test	3-5 years (6 months to 1 year for suspect bushings)	FIST Volume 3-2 Doble Bushing Field Test Guide IEEE P62-1995, 6.2 Transformer FIST Volume 3-30
Transformer and bushings - infrared scan	Annually	NFPA 70B, 18-17 Transformer FIST Volume 3-30
Core - ground and insulation resistance	If DGA shows hot metal gasses	Transformer FIST Volume 3-30
Insulating oil - dissolved gas analysis, physical, and chemical tests	Annually after first year of operation	NFPA 70B FIST Volume 3-5 Transformer FIST Volume 3-30
Windings and core - Megger test	3-5 years or if DGA indicates	IEEE P62-1995, 6.1.5 NFPA 70B 7-2 and Appendix H Transformer FIST Volume 3-30
Cooling fans - inspect and test	Annually	Transformer FIST Volume 3-30
Oil pumps and motors - inspect and test	Annually	Transformer FIST Volume 3-30
Heat exchangers - inspect	Annually	Transformer FIST Volume 3-30
Conservator and bladder - inspect	3-5 years	Transformer FIST Volume 3-30
Top oil and winding thermometers	Annually inspect and infrared scan 3-5 years calibrate	Transformer FIST Volume 3-30
Oil level indicator operation	3-5 years	Transformer FIST Volume 3-30

Maintenance or test	Recommended interval	Reference
Pressure relief device	Annually inspect and perform function test 3-5 years check oil leaks	Transformer FIST Volume 3-30
Sudden pressure relay	Annually inspect and perform function test 3-5 years test per manufacturer's recommendations	Manufacturer's Instructions Transformer FIST Volume 3-30
Buchholz relay	Annually inspect and perform function test	Manufacturer's Instructions
Tap changer maintenance	Annually	Transformer FIST Volume 3-30
Deluge system operational test	Annually	Transformer FIST Volume 3-30 PO&M 19
Inspect foundation, rails, trucks	3-5 years	Transformer FIST Volume 3-30 PO&M 19

Section 36 – Transmission Lines

General

Transmission lines carry electrical power between the facility and the power system. Reclamation maintains relatively few transmission lines. However, inspection of transmission line segments entering switchyards is recommended.

Maintenance Schedule for Transmission Lines

Maintenance or test	Recommended interval	Reference
Review equipment ratings	5 years	NERC Planning Standard
Visual inspection with binoculars	Semi-annually	NFPA 70B Appendix H
Infrared scan	Annually	NFPA 70B, 18-17

Section 37 – Blackstart Generators

General

Upon complete loss of the power system (blackout), it will be necessary to establish initial generation and begin system restoration at select powerplants. Initiating (main unit) generators are referred to as system blackstart generators and are designated as such in system blackstart restoration plans. They must be able to self-start without any source of off-site electrical power and maintain adequate voltage and frequency while energizing isolated transmission facilities and auxiliary loads of other generators.

Maintenance Schedule for Blackstart Generators

Maintenance or test	Recommended interval	Reference
Review equipment ratings	5 years	NERC Planning Standard
Demonstrate through simulation or test that the unit can perform its intended function as required by the system restoration plan.	5 years	NERC Planning Standard
Each unit tested to verify it can start and operate without being connected to the system.	Interval not yet established by NERC	NERC Planning Standard

Section 38 – Switchyards

Inspection Checklist

Items of Inspection	**Inspection Interval**
1. Yards and Fences	M, A
2. Wood structures	M
3. Steel structures	M, A
4. Footings and guy anchors	M, A
5. Guys	M, A
6. Warning signs	M, A
7. Ground connections	M, A
8. Conductors and buses	M, A
9. Hardware	M, A
10. Insulators	M, A
11. Transformers and regulators	(see sections 30 and 35)
12. Oil and air circuit breakers	(see section 13)

13.	Disconnecting switches and fuses	(see sections 22 and 33)
14.	Lightning arresters	(see section 7)
15.	Control equipment	(see section 15)
16.	Lighting	M, A
17.	Oil storage facilities	M, A
18.	Conduits, ducts, trenches, and tunnels	M, A
19.	Storage batteries and chargers	(see section 8)
20.	Power supplies and wiring	M, A

Notes:

M – Monthly
A - Annual

1. Yards and fences

Monthly inspection. Check for anything unusual on the premises. See that gates, buildings, switches, etc., are locked where necessary to prevent unauthorized persons from entering or tampering with the equipment.

Annual inspection. Check fence and gates for damage or openings through which animals or unauthorized persons might enter. Check fence ground connections. Cut weeds and grass as necessary, and apply weed killers where found to be effective. Repair eroded soil banks, retaining walls, roads, and walks. Clean up and remove rubbish. Check danger signs on fence and gates.

2. Wood structures

Monthly inspection. Make from-the-ground check of poles for signs of decay, misalignment, and damage from lightning or other causes. Check crossarms for splitting.

Annual inspection. Make close inspection of the above. Repair or replace split or weakened poles, crossarms, or braces. See that pins are tight in arms and insulators.

3. Steel structures

Monthly inspection. Make from-the-ground check of structure for signs of rusting or loose or damaged members.

Annual inspection. Make close inspection of the above. Tighten all bolts at 5-year intervals. Brush rusty spots with wire brush and apply a good paint such as gray emulsified asphalt. Apply two coats of black emulsified asphalt paint on the tower legs 18 inches above and below the ground line and over the top of concrete footings where used.

4. Footings and guy anchors

Monthly inspection. Check condition of footings and anchors, particularly in locations subject to soil erosion, movement, or settling.

Annual inspection. Check concrete footings for cracking and spalling. See that footings and anchors are firmly set. Stub poles as necessary. Check anchors and other buried metalwork for corrosion, at intervals of about 3 years, especially in corrosive soil, and apply cathodic protection if necessary.

5. Guys

Monthly inspection. Check for tightness and general condition.

Annual inspection. Tighten guy wires and clamps. After the first year of operation of the line, this can be extended to 2- to 5-year intervals. Apply emulsiphied asphalt paint on rusty spots on cable and guy rods 18-inches above and below ground line.

6. Warning signs

Annual inspection. See that an adequate number of warning signs are used on structures, fences, etc., and that they are securely attached.

7. Ground connections

Monthly inspection. Visual inspection to see that structure and apparatus ground leads are not loose or broken.

Annual inspection. Check and tighten connectors and clamps in ground leads. Check ground leads to a point at least a foot below ground line to see that they are not broken or corroding. Check resistance of ground rods or ground mat.

8. Conductors and buses

Monthly inspection. Make from-the-ground check of conductors to detect broken or damaged strands or loose connections.

Annual inspection. Adjust sag in tension buses where necessary. Check tubular buses and flexible expansion joints and adjust if necessary to relieve strain on post-type insulators and bushings. Check joints for looseness and heating. Tighten connectors and clamps.

9. Hardware

Monthly inspection. Make from-the-ground inspection of hardware to detect loose bolts, pins, etc..

Annual inspection. Tighten all clamps, pole bands, and other hardware. After first year of operation of the line, this can be extended to 2- to 5-year intervals. Paint rusty spots with gray emulsified asphalt or similar paint.

10. Insulators

Monthly inspection. Make from-the-ground inspection of condition of insulators to detect broken skirts and excessive dirt.

Annual inspection. Replace broken insulators. Repair chipped or glaze-burned spots with lacquer such as red glyptal. Clean insulators with water, chlorothene, or other suitable cleaner, if subject to excessive dirt or smoke. Check insulators at 5-year intervals with an insulator tester if a reliable tester is available.

11. Transformers and regulators (see sections 30 and 35).

12. Oil and air circuit breakers (see section 13).

13. Disconnecting switches and fuses (see sections 33 and 22).

14. Lightning arresters (see section 7).

15. Control equipment (see section 15).

16. Lighting

Monthly inspection. Note burned out lamp bulbs in yard and building fixtures and have them replaced.

Annual inspection. Try out all lights and note whether they are all in proper operating condition. Clean lamp bulbs, lenses, and reflectors. In locations subject to excessive bugs, an additional cleaning may be necessary after the bug season has passed. Tighten fixtures and other lighting devices. Check lighting circuit time switches or other automatic control devices.

17. Oil storage facilities

Monthly inspection. Check for oil leaks in storage tanks. Note amount of oil on hand and see that receiving tank is maintained empty when not in actual use for draining oil from transformers or breakers in an emergency.

Annual inspection. Check and repair oil leaks. Check valves, plugs, and piping. See that valves on active storage tanks, which can be operated without a wrench, are plugged or locked closed. Drain condensate from storage tank sump. Repaint tanks and piping if necessary. Check operation of oil pumps. Check hoses and other accessories used in draining or refilling apparatus tanks. Check for corrosion of buried oil piping and apply cathodic protection if necessary.

18. Conduits, ducts, trenches, and tunnels

Monthly inspection. Visual inspection to detect moisture or other unusual conditions in conduit and duct runs, cable trenches, and tunnels.

Annual inspection. Make close observation of above and provide suitable waterproofing and drains where necessary. Check runs of metal conduit in soil for signs of corrosion. Paint metalwork in tunnels and cable trenches as necessary.

19. Storage batteries and chargers (see section 8).

20. Power supplies and wiring

Monthly inspection. See that power is available on all essential power, lighting, and control circuits.

Annual inspection. Inspect fuses or circuit breakers on power, lighting, and control circuits. Check and tighten wiring connections at terminal points. Inspect wiring for open circuits, short circuits, and damaged insulation. Check insulation resistance of wiring with devices connected.

Section 39 – Pumping Plant Building

Inspection Checklist

Items of Inspection		Inspection Interval
1.	Doors and windows	NS, A
2.	Elevators, Cranes, and Hoists	NS, A
3.	Electric space heaters and ventilating fans	NS, A
4.	Water supply and drain piping	W, NS
5.	Water heaters and coolers	W, NS
6.	Wash basins, sinks, showers, toilets, etc.	NS, A
7.	Water supply	NS, A
8.	Lighting	NS, D, A
9.	Fire protection	A
10.	Conduit and fittings	A
11.	Wiring and wiring devices	NS, A
12.	Railings and miscellaneous metalwork	M, A
13.	Stairways and ladders	S, A

Notes:

D – Daily
W – Weekly
M – Monthly
S – Semiannual
A – Annual
NS – Not Scheduled (extraordinary maintenance–usually 5-year or longer intervals)

1. Doors and windows

Monthly inspection. Check for general condition of windows, door locks, etc. Keep window glass clean. Replace broken glass.

Annual inspection. Check windows and window operators, latches, etc. Check doors, hinges, lock operators, etc. Repair frames, doors, and sash as necessary.

2. Elevators, cranes, and hoists (see section 5)

3. Electric space heaters and ventilating fans

Weekly inspection. Visual inspection to ensure that heaters and ventilating fans are functioning properly in their respective seasons of use.

Annual inspection. Check control thermostats, contactors, and fans for proper operation. Check heating elements of heaters for open circuits, short circuits, and damaged insulation, Check air-circulating ducts. Check for adequacy of the heating and ventilating facilities during cold and hot weather, respectively. Clean and replace filter elements.

4. Water supply and drain piping

Annual inspection. Check for leaks and repair as necessary. Check for obstructions in supply and drain piping and remove as necessary. Clean out any removable traps.

5. Water heaters and coolers

Weekly inspection. Visual inspection to ensure that water heaters and coolers are functioning properly.

Annual inspection. Check electric water heaters for burned out or grounded elements. Flush from bottom of tank and observe for signs of rust. Check thermostat operation and clean contacts. Check water cooler refrigerating element. Lubricate if required.

6. Wash basins, sinks, showers, toilets, etc.

Weekly inspection. Check for dripping faucets and valves and other leaks, and repair as necessary. Check that all equipment is maintained in clean and sanitary condition. Check floor valve style toilets for leaking valve seal.

7. Water supply

Weekly inspection. Check purity and cleanliness of drinking water. Check operation of purifying equipment. Check amount of drinking water in storage and see that supply pumps are in operating condition.

Annual inspection. Check and clean water storage tanks. Check supply intake for cleanliness and freedom from obstruction. Check purifying equipment. Check and overhaul water-supply pumps, float switches, pressure switches, pressure reducers, etc. Check motors and control equipment.

8. Lighting

Weekly inspection. Try out normal and emergency lights to see that they are in operating condition, and replace burned out lamps.

9. Fire protection (see section 21).

10. Conduit and fittings

Annual inspection. Inspect conduits, condulets, outlet, and switchboxes, etc., for rust or deterioration from moisture or alkali. Check conduits for proper drainage. Arrange to keep such metalwork as dry as possible.

11. Wiring and wiring devices

Annual inspection. Inspect and tighten connections at terminal points. Check for presence of moisture. Inspect insulation. Test insulation resistance.

12. Railings and miscellaneous metalwork

Annual inspection. – Check that all stairs and guardrails are securely fastened and rigid. Check metalwork for corrosion, rusting, or other damage, and repaint as necessary.

13. Stairways and ladders

Monthly inspection. Visual inspection to detect failures, obstructions, slipperiness, or other safety hazards.

Annual inspection. Check and tighten bolts and screws. Correct slipperiness, and other safety hazards. Check metalwork for corrosion or rusting and repaint as necessary.

Section 40 – Seasonal Maintenance

Spring Startup

Before the pumping plants are energized each spring, it is important that adequate cleanup and equipment inspection be performed to insure that equipment is not damaged or will not be damaged on initial annual startup. The checklist for spring startup is given below and should be used as a guide in preparing the plants for startup. The items are listed in the preferred order of performance, so that each item of equipment will be ready for operation approximately when it is needed.

- ❑ Notify the organization or agency responsible for furnishing power that their metering and switchyard equipment should be checked and prepared for spring startup.

- ❑ Check that the switchyard disconnect switches are open.

- ❑ As applicable:

    1. Check that switchyard interrupter switch is locked open.
    2. Clean transformer bushings and lightning arresters.
    3. Check transformer for oil leaks.
    4. Perform Meggar test on transformer windings per manufacturer's instructions.
    5. Perform dielectric test on transformer oil per manufacturer's instructions.
    6. Perform all other required transformer checks per manufacturer's instructions.
    7. Clean all switchyard insulators.

- ❑ Drain or pump out the remaining water in the pump sump and remove silt and debris. Check the pump suction piece to ascertain that the entrance to the pump is free of foreign material.

- ❑ Clean and check access roads to plant and reservoir site.

- ❑ Clean and check drainage features around plant and reservoir site.

- ❑ Clean and check feeder canal.

- ❑ Clean and check reservoir inlet structure.

- ❑ Clean and check reservoir overflow structure.

- ❑ Clean and check instrument shelter floatwell inlet pipes.

- ❑ Clean and check pumping plant trashracks, moss screens, and intake pipes.

- ❑ Clean and check fences.

- ❑ Clean and check delivery stand, meter, and valve equipment at each delivery point.

- ❑ Check for excessive weed growth in and around reservoir.

- ❑ Check that all motor control breakers and switches are open.

- ❑ Check the recording demand meter to see that adequate supplies of carbon tape and recording tape are available.

- Check and close the switchyard fused disconnect switches.
- Close the switchyard interrupter disconnect switch.
- Close the main power disconnect breaker in the motor control equipment.
- Close station-service transformer switch.
- Close the station-service breakers for the motor control equipment heaters (if applicable) and the lights and receptacles. Close the remaining breakers only as they are needed.
- Energize motor control equipment space heaters 2 weeks prior to plant startup.
- Clean in and around all plant equipment. A vacuum-type cleaner is recommended where practicable.
- Clean all lighting fixtures and replace all burned-out lamps.
- Clean and check each pump and associated motor to see that they rotate smoothly when turned by hand. Check for loose fittings and oil leaks. Change the pump and motor lubricant per manufacturer's instructions.
- Clean and check each valve for loose fittings. Lubricate per manufacturer's instructions.
- Clean and check each sump float switch and each instrument shelter float-operated mechanism to see that they operate smoothly. Lubricate per manufacturer's instructions.
- Clean and check the flowmeter and recorder. Check the recorder ink and chart supply and lubricate per manufacturer's instructions.
- Check to see that the manifold drain valve is closed.
- Test the valve operating system by opening and closing each valve.
- Check the oil or grease cups to be certain the mechanical seals are adequately lubricated.

Fall Shutdown

Following system shutdown at the end of each irrigation season, the pumping plant should be prepared for unattended winter shutdown. The checklist for fall shutdown is given below and should be used as a guide for preparing the plant for shutdown. The procedure should be in approximately the order listed.

- ❑ Shut down all deliveries at the sectionalizing valves.
- ❑ Drain the exposed pipeline.
- ❑ Fill all reservoirs to maximum water level.
- ❑ Notify the organization or agency responsible for furnishing power that its switchyard and metering equipment should be checked and prepared for winter shutdown.
- ❑ Open each pumping unit motor isolating switch.
- ❑ Check each piece of plant equipment for worn or broken parts and order the parts for arrival before spring startup.
- ❑ Check and clean the flow recorder including removal of the ink supply.
- ❑ Raise the instrument shelter floats from their floatwells and store the floats on the floor of the instrument shelter. The sump float switch float on the pumping plant deck should be left in the guide-pipe, unless the float can be readily removed and stored in a sheltered location.
- ❑ Open all station-service breakers, then open the station-service transformer switch.
- ❑ Open the main power disconnect breaker in the motor control equipment and lock it in the open position.
- ❑ Open the switchyard gang-operated interrupter switch and lock it in the open position.
- ❑ After the switchyard transformer has been de-energized for a few days and has cooled off, the oil should be brought to the proper “full” level.
- ❑ Remove all loose equipment from the plant and reservoir site to minimize possible targets for vandals.
- ❑ To prevent damage to the structure and pumps due to freezing weather, the sump should be unwatered during the winter shutdown.

Section 41 - Cathodic Protection

General

Corrosion is a natural process which can significantly reduce the useful service life of a structure or its components. As structures get older, corrosion will become more evident. There are successful methods which can be employed to mitigate corrosion and, therefore, corrosion should not be accepted as a “fact of life”. Metals don’t deteriorate from age, they deteriorate from corrosion and, fortunately, corrosion can be stopped. Some of the more common methods of corrosion control are design, materials selection, changing the environment, protective coatings, and cathodic/anodic protection.

Protective coatings and cathodic protection are widely used as synergistic corrosion control methods. There are no perfect coatings. Coatings have holidays or voids, can be damaged, and deteriorate overtime. The metal exposed at the coating defects is susceptible to corrosion. The corrosion process enlarges the coating defects by undercutting the intact coating adjacent to the defects. Coatings effectively reduce the amount of metal surface area which requires cathodic protection and as a result less cathodic protection current is required for a well coated structure than for a poorly coated structure. In return cathodic protection extends the life of the coating by reducing undercutting of the coating and effectively limiting the growth of defective coating areas.

Many metallic components of pumping plants experience corrosion. Two of the most corrosive environments of a pumping plant are the water which they convey and the soil in which they are constructed. In addition to corrosive environments, the materials of construction have a significant impact on the corrosion experienced. There are numerous items at pumping plants that can be cathodically protected. Some pumping plants may have been designed with cathodic protection systems, others may not have been. For pumping plants that do not have existing cathodic protection systems many can be retrofitted with a cathodic protection system as the need arises.

This section presents typical operation and maintenance requirements for cathodic protection systems and does not provide an in depth review of corrosion. At the end of this section definitions and procedures have been included which will introduce the reader to terms and procedures typically associated with cathodic protection systems. For a more in depth understanding of corrosion and its mitigation the reader is referred to the many books and articles on the subject.

What is Corrosion?

Corrosion is the deterioration of a material due to a reaction with its environment. The following is limited to the corrosion of metallic materials. Corrosion is a natural electro-chemical reaction between a metal and an electrolyte (usually soil or water) in which a refined metal is returning to its natural state as an ore. The following are the four required components of a corrosion cell:

1. ***Anode*** **–** The anode is the electrode of the corrosion cell which experiences the physical destruction of corrosion (i.e., metal loss). Current flows from the anode surface into the electrolyte taking metal ions with it.

2. ***Cathode*** – The cathode is the electrode of the corrosion cell which does not experience the destructive nature of corrosion. Current collects on the cathode surface from the electrolyte. Because current is collecting on the surface metal ions are not lost.

3. ***Metallic path*** **–** There must be a metallic path between the anode and cathode. Current flows from the cathode to the anode within the metallic path.

4. ***Electrolyte*** **–** The anode and cathode must be in contact with the same electrolyte. Current flows from the anode to the cathode within the electrolyte.

During the corrosion process current flows between the anode and cathode while chemical reactions occur at both the anode and cathode. At the anode current leaves the metal surface and enters the electrolyte taking metal ions with it. The metal ions are a part of the corrosion products of the corrosion reaction. Rust is the corrosion product of steel. The current flows through the electrolyte from the anode to the cathode and collects onto the cathode. The current then uses the metallic path to return back to the anode.

Anodes and cathodes can be on the same metal surface or they can be on two different metals which are in contact with one another. Anodes and cathodes can be atoms apart, they can be inches apart, or on large structures, such as pipelines, they can be miles apart.

Corrosion will cease if one of the four required elements of a corrosion cell is eliminated.

What is Cathodic Protection?

Cathodic protection is a proven method of mitigating corrosion and is the only corrosion control method which can potentially halt ongoing corrosion of a structure. Cathodic protection is a corrosion cell which is used to our benefit. With cathodic protection the structure that is to be protected is made the cathode of the corrosion cell. Remember corrosion does not occur at the cathode. Since we still have an operating corrosion cell we must have an anode. Therefore, an anode material must be installed which will be sacrificed for the sake of the structure to be protected. It should be noted that corrosion is not stopped but is transferred. It is transferred from the structure that is to be protected to sacrificial material which is installed to be consumed.

Since cathodic protection is a corrosion cell, current must flow. As with the corrosion cell, current flows from the anode to the cathode within the electrolyte, and from the cathode to the anode within the metallic path. The electrolyte is the water or soil which our structures are in contact with. The metallic path is the structure itself and the cables that may need to be installed to complete the metallic return path for the cathodic protection system.

There are two types of cathodic protection systems, galvanic anode and impressed current. Both systems require the installation of a sacrificial material as the anode. Galvanic anode cathodic protection requires the installation of galvanic anodes. A galvanic anode is a material which is more electro-chemically active than the structure to be protected. Galvanic anodes use the natural potential difference between the anode material and the structure to cause current to flow. For soil and fresh water applications zinc and magnesium are typically used as the galvanic anode material. Galvanic anodes can be attached directly to the structure, or installed some distance from the structure and connected to the structure through cables.

With an impressed current cathodic protection system, external power is required to supply the current required for cathodic protection. Any DC type power supply can be used for cathodic protection, although, a rectifier is typically used. A rectifier coverts AC power into DC power. Impressed current requires the installation of anodes and a power supply; the power supply is connected between the structure and anodes. Because external power is providing the driving force for the cathodic protection current a wide range of anode material can be used. Some commonly used impressed current anode materials include high silicon cast iron, graphite, mixed metal oxides, and platinum.

With both galvanic anode and impressed current cathodic protection systems, the anode must be installed within the same electrolyte that is causing corrosion of the structure. To mitigate soil side corrosion, such as on a pipeline, anodes are installed in the soil. It should be noted that anodes installed in the soil will not protect the inside surface of a buried pipeline, they will only protect the exterior surface of the buried pipeline. To mitigate water side corrosion, such as on pump columns of a wet sump pumping plant, anodes are installed in the water.

Cathodically Protected Metalwork at Pumping Plants

From a cathodic protection standpoint the metalwork at pumping plants can be divided into two categories: submerged metalwork and buried metalwork. The category that they fall under depends on what is causing the corrosion, soil or water. Generally the cathodic protection systems for the submerged metalwork and those for the buried metalwork are separate and independent systems.

All metallic surfaces which contact water or soil can be cathodically protected. Items that are typically cathodically protected at pumping plants include:

- Pump columns
- Trash racks
- Traveling water screens
- Air chambers and elevated water tanks
- Intake and discharge manifolds
- Intake and discharge pipelines
- Miscellaneous piping such are drain and fill lines
- Various gates such as radial gates, slide gates, roller gates, and etc.

Typical Operation and Maintenance Requirements

Operation and maintenance of cathodic protection systems should be conducted by individuals who have, as a minimum, a general knowledge of such systems. Applicable training should be provided for individuals conducting the operation and maintenance of cathodic protection systems.

The operation and maintenance requirements of a cathodic protection system are dependent on the design of both the structure and cathodic protection system. The operation and maintenance requirements contain herein are typical in nature and Standard Operating Procedures should be specifically written for each individual cathodic protection system.

1. ***Operating Criteria*** – In general, the performance of a cathodic protection system is based on a structure-to-electrolyte potential. Structure-to-electrolyte potentials are determined at various locations on a protected structure, with the locations being dependent on the design of both the structure and cathodic protection system. Other requirements are useful in tracking trends and trouble shooting the system should problems arise.

NOTE: Listed below are the more common operating criteria employed. Not all the criteria listed are used on a single structure. The listed criteria are included for educational purposes only and the criteria to be employed on a specific structure shall be determined by qualified individuals.

Typical operating criteria for cathodic protection systems are as follows:

a. *Protective structure-to-electrolyte potential* – Protective structure-to-electrolyte potentials should be negative 850 millivolts or more negative, as referenced to a copper/copper sulfate reference electrode.

b. *Polarized structure-to-electrolyte potentials* – Polarized structure-to-electrolyte potentials should be negative 1100 millivolts or more positive, as referenced to a copper/copper sulfate reference electrode.

c. *Minimum 100 millvolts polarization shift* – The polarization shift can be determined by one of two methods. The polarization shift is determined in the first method by comparing the static and polarized structure-to-electrolyte potentials. The polarization shift is determined in the second method by determining the polarization decay after the cathodic protection is turned off.

d. **NOTE**: At no time should the polarized structure-to-electrolyte potential be more negative than negative 1100 millivolts as referenced to a copper/copper sulfate reference electrode. If the system can not be adjusted to satisfy the above criteria, the dominate criterion should be the polarized structure-to-electrolyte potential criterion.

2. ***Submerged Metalwork Cathodic Protection Systems*** – The cathodic protection systems for submerged metalwork may not be operated continuously. If the structure is dewatered on a regular schedule, such as being dewatered for winter, the cathodic protection system of the submerged metalwork is not operated while the structure is in the dewatered condition.

   Structure-to-electrolyte potentials should be determined at representative locations on all submerged metalwork such as pump columns, traveling water screens, trash racks, ladders, and etc. Potentials are generally determined at 5 foot intervals for the submerged height of the metalwork. Potentials should also be determined on the submerged metalwork at locations which are closest to anodes and furthest from anodes.

a. *Galvanic anode cathodic protection system* – A galvanic anode cathodic protection system will be active at times when the both the metalwork and anodes are submerged (unless the anodes have been depleted or disconnected from the structure).

   i. *Annual requirements*. – The following should be determined and recorded on an annual basis:

      1. Protective structure-to-electrolyte potentials.
      2. Current output of individual anodes.

b. *Impressed current cathodic protection system* – The cathodic protection systems should be energized during periods that water is present within the structure. If the structure is only partially dewatered which results in both metalwork and anode(s) submerged, the cathodic protection system should remain energized. The following assumes that the structure is dewatered in the winter. If the structure is not dewatered only the monthly and annual monitoring requirement are applicable.

   NOTE: When access to a submerged area of the structure is required the cathodic protection system for the submerged metalwork should be turned off before accessing the submerged area.

   i. *Spring startup requirement*. – The cathodic protection systems should be energized and properly adjusted when the structure is watered up. The following process should be used during the spring startup:

      1. Energize cathodic protection systems. If the system was properly adjusted prior to the fall shutdown adjustment of the system may not be required.

      2. Conduct annual and monthly requirements. Adjust system if necessary.

      3. Allow the system to operate between one to two weeks. Conduct annual and monthly requirements. Adjust system if necessary.

ii. *Monthly requirements*. – During times that the cathodic protection system is energized the following should be determined and recorded on a monthly basis:

1. Rectifier's current and voltage outputs.
2. Rectifier's settings.
3. Current output of individual anodes.
4. Clean debris from screened areas of rectifier and anode terminal box.

iii. *Annual requirements*. – For a system which is dewatered the annual requirements should be conducted towards the middle of the period for which the structure contains water. The following should be determined and recorded on an annual basis:

1. Conduct monthly requirements.
2. Protective and polarized structure-to-electrolyte potentials on all submerged metalwork.

iv. *Fall shutdown requirements*. – After the structure has been de-watered the cathodic protection system should be turned off. If any portion of the metalwork is submerged and any of the anodes are submerged the cathodic protection system should remain energized.

3. ***Buried Metalwork Cathodic Protection Systems*** – The cathodic protection system for buried metalwork should be continuously operated. Structure-to-electrolyte potentials should be determined at representative locations on all buried metalwork. Test stations are typically installed on buried metalwork to provide electronic access to the buried metalwork for testing purposes. If test stations are not installed at critical locations electronic assess can sometimes be obtained by contacting exposed metalwork which is electrically continuous with the buried metalwork.

a. *Galvanic anode* – The galvanic anode cathodic protection system for the buried metalwork will be active at all times unless the anodes have been depleted or the anodes have been disconnected from the structure.

i. *Annual requirements*. – The following should be determined and recorded on an annual basis:

1. Current output of individual anodes.
2. Protective structure-to-electrolyte potentials at all test locations on all buried metalwork.

b. *Impressed current*

i. *Monthly requirements*. – The following should be determined and recorded on a monthly basis:

1. Rectifier's current and voltage outputs.
2. Rectifier's settings.
3. Current output of individual anodes.
4. Clean debris from screened areas of rectifier and anode terminal boxes.

ii. *Annual requirements*. – The following should be determined and recorded on an annual basis:

1. Conduct monthly requirements.
2. Protective and polarized structure-to-electrolyte potentials at all test locations on all buried metalwork.

Data Analysis and Technical Assistance

Data analysis for cathodic protection systems should be conducted by a qualified individuals. Bureau of Reclamation's Technical Service Center (D-8180) can provide technical assistance (including specialized training, data collection, data analysis) on a cost reimbursable basis.

Definitions and Procedures

1. ***Definitions*** – The following definitions are typically associated with cathodic protection systems.

   a. *Corrosion monitoring systems* – Corrosion monitoring systems consist of bonded or welded joints for electrical continuity, insulating fittings at selected locations where electrical discontinuity is desired, and test stations to determine structure-to-electrolyte potentials. Corrosion monitoring systems facilitate testing to determine if supplemental corrosion control measures are necessary and for the application of cathodic protection, if required.

b. *Cathodic protection* – Cathodic protection is an electrical means of mitigating corrosion of a metal. Cathodic protection is provided by causing direct current to collect on all metallic surfaces of a structure. By collecting direct current on all metallic surfaces of the structure, the structure becomes the cathode of a corrosion cell.

    i. *Galvanic anode cathodic protection* – Galvanic anode cathodic protection uses the natural potential difference between metals to provide the direct current required for cathodic protection. Magnesium and zinc anodes are typically used in fresh water and soil environments.

    ii. *Impressed current cathodic protection* – Impressed current cathodic protection utilizes an external power source to provide the direct current required for cathodic protection. A rectifier is typically used to convert alternating current into direct current for cathodic protection.

c. *Current interrupter* – A device installed into the output circuit of a rectifier which provides a means of opening and closing the circuit at programmable intervals.

d. *Electrolyte* – The electrolyte is any medium which can conduct ionic current flow. Water and soil are electrolytes.

e. *Portable voltmeter* – Any portable, high-input impedance (10 megohm minimum) voltmeter.

f. *Rectifier* – A device which converts alternating current into direct current.

g. *Rectifier tap settings* – The position of the link bars of the voltage tap circle on the front of the rectifier. The tap settings limit the voltage output of the rectifier and is adjusted by changing the position of the link bars.

h. *Reference electrode* – A reference electrode is used to measure the potential of a structure which is buried or submerged in an electrolyte (soil or water). The reference electrode must be accurate, stable, and reproducible. A submersible reference electrode is a reference electrode that can be used in a totally submerged condition. A copper/copper sulfate reference electrode is commonly used in field measurements because of its ruggedness.

i. *Shunt* – A calibrated device which is placed within a circuit to determine the current flow within the circuit. A shunt has a known, fixed resistance and it's calibration is typically expressed in ohms or amperage/voltage.

j. *Structure* – The structure is the item being monitored and/or cathodically protected (e.g., buried pipeline and submerged pump columns).

k. *Structure-to-electrolyte potential* – The potential between the structure and electrolyte as referenced to a reference electrode. Also referred to as structure-to-water, structure-to-soil, pipe-to-soil, and tank-to-water potentials.

    i. *Polarized structure-to-electrolyte potential* – The structure-to-electrolyte potential determined with the cathodic protection system energized and immediately after the cathodic protection current is interrupted.

    ii. *Protective structure-to-electrolyte potential* – The structure-to-electrolyte potential determined with the cathodic protection system energized and cathodic protection current flowing

    iii. *Static structure-to-electrolyte potential* – The structure-to-electrolyte potential determined prior to energizing a cathodic protection system or after the cathodic protection system has been de-energized for a given time period. Also referred to as native structure-to-electrolyte potential.

l. *Test station* – Buried structures typically have test stations. Submerged structures may or may not have test stations.

The basic test station is composed of a housing and test cables. The test cables originate from the metallic portion of the structure being monitored and, as such, provides electronic access to the structure. Test cables are generally installed in pairs, one being sized # 12 AWG or larger and the other #6 AWG or larger. The #6 AWG is used for bonding and application of cathodic protection and the #12 AWG is used for determining structure-to-electrolyte potentials.

On buried pipelines there may be more than two cables terminated in the test station housing, the following are common sources of additional cables:

i. The test station may contain one or more cables to galvanic anodes.

ii. The test station may contain a # 12 AWG or larger cable originating from a buried permanent reference electrode.

iii. Insulating fitting test stations typically have two pairs of test cables, one pair originating upstream of the insulating fitting and the other pair originating downstream of the insulating fitting.

iv. Foreign line crossing test stations can have up to 5 test cables. Two test cables will originate from the structure being monitored, two cables may originate from the foreign line, and one cable may originate from a buried, permanent reference electrode. The test cables originating from the foreign line are installed at the discretion of the foreign line owner and, therefore, may not be installed. A permanent reference electrode may or may not be installed.

2. ***Procedures*** – The following procedures are typically associated with cathodic protection systems.

a. *Anode current output measurement* – To determine the current output of an anode, measure the voltage (millivolts) across its shunt located in the anode terminal box using a portable voltmeter and calculate the current output using Ohm's law (I=V/R). Typically the shunts within the anode terminal box are 10 milliohm shunts, although, the 10 milliohm shunts are typically not marked with a rating. For example, if 25 millivolts is measured across an anode shunt with a resistance of 10 milliohms, 2.5 amps are flowing through the shunt.

b. *Current interrupter installation* – To insert a current interrupter into the output circuit of a rectifier, the rectifier must be de-energized. The circuit breaker within the rectifier cabinet can be used to de-energize the rectifier. Remove the common anode cable from the positive terminal of the rectifier and connect it to one terminal of the current interrupter. Connect the other terminal of the current interrupter to the positive terminal of the rectifier by use of a separate insulated cable similar in size to the common anode cable. The common anode cable is typically a No. 6 AWG cable.

The “on” cycle of the interrupter is when the rectifier’s current output is not interrupted and the “off” cycle is when the rectifier’s current output is interrupted.

The “on”/”off” cycles of the current interrupter should be set such that the cycles can be easily identified with the “on” cycle being at least 3 to 4 times that of the “off” cycle (i.e., 30 seconds on and 5 seconds off).

Energize the rectifier and start the current interrupter. Verify that the current output of the rectifier goes to zero during the “off” cycle and cycle times are as desired.

c. *Rectifier current output measurement* – To determine the current output of a rectifier, measure the voltage (millivolts) across the shunt and calculate the current by multiplying the shunt's rating (i.e., 15A/50mV) by the measured voltage. The shunt's rating is stamped on the side of the shunt. For example, if 30 millivolts are measured across a shunt rated at 15A/50mV, 9 amps are flowing through the shunt.

d. *Rectifier voltage output measurement* – To determine the voltage output of a rectifier using a portable voltmeter, measure the voltage (volts) across the positive and negative output terminals of the rectifier.

e. *Rectifier voltage output adjustment* – To change the output of a rectifier the voltage output of the rectifier must be adjusted. The following procedure is for a manually tapped rectifier, if another type of rectifier is used the procedure will be different. For a manual tapped rectifier, adjustment is accomplished by changing the rectifier’s tap setting. When adjusting the rectifier’s tap setting the rectifier must be de-energized. The circuit breaker within the rectifier cabinet can be used to de-energize the rectifier. To increase the rectifier’s voltage output its tap setting is increased (e.g., from B to C or 3 to 4.) To decrease the rectifier’s voltage output its tap setting is decreased (e.g., from D to C or 2 to 1). Energize the rectifier once the rectifier’s tap setting has been changed.

f. *Reference electrode integrity* – To obtain valid structure-to-electrolyte data an accurate, stable, and reproducible reference must be used. The reference electrode integrity of all reference electrodes should be determined prior to use. Reference electrode integrity or accuracy is determined by comparing it to a freshly prepared, portable copper/copper sulfate reference electrode. In general, the potential difference (millivolts) between the two reference electrodes is determined when they are in contact with a common electrolyte.

   i. *Portable copper/copper sulfate reference electrodes*. – The accuracy of two freshly prepared, portable copper sulfate reference electrodes should be determined by submersing the tips of the two reference electrodes in a nonmetallic container of water. Measure the potential difference (millivolts) between the two reference electrodes with a portable voltmeter. The integrity of the reference electrodes is acceptable when the potential difference between the two is within 10 millivolts.

Once the integrity of the reference electrodes has been verified, identify one reference electrode as the standard. The other is used for all field measurements which require a freshly prepared, portable copper/copper sulfate reference electrode. The standard reference electrode is set aside and is only used to determine the accuracy of the other portable reference electrode which is used for field measurements.

ii. *Permanent reference electrode.* – When checking permanent reference electrodes they either need to be removed for testing or the cathodic protection system must be de-energized. If the permanent reference electrode is connected to a rectifier it must be disconnected from the rectifier before testing. The negative of the portable voltmeter should be connected to the freshly prepared, portable copper/copper sulfate reference electrode and the positive terminal should be connected to the permanent reference electrode. Determine and record the magnitude, polarity, and meter connection (i.e., negative to portable). Consideration should be given to replacing permanent reference electrodes when the potential determined is greater than 50 millivolts.

To check a buried reference electrode place a freshly prepared, portable copper/copper sulfate reference electrode directly above the permanent reference electrode. The ground at point of contact should be saturated with tap water to reduce contact resistance.

To check a submerged reference electrode place a freshly prepared, portable copper/copper sulfate reference electrode adjacent to the permanent reference electrode. The submerged reference electrodes can be tested in place or removed and tested as describe under portable reference copper/copper sulfate reference electrodes.

g. *Structure-to-electrolyte potential measurement* – Also referred to as structure-to-water, structure-to-soil, pipe-to-soil, and tank-to-water potentials.

To determine a structure-to-electrolyte potential, connect the negative terminal of a portable voltmeter to the portable reference electrode and connect the positive terminal to the structure contact. The portable reference electrode should be positioned as close to the structure being monitored as possible. Record the polarity, magnitude, and location of potential.

For buried metalwork installations the portable reference electrode should contact the soil directly over the buried metalwork. The soil at point of reference electrode contact should be saturated with tap water to reduce contact resistance.

i. Protective structure-to-electrolyte potentials are determined with the cathodic protection system energized and the cathodic protection current flowing.

ii. Polarized structure-to-electrolyte potentials are determined with the cathodic protection system energized and immediately after the cathodic protection current is interrupted. To obtain polarized potentials a current interrupter is generally inserted into the output circuit of the rectifier.

Appendices

Appendix A

AIR AND OIL CIRCUIT BREAKER PREVENTIVE MAINTENANCE

Adapted from Power O&M Bulletin No. 19 B
Maintenance Schedules and Records B October 1965, Section 10

Note: Unless the maintenance interval is specified, conduct preventive maintenance annually (indicated by *) or as the equipment becomes available during an outage. For other maintenance requirements, see section 13, ACircuit Breakers,@ in the body of this bulletin.

Foundation

* Check foundation for cracks and settling. A shift of the breaker tanks may break bushings or cause misalignment of contacts or binding of operating mechanism.

Frame and Tanks

Daily or Weekly B Check for oil leaks and note tank temperature by touch.

Oil Valves and Plugs

* Check condition of paint and repaint as necessary. Inspect oil valves and plugs and stop oil leaks. See that oil drain valves that can be operated without wrenches are plugged or locked to prevent unauthorized opening. Tighten bolts. Clean interior of tanks. Inspect underside of cover for moisture and rust, and clean and repaint as necessary. Check tank liners and interphase barriers.

Oil Levels and Gages

Daily or Weekly B Check oil level in gages of the tanks and oil-filled bushings. Replenish oil if below normal.

* Clean dirty gage glasses and connections into tank. Drain out and replace bushing oil if dirty or discolored.

Breathers and Vents

Daily or Weekly B Check for external obstructions to breakers and vents.

* Check to see that screens and baffles in vents or breathers are not obstructed or broken.

Panels and Cabinets

* Check air circuit breaker or other panels of insulation material for cracks and cleanliness. Check condition of enclosing cabinets including hinges, latches, locks, door gaskets, and paint.

Bushings or Insulators

Weekly B Check for chipped or broken porcelain, excessive dirt film, oil level and oil or compound leaks.

* Clean porcelain with water, chlorothene, or other suitable cleaner. Repair chipped spots by painting with lacquer such as red glyptal. Inspect gaskets for leaks. Tighten bolts. Check insulation resistance with contacts closed and power factor. Check oil sample from bottom of bushing for dielectric strength and presence of water and dirt which may be entering at top. Replace or replenish oil if necessary. Check and clean interior at least once every 5 years.

Bushing Current Transformers and Potential Devices

* Check tap settings and adjustments at terminal board to see that they agree with diagrams. Check insulation resistance of wiring with devices connected. Check ration and phase-angle adjustments of potential devices if changes have been made in secondary connections or burden. Tighten connections, including potential device tap into bushing.

Main Terminals and Ground Connections

Daily or Weekly B Check for presence of foreign materials, bird's nests, etc. in or near connecting buswork; loose or overheating connections; and loose or broken frame ground connections.

* Tighten all bus and ground connections. Refinish joint contact surfaces if they have been overheating. Inspect ground cable to see that it is not loose or broken.

Main Contacts

* Remove the tanks or drain out oil so that the contacts can be inspected. Dress contacts, if rough, with a fine file. It is necessary to remove only the projecting beads. Pits in a flat, smooth surface are not objectionable. Check contact drop with Aducter@ or by direct-current millivolt drop. Frequency of breaker contact maintenance should be based on number and severity of faults interrupted rather than a definite time period. Experience will tell how many faults can be interrupted before contact repairs are necessary. Data should be kept on each breaker to guide future maintenance. Inspection schedules might be extended further as oil-handling methods, methods for determining oil condition, and other improvements are made. The following factors should be established before intervals between inspections can be extended:

- ❑ All new breakers must have a complete inspection at the end of 1 year.
- ❑ Only breakers having field experience to support the program should be scheduled for extended inspection periods.
- ❑ Breakers used on special applications, such as capacitor and reactor switching, should be considered separately.
- ❑ If recurring troubles are found on a certain type of breaker, the inspection schedules should be adjusted until the trouble is eliminated.
- ❑ Breakers interrupting a large number of faults should be given special attention to determine whether or not early internal inspection is required.
- ❑ When oscillographs indicate abnormal breaker operation, an immediate inspection of the breaker should be made.

Contact Pressure Springs

* Check springs for loss of temper, breaks, or other deterioration.

Flexible Shunts

* Check flexible shunts at contact hinges for overheating and fraying. Tighten connections.

Magnetic, Air, or Oil Blowout Devices

* Check arc-rupturing blowout coils, magnetic circuit, arc chutes, deion grids, oil blast, or other interrupters for proper operation.

Crosshead

* Check contact crosshead for misalignment, breaks, bends, or looseness on lift rod.

Lift Rods and Guides

* Check contact lift rods for breaks, weakening, or warping, and pulling out at ends. Check adequacy of guides.

Operating Rods, Shafts, and Bell Cranks

* Check for loose locknuts, setscrews, keys, bearings, bent rods, or twisted shafts, etc. Clean moving parts of rust, dirt, and accumulated grease and oil. Wash out bearings, pivots, and gears with chlorothene or other suitable cleaner; and operate breaker several times to work out dirt and old lubricant. Lubricate with new grease or oil. In cold climates, it is important to use lubricant that will not stiffen too much with cold. Wipe off excess oil. Enclosed dust-tight bearings should require less servicing.

Closing Solenoid Air Cylinder, Motor, or Spring

Weekly B Visual inspection to see that equipment is in operating condition. Drain condensation from air cylinder.

* Observe mechanism during several closing operations to see that everything is in proper working order. Check solenoid plunger for sticking in guides. Check coil resistance and insulation resistance. Dismantle air cylinder and clean and re-lubricate. Check motor. Check closing springs for proper tension and closing energy.

Manual Operating Device

* See that manual operating lever or jack is kept on hand and in usable condition. See that breaker will close with it.

Latch and Trip Mechanism

Weekly B Visual inspection to see that mechanism is in operating condition.

* Observe mechanism during several tripping operations to see that everything is in working order. Check pins, bearings, and latches for wear, binding, and misalignment. Clean and re-lubricate. Check latch carefully to see that it is not becoming worn so that it would unlatch from vibration or stick and fail to trip. Tighten bolts and screws.

Tripping Solenoid

Weekly B Visual inspection to see that solenoid trip device is in operating condition.

* Observe operation during electrical tripping. See that full energy, snappy action of plunger is obtained. Check plunger for sticking in guides. Check coil and insulation resistance.

Solenoid Valves

* Check for condition of valve seat and refit as necessary. See that moving parts are free to operate. Check resistance and insulation resistance of solenoid coil.

Auxiliary Switches

* Check condition of contacts and refinish with fine file if burned or corroded. Check contact springs, operating rods, and levers. Check closing and opening position with respect to main contacts while breaker is being slowly closed and opened manually. Certain auxiliary contacts used for special purposes may require close adjustment in this respect.

Operation Counter

Monthly B Observe and record reading of operation counter.

* See that the operations counter is properly registering the operations.

Position Indicator

* See that position indicator or semaphore is properly indicating the breaker position. Check operating rods or levers for loose parts.

Dashpots or Snubbers

* Check for proper setting and adjust as necessary. Clean out and replenish liquid in liquid dashpots.

Mechanism Cabinet

* Check condition of metal and hardware. Repaint as necessary. See that door gaskets are tight and properly exclude dust and dirt.

Cabinet Lights and Heaters

Weekly B Check cabinet heaters and see that they are in service in cold weather. Replace burned-out lamps.

* Check heating elements and replace, if in poor condition.

Power Supplies and Wiring

Weekly B See that all power and control circuit switches are closed and fuses are in place.

* Inspect fuses or circuit breakers in all power and control supply circuits. Check and tighten wiring connections at terminal points. Inspect wiring for open circuits, short circuits, and damaged insulation. Check insulation resistance of wiring with devices connected.

Oil Dielectric Tests

* Check dielectric strength of the insulating oil in the main tanks and oil-filled bushings.

Filter Oil

* The necessity for filtering the insulating oil will depend on the results obtained from the oil dielectric tests and the amount of carbon in the oil. The oil should be filtered if the dielectric strength is below 25 kilovolts or if there is a noticeable amount of carbon in suspension or in the bottom of the tanks. (Refer to FIST Volume 3-5, Maintenance of Liquid Insulation - Mineral Oils and Askarel.)

Operation

* Some breakers, particularly those carrying high values of current, have a tendency to develop contact heating if left closed for long periods. Opening and closing breakers several times at intervals, as system operation permits, may reduce heating by wiping the oxide from the contact surfaces. This method also demonstrates that the breaker is in operating condition.

References

How to Maintain Electric Equipment, GET-1125, General Electric Company
FIST Volume 3-1, Testing of Solid Insulation of Electrical Equipment
FIST Volume 3-2, Testing and Maintenance of High Voltage Bushings
FIST Volume 3-5, Maintenance of Liquid Insulation - Mineral Oils and Askarel
FIST Volume 3-7, Painting of Transformers and Oil Circuit Breakers
FIST Volume 3-16, Maintenance of Power Circuit Breakers
FIST Volume 3-17, Power Circuit Breaker Problems
FIST Volume 3-18, Replacing Glaze Burned Insulators

Appendix B

GENERATOR AND LARGE MOTOR PREVENTIVE MAINTENANCE

Adapted from Power O&M Bulletin No. 19 B
Maintenance Schedules and Records B October 1965, Section 8

Note: Unless the maintenance interval is specified, conduct preventive maintenance annually (indicated by *) or when the equipment becomes available during an outage. For other maintenance requirements, see section 23, AGenerator and Large Motors,@ in the body of this bulletin.

Foundation, Base, or Support

* Check concrete foundation for cracks. Check base or support for broken, loose, or weakened parts. Check and tighten anchor bolts. Check sound-absorbing base for adequacy.

Frame

* Check for cracks and loose or broken parts. Clean and repaint as necessary. Check frame ground connection.

Laminations and Pole Pieces

* Check for loose laminations and tighten clamping bolts. If laminations vibrate and cannot be stopped by tightening clamping bolts, force some quick-drying varnish or shellac between the loose laminations while the machine is out of service. Check for damaged laminations at air gap due to rubbing or objects caught in air gap. Check and tighten field pole piece clamping bolts. (Refer to manufacturer=s instructions or contact the Hydroelectric Research and Technical Services Group at 303-445-2300 for proper torque values.)

Armature or Rotor

* Check squirrel-cage rotor bars or amortisseur windings for loose or broken bars or end connections. Check field circuit connections and tighten if necessary. Check voltage

drop across each pole by applying alternating current at the collector rings. This method will show a turn-to-turn short better than using direct current. Check pole keys for tightness. Rebalance armature or rotor if vibration is objectionable. (See FIST Volume 2-2, Field Balancing of Large Rotating Machinery.)

* Check overall rotor resistance or impedance.

Air Gap

* Check air gap at four quadrature positions and re-center rotor if necessary. On horizontal machines, the bearings may need replacing if the bottom air gap is appreciably smaller than the top.

Air Fans

* Check rotor air fans for fatigue cracks. Check and tighten holding bolts and screws.

Windings

* Inspect for damaged insulation, dirt, oil, or moisture. Blow out dust with clean, dry air at pressure not exceeding 40 pounds per square inch. Clean exposed parts of windings thoroughly with noninflammable solvent using suitable brushes for hard-to-reach places. The use of carbon tetrachloride is not recommended because of the toxic hazard. Re-varnish windings if insulation is becoming hard, brittle, or dull. Check for insulation deterioration such as tape separation, cracking, brittleness, or evidence of corona. Check insulation with high-voltage direct current method. (See FIST Volume 3-1, Testing Solid Insulation of Electrical Equipment.)

Banding and Lashing

* Check wire and string banding on direct-current armature windings. Check end-turn lashing of alternating current stator coils. Apply lashing if end turns vibrate excessively.

Slot Wedges

* Check slot wedges and replace loose ones. Tighten coils in slots by re-wedging, if necessary.

Commutator or Collector Rings

* *Daily* B Check commutator or collection rings and brush operation. Wipe commutator or rings if needed. Have brushes replaced if worn too short.

Brushes and Brush Rigging

* Turn down, stone, or polish commutator or collector rings if grooved, rough, or eccentric. Undercut mica if high. If commutator or rings have a good polish, they should not be disturbed. Check brush spring tension and brush fit. Tighten bolts, screws, and connections. Reset brush holders if not properly spaced. Check brush neutral position. Replace and sand in new brushes if needed. Clean up carbon or metallic dust.

Shaft and Bearings

Daily B Check bearing temperature, lubrication, and oil level. (See FIST Volume 2-4, Lubrication of Powerplant Equipment.)

During Shutdown/Inspection B Check bearing clearances. Check oil for dirt, sludge, and acidity, and filter or replace as necessary. Check end play on horizontal machines. Replace or refinish rough bearings. Inspect bearing oil piping and cooling water piping for leaks. Check shaft for wobble and alignment. Check for shaft currents through bearings on larger machines. Check insulation of insulated bearings. Check oil film resistance occasionally with machine in operation with ohmmeter of 6 volts or less on thrust bearings provided with test terminals.

Couplings, Gears, and Pulleys

* See that keys, setscrews, and coupling bolts are tight. Check parts of flexible couplings for wear or fatigue. Adjust belt or silent chain tension. Flush out and renew grease in gearboxes. Inspect belts, chains, or gears. Check alignment between driving and driven machine.

Cooling Coils and Air Coolers

* Check for water leaks in bearing cooling coils and surface air coolers. Check cooling water flow. Check external supply and piping for leaks. Flush out cooling coils with air and water. Test bearing cooling coils for leaks by applying air pressure to coils and

observe for air bubbles rising in oil and drop in air pressure with supply valve closed, or use hydrostatic pressure test. Use hydrostatic pressure test on air coolers. If water scale is present, circulate a solution of 25-percent hydrochloric acid and water through the coils until clean. Then flush out thoroughly. Clean external surfaces of coils if practical. A pressure of 75 pounds per square inch is recommended.

Temperature Indicators and Relays, Water and Oil Flow, and Pressure Gages and Relays

* Check indicators, gages, and relays for correct operation and sticking, dirty contacts. Check calibration if in doubt.

Recordkeeping

Maintain detailed records tracking armature temperature against generator load. If temperature readings begin to rise over 5 degrees Centigrade for the same loading conditions, this may indicate a problem that should be investigated.

References

How to Maintain Electric Equipment, GET-1125, General Electric Company
FIST Volume 1-4, Permissible Loading of Generators and Large Motors
FIST Volume 2-2, Field Balancing of Large Rotating Equipment
FIST Volume 2-4, Lubrication of Powerplant Equipment
FIST Volume 3-1, Testing Solid Insulation of Electrical Equipment
FIST Volume 3-3, Electrical Connections for Power Circuits
FIST Volume 3-11, Generator Thrust-Bearing Insulation and Oil Film Resistance

Appendix C

DISCONNECT SWITCH PREVENTIVE MAINTENANCE

Adapted from Power O&M Bulletin No. 19 B
Maintenance Schedules and Records B October 1965,
Section 11 and NFPA 70B, Appendix H

Note: Unless the maintenance interval is specified, conduct preventive maintenance annually (indicated by *) or when the equipment becomes available during an outage. For other maintenance requirements, see section 33, ASwitches, Disconnect,@ in the body of this bulletin.

Inspection

Semi-Annual B Observe components visible through inspection windows: switch contacts, auxiliary devices, wiring, terminal blocks, fuse clips and fuses, insulators and insulating materials, space heater operation, cable terminations, adequate grounding, cleanliness, evidence of water leaks, and overheating of parts. Observe stress cones and leakage sections for cleanliness and tracking. Record loads if equipped with meters.

Weekly B Note whether multiple-shot re-closing fuse has operated. Replace as needed. Check fuse latching and tripping mechanism for proper operation.

Major Maintenance or Overhaul

Depending on ambient, 3 to 6 years.

Major maintenance or overhaul	Maintenance to perform
Structure and enclosure	Repair rust spots and paint.
Base and mounting	Check for loose bolts and insecure or inadequate supporting structure.
Ventilating louvers and air filters	Clean and replace as needed.
Buses, splices, and bolts	Check bolts for manufacturer=s recommended torque.

Major maintenance or overhaul	Maintenance to perform
Insulators	Check for chipped or broken porcelain, excessive dirt film, and tracking; clean as necessary; replace broken insulators; tighten base and cap bolts.
Space Heaters	Verify operation or operate continuously to overcome thermostat malfunction.
Main switch blades and contacts	See that blades are properly seated in the contacts; operate the switch several times and see that blades are properly aligned to engage contacts; clean contact surfaces if corroded; lubricate; tighten bolts and screws.
Contact and hinge spring and shunts	Check pressure springs in contact and hinge and replace, if not adequate; replace flexible shunts, if frayed.
Blade latches and stops	See that blade latches, where provided, are engaged; check latches for proper engaging and holding blade against opening force. See that stops are in place and tight.
Arcing switch blades and contacts	Do not lubricate.
Arc chutes or interrupter device	Check for condition, alignment, and proper operation.
Switch operating mechanism and linkage	Adjust for adequate contact closure and over travel; lubricate.
Operating rods, levers, and cranks	Check and tighten bolts, screws, and locknuts; see that rods, levers, and cranks are in serviceable condition and repair as necessary; lubricate pivot points and bearings.
Gearboxes	Check gears and bearings; flush out oil or grease and re-lubricate.
Operating motor and mechanism	Check motor operation and megger; check adjustment of brake.
Auxiliary and limit switches	Check condition of contacts and refinish with fine file if burned or corroded; check contact springs, operating rods, and levers; check closing and opening positions with respect to main switch contacts or travel or motor mechanism.
Door and other interlocks	Functional test for proper sequence.
Switch disconnect studs and finger clusters (if drawout type)	Lubricate unless manufacturer=s instruction says not.
Cable terminations and connections	Clean and inspect for surface tracking; check connections for correct tightness.
Meters	Check calibration.
Fuse clips and fuses	Check clips for adequate spring pressure and proper fuse rating.

Major maintenance or overhaul	Maintenance to perform
Grounding	Check base and operating handle ground connections; see that ground cable is not broken.
Potential, current, and control transformers	Evaluate and make necessary repairs.
Switch sticks	See that switch-operating sticks are in good condition and are kept in a dry place; inspect sticks for damage and deterioration; discard suspect switch sticks; test sticks per requirements under FIST Volume 4-1B, Personal Protective Equipment.

References

FIST Volume 3-18, Replacing Glaze Burned Insulators.

Mission

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

The purpose of this bulletin is to serve as a medium of exchanging operation and maintenance information. Its success depends upon your help in obtaining and submitting new and useful operation and maintenance ideas.

Advertise your district's or project's resourcefulness by having an article published in the bulletin—let us hear from you soon!

Prospective articles should be submitted to one of the Bureau of Reclamation contacts listed below:

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