RECLAMATION

Managing Water in the West

Canal Operation and Maintenance:

Mechanical Equipment

U.S. Department of the Interior
Bureau of Reclamation
Office of Policy
Technical Service Center
Denver, Colorado

November 2017

Mission Statements

The U.S. Department of the Interior protects America's natural resources and heritage, honors our cultures and tribal communities, and supplies the energy to power our future.

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.

Acknowledgements

For this canal operation and maintenance manual, Reclamation staff, operating entities, and others provided their insights and experiences and their contributions and hard work are greatly appreciated. They include Chris Vick, Chris Duke, Kylie Fink, John Shisler, Bill McStraw, Kyle Converse, Matt Shaw, Alan McCann, Lisa Gentry, Jessica Torrey, Bobbi Jo Merten, and Deena Larsen. The assistance and diligent reviews of these and numerous others is gratefully acknowledged.

Disclaimer

Reclamation developed this manual to provide basic guidance to promote safe and effective operations and maintenance for canal systems. This information complements—and does not replace—experience and sound judgment. As each canal system has unique designs and features, these general guidelines cannot substitute for facility or operating-specific guidance and specifications. Every operating entity is different, and this advice and strategies may not be suitable for your situation.

This manual coordinates with other Reclamation manuals, including the Facilities Instructions, Standards, and Techniques (FIST). 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., manufacturers recommendations, unusual operating conditions, and personal experience with the equipment) in conjunction with these maintenance recommendations. Reclamation's policy is that if there is a difference between any provisions of these laws, standards and regulations, State plans, or manufacturer's instructions, the more stringent provision will apply.

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Acronyms and Abbreviations

AHJ	Authority Having Jurisdiction
ATS	Acceptance Testing Specification
CARMA	Capital Asset Resource Management Application
CO_2	carbon dioxide
dB(A)	A-weighted decibels
DGA	dissolved gas analysis
EPA	U.S. Environmental Protection Agency
GACP	galvanic anode cathodic protection
HI	Hydraulic Institute
hipot	direct-current high potential
hp	horsepower
HPU	Hydraulic Power Unit
HVAC	heating, ventilation, and air conditioning
IBC	International Building Code
ICCP	impressed current cathodic protection
FIST	Facilities Instructions, Standards, and Techniques
JHA	Job Hazard Analysis
LOTO	Lock Out Tag Out
MCP	motor circuit protectors
Megger	insulation resistance
MTS	Maintenance Testing Specifications
NEMA	National Electrical Manufacturers Association
NETA	International Electrical Testing Association
NFPA	National Fire Protection Association
O&M	operation and maintenance
OSHA	Occupational Safety and Health Administration
PPE	personal protective equipment
PT	potential transformer
psi	pounds per square inch
Reclamation	Bureau of Reclamation
RO&M	Reclamation's Operation and Maintenance
SOP	Standing Operating Procedure
V	volts
VLF	very low frequency

Table of Contents

1. Purpose and Scope

This manual is designed to help operating entities better understand how to maintain machinery associated with the Bureau of Reclamation's (Reclamation) canals. This volume describes how machinery is maintained, inspected, and tested.

> Reclamation staff are available to provide advice and technical support on Reclamation-owned canals. Contact Reclamation before making modifications to the canal's mechanical equipment. If you determine work outlined in this manual requires more expertise than your staff can provide, please contact Reclamation for technical support at: www.usbr.gov/main/offices.html.

2. Why Keep Equipment in Good Shape?

Preventive maintenance, repairs, replacement of worn components, and other activities keep equipment functioning and extend its useful life. Spend less money up front to avoid major replacement costs in the future (Figure 1).

Figure 1. Where will you spend your equipment dollars?

2.1. Ensure Reliable Operation

Mechanical equipment failures can lead to canal failures, which in turn can cause significant immediate economic damages, loss of project benefits, injuries, and even loss of life. Experience has shown that mechanical failures can usually be traced to neglecting maintenance requirements and procedures.

Keeping equipment in good shape is vital to avoiding problems and ensuring reliable control. A rigorous testing and preventative maintenance program is the best way to ensure reliable, trouble-free operation of mechanical equipment. The basic premise of a maintenance program should be to:

- Prevent problems through planned maintenance
- Identify and address problems through inspection and testing

This gives an opportunity to correct issues before a crises erupts—thus avoiding component damage, emergencies, and safety hazards.

2.2. Extend Life Spans

Without maintenance, equipment has a shorter lifespan, resulting in costly premature replacement. While regular maintenance will rarely return a facility or its components to their original condition, scheduled maintenance activity keeps equipment running, improves performance, and extends life cycles (Figure 2).

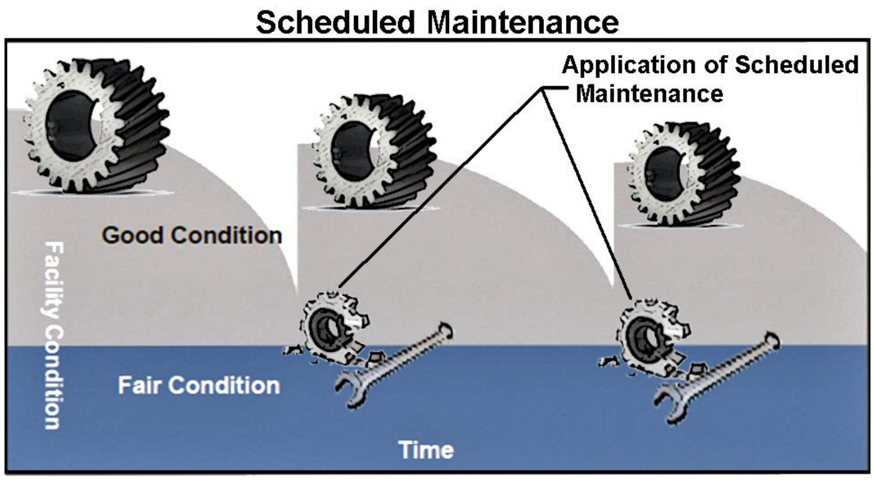

Figure 2. The life cycle of a typical facility or component with maintenance.

3. Develop an Equipment Maintenance, Inspection, and Repair Program

An organized maintenance management program is critical to the sustained and successful operation of the canal system. Most of the procedures outlined here are simple and cost effective. Adapt your maintenance program to your facilities. Actions cannot be a one-time response to each incident. There needs to be an ongoing, proactive approach to identify and address problems before they lead to a failure.

3.1. How to Plan and Document

Equipment conditions, regular maintenance activities, and special and emergency maintenance and replacement activities must be well documented in equipment inventories and job plans/work tracking.

Chances are your maintenance, repair, and inspection processes are running on their own inertia. Analyze your facilities and programs to improve productivity, safety, and reliability.

Compare your existing programs with other programs in your area. Look at the old and keep what is good—what still makes sense.

Stretch your thinking beyond the conventional, accepted norms; seek new solutions.

Develop standard forms for recording data about all equipment (location, purpose, links to drawings, condition, etc.). Keep the maintenance recordkeeping system 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. The record system also provides documentation needed for Reclamation's Review of Operation and Maintenance (RO&M) examinations.

For simple systems, this information could be maintained on a tag on the equipment. However, most systems will require a database program.
Tips for successful documentation systems include:

- Simplicity and flexibility are key factors to consider when determining what program to use. Take care not to purchase a program that is so complex that it becomes difficult to use and manage. Sometimes less is more!

- As your program's success depends on how much the end users want to use the system, get key end users involved in developing database needs. Work with those who will enter data as well as managers and front level supervisors who use the data.

- Establish information flows. Document how staff will retrieve and provide information when required in the future.

- Determine how long records will be kept and develop a process for updating and retaining records. Some records, such as annual inspections of fire systems, can be discarded after a specified period. Other records can be valuable historical data to keep track of maintenance over the equipment's lifespan, help determine the average life of equipment, and provide patterns to spot recurring problem areas.

- Consider the ability to upgrade in the future.

To effectively manage inventory usage, documentation programs should allow staff to:

- Develop standard forms for recording inventory activity

- Develop standard forms for performing physical inventory counts

- Manage account codes, vendors, and inventory locations

- Track line item status with regard to minimum and maximum stock levels

- Create various reports for tracking inventory status, including stock levels and total inventory value at any point in time
- Create various reports for tracking inventory usage by type of activity
- Support annual and cycle counts by generating special count tables and forms
- Change the active status of an inventory item (stock or nonstock) depending on usage level
- Use a bar code scanner to record inventory transactions and to facilitate the performance of cycle counts and physical inventories
- Reserve items of inventory for use with specific work orders
- Allow users the capability to archive completed work orders and restore them if necessary

Reclamation can help set up a documentation system for your district.

3.2. What to Plan and Document

3.2.1. Equipment Inventory

Keep a permanent record of all equipment and continually update changing conditions, performance measurements, and maintenance actions. Comparing a one-time reading taken during a crisis with manufacturer, design, or nameplate data is completely inadequate. Knowing the unit’s past operating history is absolutely essential. When trouble arises or a complaint is made, you need to be able to verify information quickly. Equipment inventories with records will be invaluable when helping to troubleshoot and make critical decisions to remove and repair the equipment. To create and maintain an equipment inventory:

- **Inventory all mechanical equipment.** Develop standard forms for recording data about all equipment (location, purpose, links to drawings, condition). For each piece of equipment:
  - Establish a baseline. Describe equipment details (pressures, voltages, and currents; take photos and document findings) to determine if the equipment performances change over time

- Incorporate manufacturers' maintenance requirements and incorporate these requirements with the equipment inventory.
- Establish performance criteria. Document baseline operational data such as cycling times, hydraulic pressures, and motor amperages.
- Perform condition assessment surveys to determine the current condition of each component.
- Note what maintenance is needed. Develop a system that tracks equipment deficiencies and their repair status.

- **Plan regular inspections.** Establish timelines for inspection of each component to catch problems early. Consider inspecting problem equipment more frequently.

- **Prioritize actions.** Generate annual work plans, including preventative maintenance. These work plans can help prioritize rehabilitation and other projects, develop and justify budgets, and create plans for accomplishing work (contracting out or done in-house). Equipment should be repaired or refurbished before it fails. In-house maintenance staff should focus on scheduled maintenance as the number one priority—even before special projects. This regular maintenance will help reduce the time spent on emergencies.

  Address equipment problems where the risks of a failure are the highest first. Consider:

  - How critical is that equipment?
  - What are the risks involved if the equipment fails (water delivery, further damage, canal breaches)?
  - What is the overall condition?
  - Does further damage or degradation occur with continued operation or deferred maintenance?
  - Can maintenance be conducted when the equipment is in service or is it required to be taken out of service?

- **Report deferred maintenance.** Use the life-cycle costing method or condition assessments.

- **Document replaced equipment's condition.** Keeping accurate records of the "as found" condition of equipment when it is torn down for maintenance can help determine what maintenance was really necessary.

This knowledge can help adjust maintenance schedules for similar equipment in similar situations.

3.2.2. Work Tracking

Use a work tracking system integrated with the equipment inventory to assign maintenance, inspections, and repairs. Keep a record of equipment maintenance:

- When
- Who
- What was done
- Performance measures
- Testing results (if applicable)

Update the system as jobs are accomplished. Also update the equipment inventory to reflect what was done for each piece of equipment. To track inventory usage (e.g., supplies and spare parts), link records of what was used to work orders for each job. This link could be initiated automatically or manually. Reclamation uses an IBM MAXIMO-based system, Capital Asset Resource Management Application (CARMA), which stores and tracks job plans created by various facilities.

Job plans should be integrated with the equipment inventory to schedule actions based on:

- Manufacturers' recommendations
- Reclamation's Design Operating Criteria for that project
- Documented standard operating procedures for meeting testing and maintenance requirements

Table 1 shows a basic form for tracking tasks for a job.

Table 1. Sample Work Plan Tracking Form

Location	Equipment	Recommended interval	Reference /Standards	Date Inspected	Notes

4. Prevention is the Best Cure

The costs of effective equipment maintenance are comparatively less than the costs of emergency repairs, flood damage, loss of project benefits, and litigation costs if a canal breach that could have been avoided occurs. Moreover, the earlier a problem is addressed, the less expensive it will be to fix.

4.1. Keep Constant Vigilance and Keep Improving!

Keep constant tabs on potential problems, not only at regular inspections, but throughout the year. Make it easy for staff to report problems and encourage everyone to be vigilant and note problems (e.g., oil or water leaks, rust, damaged equipment, unusual noises).

Never stop improving your processes and systems. Get feedback on how to improve documentation, priorities, and work processes.

4.2. Inspect Regularly

Implement a regular inspection program, including:

- **Regular annual inspections** at the end of the irrigation seasons to set priorities for maintenance before next irrigation season.
- **Follow up inspections** after inspections as noted in manufacturer's instructions and Designers' Operating Criteria.
- **Periodic inspections.**

Reclamation's Facilities Instructions, Standards, and Techniques (FIST) manuals provide valuable resource for inspections and maintenance techniques: www.usbr.gov/ power/data/fist_pub.html.

5. Equipment

5.1. General

5.1.1. Corrosion

One of the primary mechanisms for deterioration of metals is corrosion. Corrosion, commonly referred to as rusting, is a natural electrochemical reaction between a metal and its service environment (usually soil or water). If left unchecked, corrosion can significantly reduce the useful service life of a structure or equipment (Figure 3). Carbon steel and cast iron are the structural materials most susceptible to corrosion, but corrosion can also occur on stainless steel, bronze, brass, and other metals.

Figure 3. If there is too much corrosion, your gates won't hold water.

Detrimental effects on canals and other equipment from corrosion can include:

- Perforation resulting in water leakage
- Inhibition of movement, increased wear, or altered clearances due to buildup of corrosion products
- Structural weakening of parts or structures due to thinning metal

Varying levels of corrosion can be found at most facilities. If left unabated, damage can lead to costly repairs or replacements. Fortunately, corrosion can be managed. Some of the more common methods of corrosion control are design (e.g., fabricating drain holes to eliminate standing water or avoiding dissimilar metals in contact), materials selection (e.g., choosing plastic or fiberglass), protective coatings, and cathodic protection. The most effective corrosion protection system for buried and submerged structures incorporates both a good bonded coating and cathodic protection.

If there is corrosion, then consult Reclamation to help address existing corrosion problems or to design preventative maintenance plans.

5.1.2. Protective Coatings

Protective coatings are designed to extend the life of equipment by creating a barrier between the metal and the service environment. They can greatly reduce the damage from environmental threats, such as corrosion and abrasion. Coatings provide a high degree of protection from corrosion, but they are imperfect and often contain defects and degrade with time, meaning that the coatings themselves also require routine inspection and maintenance to most effectively protect structures and equipment.

Properly coating metal is a difficult process that requires coating material selection, attention to surface preparation, and specialized equipment and knowledge particular to the selected coating system to be applied. A qualified coating contractor is recommended, especially in cases of difficult to access components or strict environmental/hazardous material requirements.

The key to a successful coating application lies in preparing the surface to be coated: a rule of thumb is that surface preparation should take up 90 percent of the total time for the coating job. Abrasive blasting is recommended, where practical, and generally provides the highest quality coating job. New coatings will not adhere to existing corrosion, organic matter, or dirt (Figure 4). Testing for surface contaminants before application, such as chlorides or other salts and oil/grease, may help to ensure the coating performs as expected.

Coating application should adhere strictly to manufacturer's instructions. Considerations include humidity, temperature, application method, recoat times, and coating thickness.

Once applied, periodically inspect these coatings throughout their service life to identify any damage and determine if a spot repair or complete recoating is needed.

Figure 4. Properly prepare surfaces before coating. This includes cleaning such as abrasive blasting.

Consult with Reclamation for assistance to assess the condition of the coating and to help develop coating specifications.

5.1.3. Cathodic Protection

While protective coatings are the primary defense against corrosion, cathodic protection provides a complementary technique to further reduce corrosion of the structure and ensure that the coating system and structure see an optimized service life. Cathodic protection is primarily used to protect steel structures in burial or immersion service.

There are two types of cathodic protection systems: impressed current and galvanic anode. Galvanic anode cathodic protection (GACP), also called sacrificial anode cathodic protection, uses the natural potential difference between metals to provide the direct current required for cathodic protection of a structure. Sacrificial anodes, typically made from magnesium or zinc, are electrically connected to the structure, often through a test station or junction box. Both the structure and anode must be in the same electrolyte in order for cathodic protection to work. Anodes used for GACP are consumed and must be periodically replaced (Figure 5). A common replacement schedule is every twenty years.

Figure 5. Replace GACP anodes.

Impressed current cathodic protection (ICCP) uses an external power source, typically a transformer rectifier, to provide current. ICCP can be used to protect very large structures or structures with poor coatings. The anodes used in ICCP, for example mixed metal oxide, high silicon cast iron, or graphite, are fairly stable and not consumed over time.

Both GACP and ICCP systems require periodic testing and maintenance to ensure efficient operation and adequate protection of the structure or equipment. Conduct operation and maintenance (O&M) and testing for cathodic protection systems in accordance with the SOP. Record testing results as part of your equipment inventory.

Reclamation can provide technical assistance in designing and installing new cathodic protection systems as well as with inspection, testing, and repair of existing systems.

5.1.4. Lubrication

Lubrication is one of the most obvious areas of concern for mechanical equipment. Proper lubrication serves to protect sliding surfaces by reducing friction—resulting in many benefits. A properly lubricated surface will have a half to a third less friction than a non-lubricated surface. This extends a component's life by reducing hoist loads, reducing part wear, and preventing galling (wear between sliding surfaces). In addition, lubrication can help protect a surface from corrosion by excluding oxygen. It is important to keep sliding surfaces free of dirt to the maximum extent possible as foreign material will not only increase friction and damage surfaces, but can also break down oils and greases.

Always use the proper type of lubricant and in the proper amounts. Too little lubricant will cause excessive wear and lead to a mechanical failure. Too much lubrication can also cause failure through over pressurizing seals or overheating.

Always insist on top quality lubricants and resist the temptation to economize by using lower-graded materials. Reclamation may recommend the grade or type of lubrication for any particular system. Contact local distributors directly to procure the proper product.

5.1.4.1. Lubricating Oil

Oil keeps a lubricating film between moving surfaces. Oil lubrication can take many forms—from a simple squirt oil to a complex circulating system. While having as few types of oil in stock as possible makes it easier for storing and reordering oil, no one all-purpose oil can be used in all applications. Various additives (e.g., emulsifiers, rust and corrosion inhibitors, detergent, and dispersants) are added to oil to enhance performance for a given application. Characteristics that may be desirable in one case may be very undesirable in another. For example, for a motor, emulsifiers are added to the motor oil to allow the oil to hold water in an emulsion until the engine's heat can boil it away. Bearings, on the other hand, won't generate enough heat to evaporate the water, so the oil must be able to readily separate from water for bearing lubrications.

The appropriate oil must be selected, properly applied, and kept clean and uncontaminated. Periodically take a sample of the oil and take it to a local facility to test for viscosity, water, and particles.

5.1.4.2. Hydraulic Oil

The hydraulic oil is the working fluid in a hydraulic operating system. This oil can have a very long service life if properly operated and maintained. Oil in the tank site glass should be looked at for any suspended solids, separated water, or a milky appearance (which would indicate entrained water). When makeup oil is added, first filter it with a mesh size based on the type of components in the system and manufacturer recommendations. Oil in the system should be sampled and sent to a lab for testing after maintenance or replacement of system components, or every couple of years.

5.1.4.3. Grease

A very wide range of greases are commercially available. When selecting a grease, consider what the grease will be used for as well as where it will be used. Important characteristics to consider include: temperature range, water resistance, environmentally friendliness, component speed, stability over time, cold weather pumpability, and the type of material the grease will be protecting. A few tips:

- **Remove the old grease first.** Continually adding grease can lead to misaligning gears and broken parts (Figure 6). So the old hardened lubricants must be removed before applying new grease.

- **Don't mix greases.** Mixing two different types of grease can result in an inferior mixture. If you need to change the type of grease, disassemble completely and clean thoroughly to remove all the old grease. If this is not possible, purge the old grease by flushing the system and increasing the greasing frequency.

- **Don't overdo it.** The idea that more is better, coupled with the fact that it usually is difficult to determine the actual amount of grease in a bearing housing, causes many bearings to be "over greased." This can cause overheating and even bearing failures.

Figure 6. Hardened lubricant led to misalignment of gears, causing the pillow block to move downstream and crack.

5.1.5. Wire Rope

Well-cared for wire ropes subject to the elements can last for 15 years—and even longer.

5.1.5.1. Lubricating Ropes

For wire ropes, the key to a long life is to lubricate before installation and regular lubrication once installed.

Figure 7: Penetrating oil on wire ropes before installation.

Lubricate rope before installing to prevent friction inside the rope. Each strand of a wire rope is designed to share the load equally. This requires strands to move against one another. This is particularly true when a rope bends such as when wrapping around a drum. When the strands move, especially when heavily loaded, heat can build up due to friction. This heat can result in galling or other damage to the individual strands. Penetrating oil reduces friction between strands. When a wire rope is selected, ensure that the supplier has soaked the rope in a penetrating oil bath (Figure 7). A wire rope is generally only required to be soaked in penetrating oil one time.

Lubricate rope regularly to protect the rope and to prevent friction outside the rope. Coating lubrication is designed to stay on the outside of a wire rope (Figure 8). This thicker lubrication will reduce friction between the wire rope and other parts such as a drum. In addition, this lubricant will prevent water and other contaminants from entering the rope. It will also exclude oxygen to help prevent corrosion. Once installed, coat the rope with a lubricant designed to stay on the outside of the wire rope—preventing contaminants from becoming trapped between the rope strands.

Figure 8: Regular coatings of lubrication after installation.

When inspecting wire ropes, take care to inspect the entire rope. Do not assume different portions of the rope will be in the same condition. For example, the top of a radial gate wire rope hoist is always out of the water and subject to larger temperature variations. When the gate is operated, the wire bends around the drum. The bottom of the wire rope is often submerged or subject to wet-dry cycles. This portion of the wire rope is rarely bent. These two sections are subject to very different conditions and will not wear at the same rate.

Figure 9: Common damage on wire ropes.

5.1.5.2. Failure

Wire ropes that are damaged in any way can't carry as much load and should be replaced. Wire ropes can fail from overstress, fatigue, corrosion, galling, etc. Figure 9 shows some common forms of damage to wire ropes.

5.1.5.3. Connection Pins

Connection pins attach the wire rope to the radial gate. Periodically inspect connections for wear, corrosion, and metal fatigue (Figure 10). Replace damaged connections as needed.

Figure 10. Corroded cotter pins and oversized pin holes from wear.

Figure 11. Tying the pipe will not last.

5.1.6. Unauthorized Modifications

A quick fix can seem like a good idea, but this can lead to more problems than it is worth. A quick fix can inadvertently become semi-temporarily-permanent as you mean to come back to it, but do not—until something worse happens. Taking short cuts may compromise safety. Also, the quick fix may break more easily and cause extensive damage (Figure 11). Fix it right the first time so that you don't risk the lives of staff and equipment. Spend the time upfront to look at the problem and repair it according to designer and manufacturer specifications. Consult Reclamation for repairs.

5.2. Gates and Valves (Check Structures)

Gates and valves (check structures) are used to control the flow in pipelines and canals (Figure 12). Gates and valves are the heart of the system, and they are exposed to weather, water pressure, debris, and sediment.

Radial, slide, sluice, flap, overflow, and weir gates are typical gates used in canal delivery systems. Butterfly, pinch, jet flow, and needle valves are types of valves used in canal systems. The gates and valves have various types of operators, depending on their intended use. The operators for the gates and valves can be manual, electric motor, hydraulic, or float controlled.

Figure 12. Gates and valves schematics and examples.

A valve is usually associated with piping or conduits. Valves are typically part of a closed system and act as a type of fitting (so that the body of the valve connects to the piping) which contains the mechanism for controlling flow of a fluid. A gate is usually associated with open channel flow or controlling the flow into a system (e.g., a gate installed at the upstream opening of a pipe or conduit).

5.2.1. Maintenance and Testing

Follow the manufacturer's instructions, Standing Operating Procedures (SOP), and Design Operating Criteria. Regular maintenance may include lubrication and replacing broken and missing components. Regular gate and valve testing programs will identify failures and other problems early in a controlled environment. Do not wait to test until there is an emergency, because you just might find out that the gates or valves won't operate when they're needed the most. Document results and coordinate with the equipment inventory to keep track of the conditions of all gates and valves.

5.2.1.1. Typical Maintenance

While operating the gates and valves:

- Ensure free operation and uniform flow
- Maintain proper clearances

Periodically check alignment and adjust supports and moving parts to:

- Prevent binding
- Guarantee proper gate position: when gates are open they should be out of the water flow and when closed, they should provide a complete seal
- Ensure that metal on metal sealing surfaces are not galling
- Remove minor organic growths and corrosion

Lubricate in accordance with manufacturer's recommendations:

- Chains
- Gear mechanisms
- Trunnion pins

Grease the bearings or other components equipped with grease fittings. Be careful not to overgrease and damage grease seals. Drain gear boxes and refill with new oil. Grease coated gears and stems should be cleaned and recoated with new grease.

5.2.1.2. Tests

Regularly testing the gates and valves—both to their fullest extent (balanced head) and when they are operating (unbalanced head)—is important to identify problems (Figure 13). SOPs require balanced head testing outlet gates and valves yearly and unbalanced head tests (a 10 percent open test) every six years. Unbalanced tests for gates and valves are required periodically to verify gate and valve dependability and determine maintenance requirements.

Figure 13. Reasons for testing gates and valves.

5.2.1.2.1. Balanced Head Test

Balanced tests have been referred to as "full travel tests" because you move the gate or valve to the fully open position and then to the fully closed position while the canal is either fully dry or has an equal amount of water on both sides. These tests ensure gates and valves function completely in a controlled environment; verify that structural movement hasn't occurred; distribute lubricants; loosen minor dirt, corrosion, and organic matter; ensure alignment is correct; and clean wear surfaces.

When the canal is dry or has minimal flows, open gates to their fullest extent and then close them completely. If the canals run continuously, then install stoplogs or wait for a low water surface. Exercise gates both before watering up and dewatering if possible.

5.2.1.2.2. Unbalanced Test

Unbalanced tests have been referred to as "performance tests" because they test while the gate or valve is operating. These tests identify corroded, sticky, and worn parts that need to be repaired or replaced.

Test the gates and valves when the canal or pipe is operating. Unbalanced testing is performed by opening the gate or valve to 10 percent of the full open position (so a 10-foot gate would open by 1 foot). The higher the head, the more rigorous the test.

5.2.1.3. Power Use

Measure and record voltage and amperage on hoist motor or hydraulic system pressure during balanced and unbalanced testing or whenever an operational problem is encountered. See Section 6.6. *Electrical Safety* and follow all safety precautions as noted by the manufacturer and Reclamation.

5.2.1.4. What to Look For During All Operations and Testing

When operating the gates and valves, always look for:

- Debris in moving parts
- Corrosion or coatings failure
- Missing/broken fasteners
- Broken supports
- Bent stems
- Hydraulic system
- Leaks
- Leaks between the gate frame or thimble and concrete
- Operating pressures
- Clogged filters
- Color and level of oil
- Water leaks
- Seals
- Joints
- Piping/fittings
- Unusual noise, vibrations, or heat

Figure 14. Typical damage on a radial gate
(corroded rivets and debris build up due to periodic water intrusion).

If there are any problems (Figure 14), take pictures and report it.

5.2.2. Inspections

Inspect as frequently as the manufacturer recommends. In general, inspect exposed and accessible components for corrosion, minor organic growths, coatings deterioration, or any other damage (Figure 15). Unwater the penstock or water conduit and inspect the downstream portion of the gate or valve. 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.

Figure 15. Examples of problems for gates.

5.2.2.1. Moving Parts

Ensure moving parts are clean. If they are not (Figure 16), either clean during the inspection or provide a work order to do so.

Figure 16. Debris in moving parts gums up the gears.

5.2.2.2. Seals and Seal Seats

Leaking gates and valves cause maintenance problems and pose potential safety hazards. Some leakage will occur, particularly for slide gates (Figure 17). Check for excessive leakage. Look for water leaks, spraying water, and pooled water. Note the leaks, take pictures, measure, and keep track to determine if leaks get worse. Leakage, especially through high-pressure gates or valves, can cause further damage if not corrected.

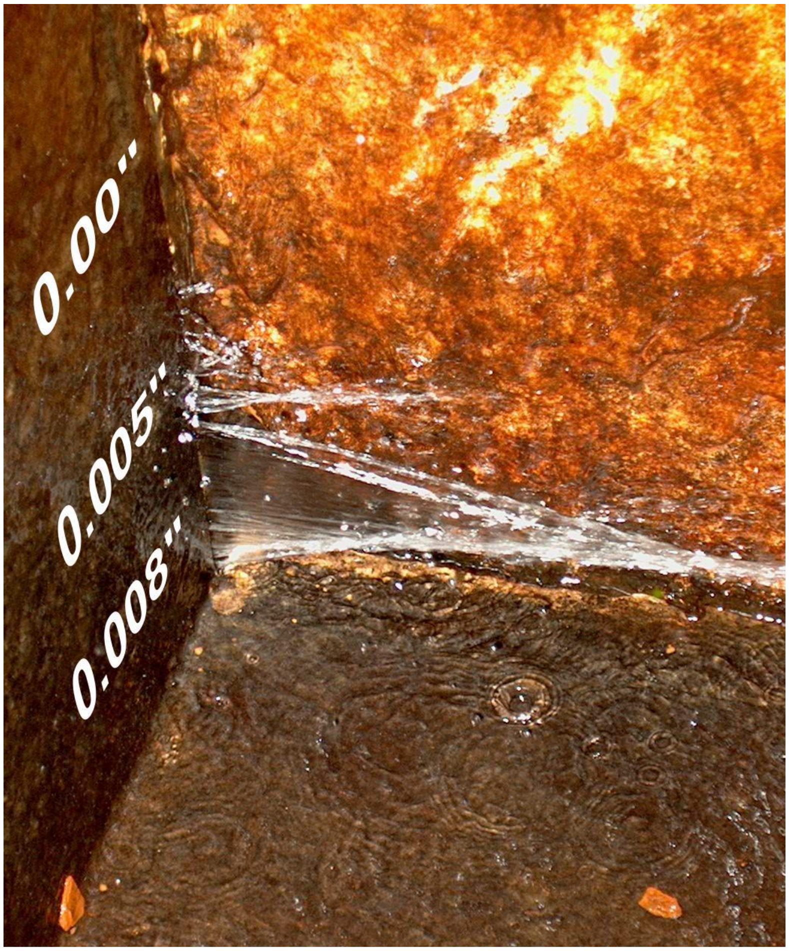

Figure 17. Cast iron slide gate with leaks.

Adjust seals or schedule maintenance as required. Where accessible, check rubber seals for cracking or other signs of deterioration and bronze seals for wear, cavitation erosion, or galling. Check for damaged or missing seals, seal retainers, and bolts. Check operation of greasing systems where applicable. Look for signs of misalignment, such as uneven wear on the seals or seal seats.

If leaking still occurs, unwater and check that water-actuated seals are free to move and that water lines and ports are clear. Check seal seats, wall plates, gate sills, and adjacent concrete for wear or other damage.

5.2.2.3. Hoist and Mechanical Operators

Regularly replace the oil or grease and if possible, inspect between oil replacements. For gear boxes that are easily accessed and opened without spilling oil or grease, check:

- Motor coupling for misalignment
- Oil in gear boxes for water contamination and for proper lubrication level
- Grease-coated gears, stems, and stem nuts for dirt or dust contamination
- Gears, stem, and stem nut for wear, galling, or other damage

Figure 18. Leaking shaft seal on a gate hoist.

- Gear cases for oil or grease leaks or other damage
- Leaking oil and grease seals (Figure 18)

During operations and tests, check for unusual or excessive vibration or noise.

Disassemble as required to check condition of gears, bearings, or other normally inaccessible components.

5.2.2.4. Water and Hydraulic Glands

Monitor and inspect the water and hydraulic glands on the gate and valve shafts (Figure 19). Record the amount of leakage by a packing and adjust the packing to minimize the leakage. Leaking oil packing indicates the packing may need to be replaced. Completely dry packings should be inspected to make sure they are not too tight. A tight packing will increase the load on the stem and increase the load required to open and close the gate or valve.

Figure 19. A flooded stem packing will cause corrosion and damage the packing.

5.2.2.5. Emergency Gates

Emergency gates are used on dams and less often in canal operations. They are the main shut off for water to a canal. If there are emergency gates (sometimes called guard gates) then these can be used to inspect upstream portion if needed.

5.2.2.6. Cast Iron Gates

In general, cast iron gates are allowed to build up a surface layer of corrosion as long as the gate is structurally sound and seals well. Corrosion of gates fabricated of structural steel is detrimental to the gate and should not be allowed (Figure 20). Left unabated, this level of corrosion will cause the gate to fail structurally or seize and become non-operational.

Figure 20. A small amount of corrosion is allowed—until it starts to destroy components.

5.3. Hydraulic Control Systems

Hydraulic Power Units (HPU) provide power for the operation of various gates and valves. The HPU is comprised of:

- Power source: standard and auxiliary
- Oil storage tank
- Pumps
- Filters
- Pressure relief valves
- Control valves
- Piping
- Isolation valves

5.3.1. Testing

Test HPUs during the balanced and unbalanced gate and valve tests. Perform a complete physical examination and operational examination of the HPU during the scheduled system testing. Test and document:

- Hydraulic system pressure during open and close cycles
- Breakaway pressures
- Open/close time duration

- Pressure relief setting
- Reservoir elevation
- Condition of the oil
- Operation of the standard and auxiliary power sources
- System oil leaks
- Any abnormal gate or valve operations

5.3.2. Inspection

Each component of the system helps to control the operation of the gate or valve. The system should be inspected and monitored during operation and on a regular basis. Check:

- Operating hydraulic system pressure
- Oil level
- Vibration or jerking
- Overheating of motor or oil
- Oil filter indicators
- Adequate labeling
- Unusual noises

5.4. Pumps

A comprehensive regular preventive maintenance and inspection program is needed to operate at peak efficiency, protect a capital investment, and avoid costly breakdowns and expensive downtime. Keeping pumps operating is of primary importance, especially when there is minimal, or no redundancy in pumps. The three easiest ways to increase pump efficiency are: have proper lubrication (Section 5.4.1), replace bearings (Section 5.4.2.9), and ensure correct shaft alignment (Section 5.4.2.10).

5.4.1. Keep Track of Pump Performance

Perhaps the most common complaint by water users is: "The pump is not pumping as much water as it used to." It is essential to know if the complaint is valid. Keeping a record of the pump parameters and operation conditions, in the equipment inventory can greatly assist in determining problems with a pump. The past operating history of the pump and motor must be known to determine if a pump is not operating properly. Regularly measure and record:

- The quantity of water being pumped by using a reliable water measurement device (such as an in-line flow meter)

- Bearing temperatures, unit voltage, current draw, flow output, inlet elevation, and, where possible, vibrations

Very reliable measurements can be obtained by using a good amperage meter or a watt-hour meter to measure the amount of electrical energy the motor is using. Remember that if no other data are available, the amperage or watt-hour meter readings will provide an excellent reference point to determine the operating condition of the pump. Lower power consumption can indicate problems with the pump motor. For example, an electric motor will use only the amount of electricity required to operate the pump in normal circumstances. If wear between the pump impeller and wearing ring increases, thus lowering efficiency, then the power consumption will also decrease.

5.4.2. Maintenance

A pumping plant's primary mechanical and electrical equipment consists of the pump, motor, switchgear, and often transformers and substation equipment. A failure in any of these components will force the pump out of service. Basic maintenance procedures for pumps, motors, and associated equipment for pumps and electrical equipment are really quite simple. Good mechanical knowledge and common sense, applied in a timely manner, will be sufficient in most situations.

Pumps driven by electric motors are extremely reliable, and often districts can spend less money to maintain pumps than they do to maintain vehicles and heavy equipment. For example, one district's annual budget for maintaining 198 pumps, motors, switchgear, 400 distribution transformers, and substation equipment is less than the budget for maintaining the district's mobile fleet of 32 pickups, 9 trucks, and 24 pieces of heavy equipment. Pumps are so reliable that they can continue operating in substandard, poorly maintained conditions, thus giving a false sense of security. However, do not neglect proper maintenance procedures, because that could lead to an eventual catastrophic failure.

Many different pump manufacturers produce numerous types, sizes, and models of pumps for various uses, including vertical turbine, horizontal centrifugal, end suction, axial flow, and other types. Many installations combine different types of pumps, such as centrifugal booster pumps with deep well pumps. Regardless of the type or size, the major components and maintenance items are similar for all types of pumps.

The pump's Final Data Manual (also called the Pump Manual) should be your primary reference. Pump Final Data Manuals have pump-specific information for every pumping unit, including a maintenance schedule from the pump manufacturer. If you do not have a Final Data Manual, start by contacting Reclamation to find if an archived copy is available. Alternatively, contact the pump manufacturer and provide the pump serial number located on the pump name plate.

The typical information found in a Pump Manual is tabulated in ANSI/Hydraulic Institute [HI]) Standards:

- 1.4. *Centrifugal Installation, Operation, and Maintenance*.
- 2.4. *Rotodynamic (Vertical) Pumps for Manuals Describing Installation, Operation and Maintenance*

5.4.2.1. Pump Troubleshooting

Solving pump performance problems is a complicated and difficult task. Use all the tools available to:

- **Find the cause.** Determine if this is a system problem—examine flows and ensure that the canals, pipes, valves, gates, etc. are operating smoothly. If there is still a problem, then it may be a mechanical problem with the pump. In that case, be a detective to determine the cause of the pump performance problems.

- **Identify patterns.** Consult all records and try to determine a pattern—when did the problem first occur? Under what flows and conditions does it occur? Are there noises or other indications of problems when this occurs?

- **Develop solutions.** Use the troubleshooting guide in the Pump Manual. Consult Reclamation on the best way to identify and address the problem.

5.4.2.2. Protective Coatings

Applying protective coatings to both the pump exteriors and interiors may reduce friction and wear and keep water from contacting metal to prevent corrosion (Figure 21). Corrosion reduces flow passageways inside pumps and pipes, so keeping corrosion out increases output.

Figure 21. Corrosion can cause water flow issues or other operational problems.

Check with coating manufacturers and other individuals who have experience using different kinds of coatings, as different parts of the pump may require different types of coatings, depending on function and location. This information can greatly help in determining which types of coatings to use.

5.4.2.3. Packing or "Stuffing Box"

Drive shafts and pump sleeves can be high maintenance. Maintenance costs in this area can be significantly reduced by flame-spraying the sleeves with stainless steel or other materials and carefully selecting the replacement packing (see Figure 22 for examples of packing and Figure 23 for packing location). Packing should be replaced periodically, especially if there has been a history of installing extra rings of packing to stop leaks. Pump sleeves with wet lantern-ring packing can wear very rapidly. Overtightening the packing can severely damage shafts and sleeves.

Figure 22. Types of packing (Photo courtesy of YC Industries, all rights reserved).

Careful packing designs can avoid costly maintenance requirements. For example, in a large pumping plant, the impeller shaft sleeves had to be removed and repaired before changing the packing system every year. The pumping plant conducted a retrofit by metalizing the sleeves with stainless steel and installing grease-impregnated wood-metal packing. After this, the sleeves no longer had to be removed annually. After 16 years of service, one of the 70-cubic-foot-per-second, 500-horsepower (hp) impellers was removed, and the sleeves were only worn by 0.002 to 0.004 inches. The five large pumps in this plant continue to operate without any significant wear on the sleeves.

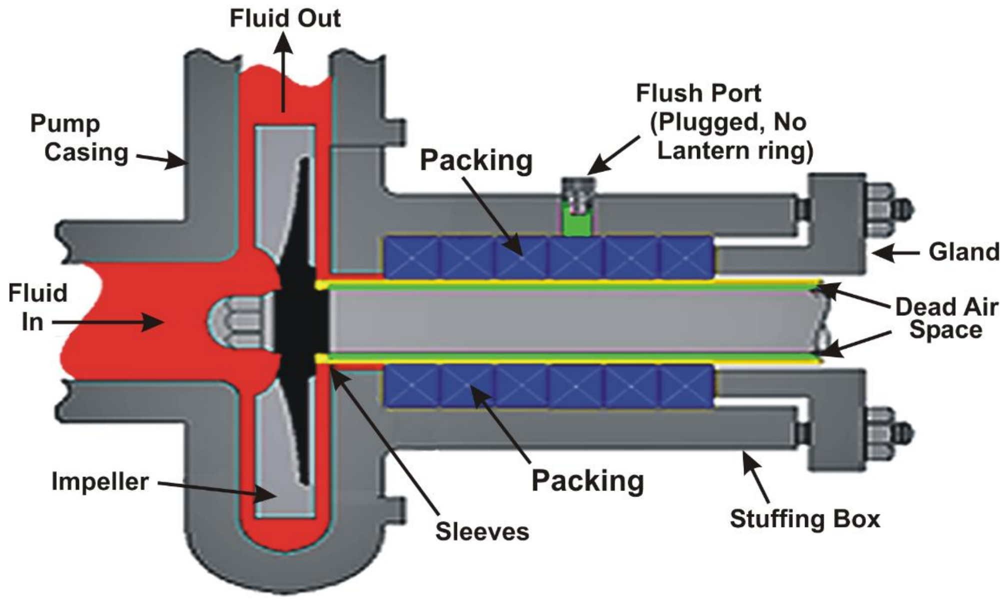

Figure 23. Pump components and packing location (modified from the original drawing [courtesy of Slade, Inc.])

5.4.2.4. 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. 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.

Dirt that is about 100 microns or larger will compromise your seal (Figure 24). Just a small amount of dirt, fingerprints, or other contaminants on the polished sealing surfaces can allow leakage past the seal and reduce the seal's life.

Keep filters for mechanical seal water clean.

Follow the seal manufacturer's installation instructions as closely as possible. The manufacturer also should provide information about the allowable shaft runout and endplay for their particular seal.

Figure 24. A tiny amount of dirt or even a fingerprint can cause major problems.

5.4.2.5. Wear Rings and Impellers

The pump seal is the interface between the rotating impeller and the pump case (Figure 25).This seal is not to be confused with the shaft seal or packing gland. All pumps have one or more seals, and they are usually fitted with replaceable wearing rings. Normal wear increases the annular clearance between the pump impeller and wearing rings. On large pumps, the clearances should be measured and recorded during the annual inspection.

Low pump discharge can be caused by excessive wear at the pump seal, as there may be defective wear rings or impellers. Repairing older, large impellers is generally much less expensive than purchasing replacements, and these can be repaired at any good machine shop. Satisfactory repairs can be made by boring out the wear rings, if there is sufficient material remaining, or replacing them if they are severely worn. Build up the impeller sealing surface, or skirt, by flame spraying or metalizing with stainless steel or other materials. Then machine the impeller skirt to proper tolerances per manufacturer’s or designers’ specifications as noted in the Pump Manual. Badly damaged and broken impellers can be repaired by modern welding and flame-spraying techniques.

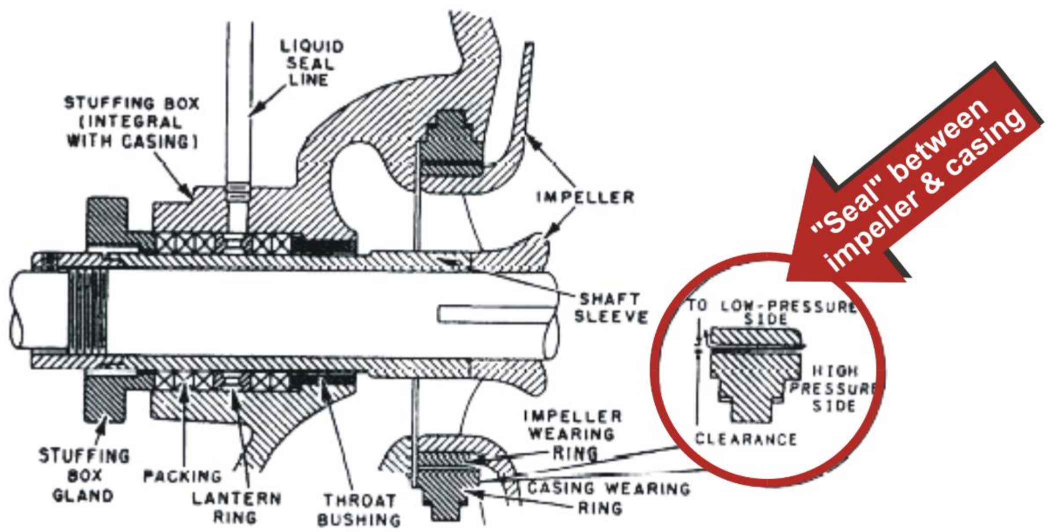

Figure 25. Pump seal location.

While the pump is disassembled, replace the bowl shaft and pump case bearings along with any other worn or damaged parts. After the repairs are completed, the pump will perform as good as new.

5.4.2.6. Excessive Vibration

Modern vibration meters are very useful for determining the normal vibration pattern of a unit. Any change or worsening of the normal pattern is always a sign of trouble and, unless corrected, will almost certainly lead to damage or failure.

5.4.2.7. Foreign Materials

The most common problem affecting pumps, pumping from surface sources, is floating trash and aquatic vegetation. Foreign material such as trash, sticks, rocks, plastic, and even rodents and reptiles are often picked up by pumps. Even small amounts of small-sized trash will reduce pump output. Screening should be provided to prevent entry of foreign materials into the pump. Adequate screening will help to eliminate damage to the equipment and substandard performance. Air introduced into a pump is also a foreign material and can cause damage to the system so eliminate any vortices entering the pump.

5.4.2.8. Cavitation

Cavitation happens when water vaporizes due to pressure changes. Bubbles of water vapor form and implode, triggering shockwaves inside the pump. Cavitation can be caused by improper pump selection or operating the pump outside the range of designed head conditions, especially operating with less than the recommended net positive suction head. A sharp crackling sound coming from the pump while it is running is a very good indication that cavitation is occurring. This sound is similar to rocks passing through the pump. It is frequently heard while filling an enclosed system or when the suction side of the pump is throttled. When cavitation damage is occurring within the pump, very serious damage can be done in a short length of time (Figure 26). Pumps should never be operated over long periods of time while cavitation is occurring.

Cavitation damage and/or impeller wear will usually start any place within the pump where water abruptly changes direction.

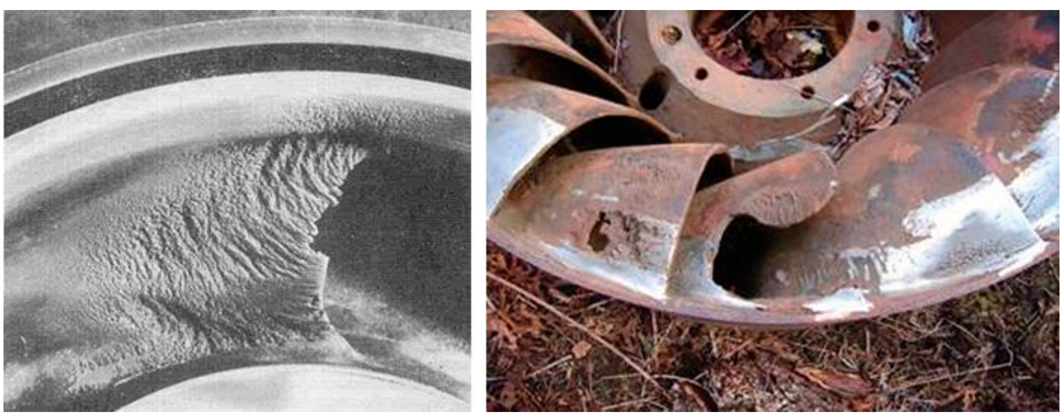

Figure 26. Cavitation damage (courtesy of Dr. Pump, all rights reserved).

5.4.2.9. Bearings

Bearings and bushings keep pump shafts aligned and operating smoothly. Uneven wear patterns in bearings or on shaft surfaces are a clear indicator of trouble. Troubleshooting guides for pumps point to various causes for each type of uneven bearing wear pattern, the problems that this wear can cause, and potential solutions.

Bearings and bushings can be lubricated with oil, grease, impregnated material (graphite) or a sacrificial material (for bushings). The outline drawings for the pump in the Pump Manual will show where the bearings are.

Horizontal pumps generally have roller and journal bearings. Bearings for horizontal pumps are generally either grease or oil lubricated.

Vertical pumps generally have bushings or guide bearings. Bearings or bushings along the shaft of vertical pumps are lubricated with either:

- **Product (pumped water).** Product-lubricated bearings are used only where the pump setting is not too deep to prevent the bearings towards the top of the column being damaged during the time they run dry at pump start-up. Product-lubricated pump settings are typically less than 25 to 30 feet, unless auxiliary lubrication is provided to the upper bearing before starting the pump.

- **Oil, water, or grease lubricated.** Bearings lubricated with special oil, water, or grease are isolated from the pumped liquid by an enclosing tube which extends from the tension nut assembly at the base of the discharge head or motor stand down to the pump bowls.

    - For water or oil lubricated bearings, a valve regulates the gravity flow of lubricating water or oil from a tank, into the shaft enclosing tube, and out of the bypass port in the pump bowl assembly. Water or oil lubricated bearings which are not operated regularly begin the flow of water or oil before the pump is started to provide adequate lubrication of the bushings.

    - Grease-lubricated bearings need to be checked to ensure there is enough grease.

Replenish lubrication materials with the manufacturer's recommendations in the Pump Manual.

5.4.2.10. Shaft Alignment and Couplings
Problems with shaft alignment are also associated with shaft coupling. Shafts become bent or bowed causing vibration issues. Shafts can also be misaligned during installation causing vibration issues.

5.4.2.11. Electric Motor Maintenance
See Section 6. *Safety* for electrical maintenance recommendations.

5.4.3. Inspections
Inspect pumps according to the Maintenance Schedule in the Pump Manual. In large pumping plants, for example, the pumps and motors should be inspected about every three years. All interior parts of the pumps and motors should be

inspected, wearing ring bearing clearances measured, and the entire system thoroughly inspected for damage.

As pumps need to be disassembled to inspect and the pump may need to be repaired and cleaned, plan to take the pump out of service for roughly three months for each inspection. Rotate these inspections: for example, an operating entity with six pumps may plan on inspecting two of those pumps each year.

5.5. Air Systems

5.5.1. Air Compressors

Air compressors are a common piece of equipment found in most pumping plants and maintenance shops.

Reciprocating compressors are efficient and relatively simple to operate and maintain. Most reciprocating compressors can be overhauled completely with a minimum of tools and parts.

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. While little maintenance can be done in the field for rotary screw compressors, the lubrication for the oil filtration system can be maintained. This is important as the tight tolerances make clean oil a 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.

5.5.2. Air 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.

5.5.3. 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 since they could clog. Receiver tanks also should 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 pressure retaining item 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.

5.5.4. Air Receiver Tanks and Air Chambers

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. If moisture is not drained, it can lead to corrosion of the receiver. Air receivers and governor accumulator tanks are examples of pressure vessels found in Reclamation plants. Periodic inspection is required to ensure that pressure vessels are in safe operating condition.

Reclamation Safety and Health Standards, Section 17.12, requires the inspection of all pressure vessels.

FIST 4-1A. *Maintenance Scheduling for Mechanical Equipment* and FIST 2-9. *Inspection of Unfired Pressure Vessels* provide inspection and testing guidelines for pressure vessels.

5.6. Fire Systems

Fire systems are crucial to the safety of personnel and the public. Correct design, operation and maintenance, testing, and inspections of fire systems will provide a reasonable degree of protection for life and property. Regular maintenance and inspections of systems in unstaffed facilities is particularly important because O&M staff are usually not there to detect problems.

Periodic inspection, testing, and maintenance of facility fire systems are critical to ensuring a functional system that will provide a reasonable degree of protection for life and property. Consult the appropriate codes and work with local fire and emergency personnel for these requirements.

Facility personnel directly interacting with the systems should be thoroughly trained in how to perform operation, maintenance, and isolation of the system.

As an important note some facility fire systems can represent safety hazards to facility personnel. Examples of these types of systems include carbon dioxide (CO_2) or other gas based fire suppression systems which result in a low oxygen or toxic environment when deployed. All facility personnel at locations with these systems should be aware of the hazards involved and should adequately plan to mitigate the hazards when performing activities which may affect these systems or areas where these systems may be deployed. This may include isolating and locking the suppression system to prevent operation when performing activities in confined areas where the suppression system may be released (See Section 6.3 *Lock Out Tag Out* and Section 6.4 *Confined Space).*

The FIST manuals and listed codes often contain minimum requirements, depending on the type of fire system, for periodic inspection, testing and maintenance activities including minimum documentation requirements for those activities. . Reclamation FIST manuals also include minimum inspection, testing and maintenance requirements for several types of fire systems.

National Fire Protection Association (NFPA) 72. *National Fire Alarm and Signaling Code* and NFPA 25. *Standard for the Inspection, Testing, and Maintenance of Water-Based Fire Protection Systems* include a significant amount of information on minimum requirements. It is important to note that the referenced national codes are periodically updated, and those updates often include inspection, testing and maintenance requirements that apply to fire systems installed under prior versions of the codes.

5.7. Heating and Ventilation Systems

While developing for operating and maintaining heating and ventilation systems, it is important to remember they can perform several different roles. They may be providing a comfortable work environment for personnel, preventing damage to equipment, or performing a life-safety function. It is important to identify the role that a heating or ventilation system is performing when developing a plan for operation and maintenance of that system. A system with a life-safety function may require more inspection and testing than a system which is only used to maintain personnel work environments.

Heating and ventilation systems intended for buildings or potentially occupied structures are not discussed in this manual; this section is written to address industrial equipment and process related heating and ventilation systems. It should be noted that the heating and ventilation systems not discussed here may have life-safety implications. Some examples of this include stairwell pressurization systems and smoke control systems.

5.7.1. General Maintenance

Periodic maintenance and periodic verification of operation will benefit both the heating and ventilation systems and the equipment they protect.

See FIST 4-1A. *Maintenance Scheduling for Mechanical Equipment* for recommended maintenance intervals.

5.7.2. Life-Safety Related Systems

Some heating, ventilation, and air conditioning (HVAC) systems make a location safe for personnel to occupy a space (e.g., ventilation systems for confined spaces or for locations with hydrogen sulfide). As lives are at stake, verify these systems are working before entering that space. Personnel entering these locations should be familiar with the operation of the system and its intended function. If the system requires a delay to make a location safe, for example, a certain number of air changes need to be performed before the location is safe to enter, then personnel should be familiar with these requirements and allow sufficient time before entering the space. See Section 6.4 *Confined Space.*

These recommendations are not intended to provide a definitive list of all requirements which must be met to ensure your safety. In particular, various workplace safety requirements must also be met, including Occupational Safety and Health Administration (OSHA) regulations.

5.7.3. Freeze Protection Systems

Heating systems are commonly used to provide freeze protection to prevent damage to equipment. This heating can be provided by several different types of equipment, from unit heaters for heating rooms and similar spaces to heat tracing for piping and tubing to heated enclosures for outside equipment.

Evaluate your heating system to ensure it adequately addresses:

- The ambient temperature that the component will be exposed to
- The diameter of the pipe or tube in piping or tubing systems (including small diameter piping or tubing in associated components)
- Any possible stagnant liquid in the equipment, tanks, or piping
- Temperatures or conditions when the material in the pipe or component starts to freeze or harden
- Conditions at the location

Follow the manufacturer’s guidelines for the equipment being protected and manufacturer’s and designers’ guidelines for installing, designing, and operating the freeze protection system.

5.7.3.1. Installing Freeze Protection Systems

Ensure that freeze protection systems are installed according to the manufacturers’ recommendations for both the component being protected and the freeze protection system. Follow requirements for insulating the area or component that uses the freeze protection. Freeze protection systems are designed based on the level of insulation, so it is important that the installed insulation matches the design or the equipment may not get enough heat. Heat trace systems in particular will not transmit the heat they are generating to the component unless there is insulation between the heat trace cable and the air.

The freeze protection system equipment should not interfere with system O&M. Heat trace systems in particular should be installed so they don't interfere with operating or removing valves or similar components. A number of different manufacturers can provide information on recommended installation techniques to try and minimize this.

5.7.3.2. Controlling Freeze Protection Systems

Freeze protection systems may be directly connected to a power source that is "always on" or a power source that is operated by controllers. Components like unit heaters or space heaters are often thermostatically controlled, where a thermostat (either within the heater or mounted as a separate thermostat) is used to turn the heater on and off.

Heat trace systems can also be used in an "always on" configuration, controlled by a thermostat, or controlled by one of the control panels designed for heat trace systems. Controlling the temperature in heat trace systems is slightly more complex than heaters, because there are several varieties of heat trace cables. Some types of heat trace cables inherently adjust the amount of power they are putting out to heat the component, based on the ambient temperature of the cable. Heat trace systems also generally require ground fault protection, and it is recommended they include some sort of indication, like a light, to show the heat trace system is on.

5.8. Engine Generators

Engine generators provide essential power to supply critical loads in the event of loss of the normal power source. Engine generators must be maintained and tested regularly to ensure they will perform as expected. Follow manufacturer and NFPA standards.

Use manufacturer's specifications and instructions to develop a maintenance and testing schedule. In general, engine generators should be operated on a weekly test cycle and under load once a month to verify the system works properly.

5.9. Electrical

5.9.1. General

Most electrical failures are a result of not keeping equipment clean, tight, dry, and cool. Strictly adhering to these four key requirements for electric equipment maintenance will eliminate many problems.

5.9.1.1. Keep Equipment Clean

Dirt and oil provide an environment for moisture to collect and remain in contact with energized parts and insulating materials. These contaminants can also be conductive and provide a path to degrade electrical insulation. Dirt, oil, and moisture remaining in contact with motor windings may not allow for proper cooling of the motor and may reduce the insulating properties of the insulation. These contaminants can also introduce abrasive materials into moving parts, thus increasing wear.

5.9.1.2. Keep Equipment Tight

Probably the most common cause of electrical failures is a loose connection (Figure 27). Electric current flowing across a loose connection generates heat— causing insulation failure, brittle wires, fires, explosions, etc. Follow a regularly scheduled program to inspect and tighten all electrical connections within the system. Infrared cameras and remote temperature sensors are excellent tools for diagnosing trouble spots caused by loose connections and other discrepancies. They have the advantage of inspecting the system remotely, while it is in operation, and pinpointing trouble spots before a failure can occur. Many service shops offer inspections using these cameras at an attractive price. Besides pointing out potential problems, they also provide peace of mind by visually showing normal operating conditions. These cameras are one of the best diagnostic tools available.

Figure 27. Rear view of indicating light terminal connections (fault initiated on lugs connected to center red light terminal). Fault caused by a loose screw connection and a malfunctioning circuit breaker.

5.9.1.3. Keep Equipment Dry

Water and electrical equipment simply do not mix. Moisture can provide a conductive path and greatly reduce insulation resistance, which could cause the electricity to short or arc (Figure 28). Moisture can cause problems for moving parts as well due to corrosion and other contaminants being attracted to the moisture. Ensure the system does not introduce water onto electrical equipment. For example, irrigation sprinkler systems should never be allowed to spray directly onto pump motors and electrical equipment.

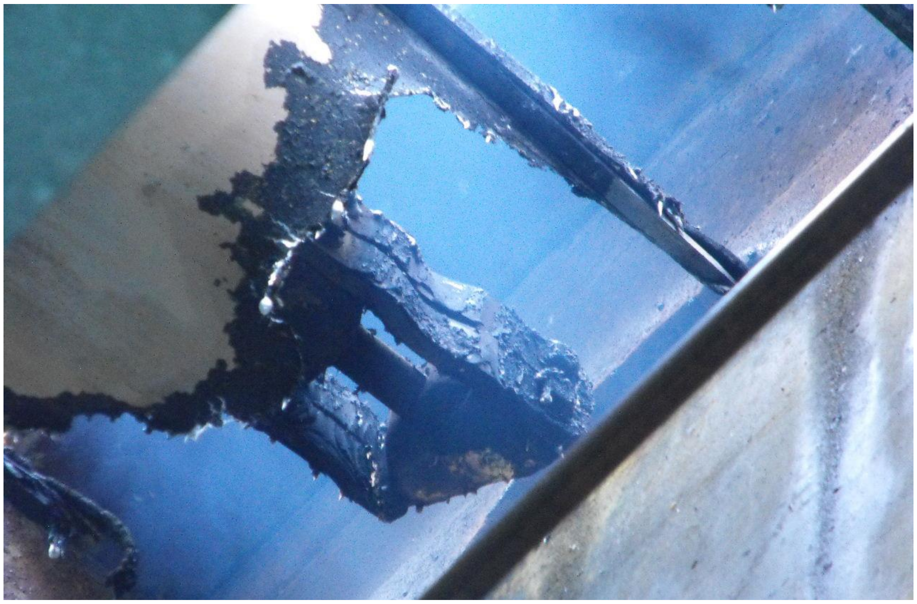

Figure 28. Melted metal from an arc flash caused by water coming into contact with electrical equipment.

5.9.1.4. Keep Equipment Cool

Heat is a major enemy of insulating material, especially in older motors and wiring. Studies have shown the life of an electric motor is doubled for each reduction in operating temperature of 18 degrees Fahrenheit. Sunshades for motors, reflecting paint, ventilating fans, and, if feasible, separate air-conditioned enclosures for pumping plant switchgear are effective measures to reduce temperatures.

Figure 29. Typical megger. Photo courtesy of Megger, all rights reserved.

5.9.2. Electrical Insulation Testing

Follow a program of regular electrical insulation resistance testing for appropriate components. Several types of insulation resistance testing include:

- Direct-current high potential (hipot) testing,
- Insulation resistance (“Megger”) testing (Figure 29)
- Very low frequency (VLF) over potential testing

Different tests are applicable for different types of equipment. Follow industry standards for testing. Megger testing is the most common form of testing, and is often widely applied on the medium voltage and low voltage distribution systems. Hipot testing can be a destructive test which may cause some degradation in the insulation, but can detect problems that a Megger test can’t. Since hipot testing can be destructive, it is generally used for components at the medium voltage level and is rarely used for low voltage components. VLF testing is primarily used on cables or rotating machinery in lieu of hipot testing, partly because VLF testing is less destructive than hipot testing.

Megger, hipot, and VLF testing are all performed with test sets specifically designed to perform the desired type of testing. It is extremely important the tests be performed at the appropriate voltage for the equipment being tested. It is best to use the manufacturer's recommendations to determine this voltage. If this information is not provided in the information supplied by the manufacturer, there are industry resources like International Electrical Testing Association (NETA) "Acceptance Testing Specifications" (ATS) and NETA "Maintenance Testing Specifications" (MTS) and information supplied by the test set manufacturer that provide guidelines on these values.

Keep a permanent record of these tests and other maintenance procedures to identify and follow trends. Quite often the Megger readings may not look bad, but the trend may show the component is starting to degrade. Maintaining trend records will allow personnel to evaluate and plan for a replacement or some form of corrective maintenance.

See FIST 4-1B, *Maintenance Scheduling for Electrical Equipment*.

5.9.3. Enclosures

Enclosures may protect electrical equipment against water, sound, temperature, dust, insects, rodents, and more. Ensure that enclosures for electrical equipment provide enough protection for the location and conditions. Electrical enclosures generally use ratings from National Electrical Manufacturers Association (NEMA) NEMA 250 *Enclosures for Electrical Equipment (1,000 Volts Maximum)*. Wet equipment can lead to energized water, shocks, corrosion, and equipment failures (Figure 30).

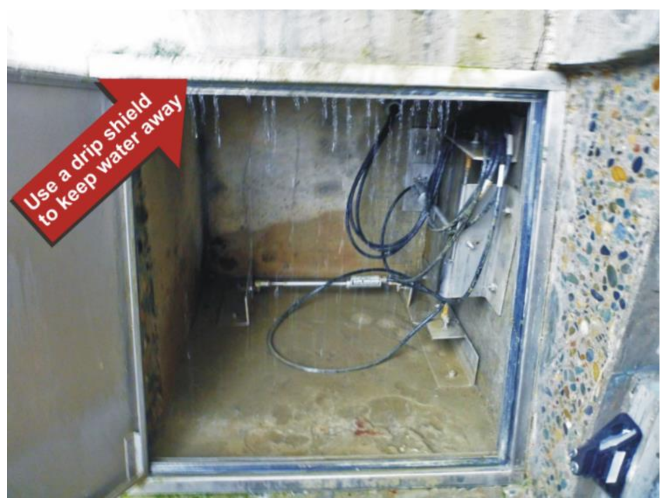

Figure 30. This enclosure has water dripping into it and puddles, making the equipment wet. This enclosure needs a drip shield to divert water running down the wall and door gasketing.

Enclosure types have varied amounts of protection: from protection against hose directed water, windblown dust, ice, and corrosion to protection only against dripping water. Other options are also available for electrical enclosures, including rodent screens, cooling systems, anti-condensation heaters, corrosion resistant materials, and a variety of hardware and enclosure configurations.

Analyze the situation and use the proper enclosure for the conditions the system may encounter.

Enclosures or housings with noise insulation are also available. These enclosures are uncommon for small electrical boxes but are sometimes provided for equipment—either to limit the need for employee hearing protection or to limit the noise in the surrounding area. Examples of equipment where noise insulation is sometimes provided include standby generators located near residential areas. When purchasing equipment with noise insulation, it is often good practice to list the desired maximum sound level in A-weighted decibels, (dB[A]) and the distance from the equipment the sound level is specified at (e.g., 3 feet). Some options are available for retrofit noise insulating enclosures, however they are generally much easier to install if installed with the equipment.

5.9.3.1. Maintenance and Inspections

Periodically look at the outside and inside of each electrical enclosure for any signs of damage to the enclosure, wiring, and equipment. Check for:

- Damage
- Dust build-up
- Water
- Corrosion

Look for any staining or discoloration, as this may indicate damage that cannot be seen (such as aging electrical insulation, heat damage, or water damage).

If any of these problems are noticed, take a picture and report it and investigate further. For example, if dust has built up inside the enclosure, clean all components inside the enclosure. If significant dust build-up is occurring between cleanings, investigate how the dust is getting into the enclosure and try to prevent it. If water is getting into the enclosure, find a way to keep the enclosure dry (e.g., repair the rubber gaskets in the door).

5.9.3.2. Repair and Installation

When repairing and installing new wire, use good installation practices to protect the equipment, provide a safe work environment for personnel working in the enclosures, and make it easier to perform work in the enclosures.

The electrical enclosures should have a neat appearance with wiring restrained, supported, and routed neatly in the enclosure (Figure 31 and Figure 32). This is often done using wireways or tie-wrapped cable bundles.

Wiring inside the enclosure should also be restrained and not flopping loose (Figure 33). Do not over bend wire, as this will damage the insulation of the cable and lead to failure (Figure 34). Wire should not be bent more than the “minimum bend radius” recommended by the manufacturer. Leave enough space inside enclosures to route wire and cable so it is easier to install and wires do not have to be bent or twisted to fit.

Figure 31. Wiring installed neatly in wireways.

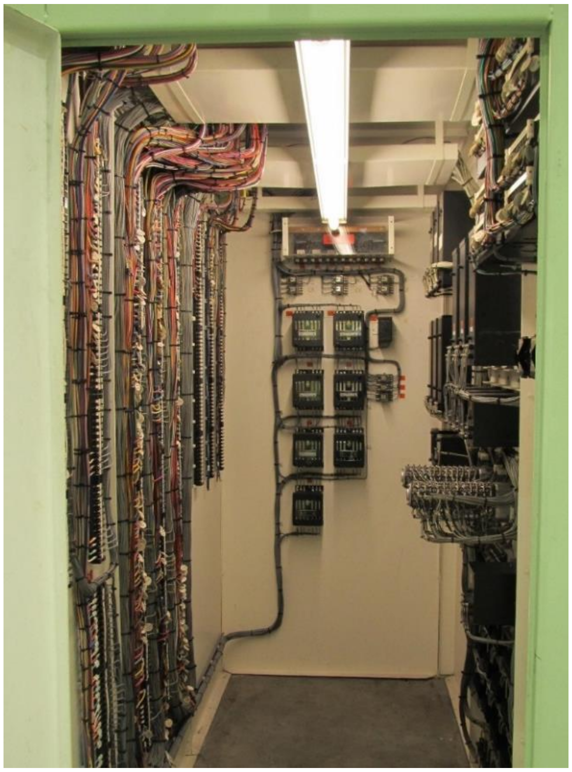

Figure 32. Wiring installed in tie wrapped cable bundles.

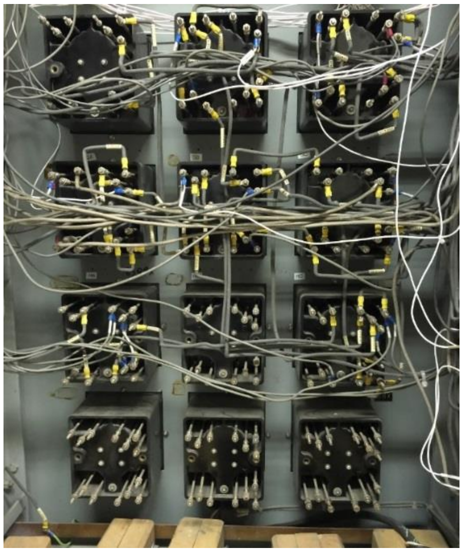

Figure 33. Unrestrained wiring.

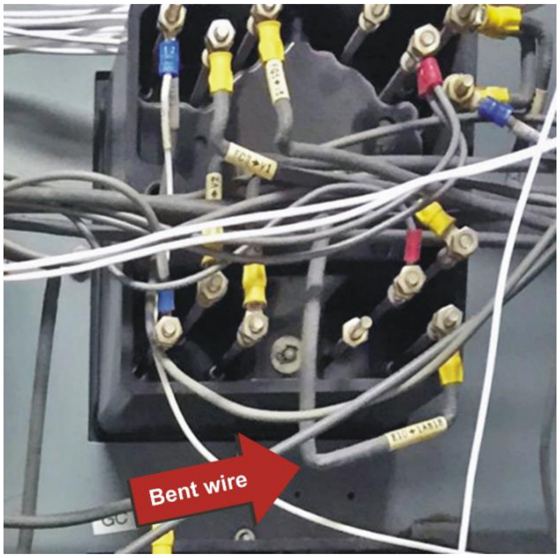

Figure 34. Over-bent wire.

5.9.4. Surge Arresters and Surge Protection Devices

Lightning arresters, surge arresters, and surge protection devices provide protection for important equipment from high energy surges. Types and applications range widely from a small surge arrestor used on a digital control circuit to surge arrestors used on large transmission lines. Surge suppressors for low voltage or low power application may include circuit board mounted or digital components, which may have internal diagnostic capabilities or require special diagnostic equipment purchased from the manufacturer to perform manufacturer recommended maintenance.

These devices require periodic inspections. This can range from ensuring the indicator light is still on in smaller surge protectors (lower than 480 volts [V]) to insulation resistance tests (480 V or higher). Perform all testing in accordance with manufacturer's instructions and industry guidelines to avoid damaging the equipment.

> FIST 4-1B. *Maintenance Scheduling for Electrical Equipment* includes maintenance recommendations and inspection requirements for surge arrestors used in larger power applications (usually over 600 V porcelain-type surge arrestors). However, these recommendations may not apply to arrestors used in low voltage or low power applications.

5.9.5. Batteries

Battery systems provide "last resort" power for performing communication, alarm, control, and protective functions (relaying and breaker tripping) when other sources of power fail. Batteries are split into several types: batteries which are stationary and permanently installed in a specific location, and batteries that might move around (for things like vehicles). This section is intended to address permanently installed, stationary batteries.

5.9.5.1. Maintenance and Inspections

Perform battery maintenance in accordance with the guidelines in FIST 3-6 *Storage Battery Maintenance and Principles*. Battery testing requires specific training and knowledge of batteries. Have a staff member trained to perform this and ensure that they have the proper equipment.

Periodic inspections and load testing should be done on every stationary battery to check battery life and ensure proper battery condition. Battery maintenance test data should be trended over the life of the battery, as this helps predict when the battery will fail.

5.9.5.2. Replacement and Installation

Battery installations can be hazardous: batteries themselves are toxic and often made of highly acidic material, and batteries can emit explosive hydrogen gas. Ensure safety precautions such as pill containment, installing ventilation, providing eyewash stations, and using appropriate personal protective equipment (PPE) can help mitigate these risks.

> Stationary battery installation requirements and requirements for the location where the batteries are installed are included in:
> FIST 3-6. *Storage Battery Maintenance and Principles*
> NFPA 1. *Fire Code* Chapter 52
> NFPA 70. *National Electrical Code*
> And OSHA and U.S. Environmental Protection Agency (EPA) requirements
>
> These documents contain requirements for ventilation and monitoring for battery installation locations, spill containment, and support and bracing.

5.9.6. Motors

5.9.6.1. General

Perform periodic inspections of all motors. Inspections should include overall condition of the motor and base and tightness of electrical connections. Check for:

- Damage to the motor housing
- Dirt
- Signs of corrosion
- Condition of any belts

Ensure that all ventilation openings and filters are clean and free of obstruction.

Verify the quantity and condition of motor grease and oil. Add grease and replace oil according to manufacturer's recommendations for the motor arrangement and bearing types. Check any gauges or instrumentation on large or critical motors daily against normal operating values. Record values periodically for long term trending.

> See FIST 3-4, *Keeping Motor Windings Dry*.

5.9.6.2. Small Motors (Smaller than 500 hp)

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. Routinely check critical motors.

5.9.6.3. Large Motors (Larger or Equal to 500 hp)

5.9.6.3.1. Maintenance

In harsher climates, winterize outdoor motors during the non-irrigation season. Install snow shields to cover the ventilation openings in the motors. Ensure the shields are a bright contrasting color so the motor will not be operated with them in place. Overfill the bearing oil reservoirs to submerge the bearings and prevent rusting. Replace the bearing oil in the spring or more often if conditions warrant. Pumps frequently operate continuously for the entire season without changing bearing oil. Use a good grade of oil and avoid the temptation to economize.

Recondition electric motors operating outdoors on a regular basis, working with qualified personnel. The reconditioning procedure consists of a thorough steam cleaning and drying. While the motors are disassembled for reconditioning, this is an excellent opportunity for a thorough inspection, making sure all mechanical parts are in peak operating condition. Any problems in the electrical components, such as cracked leads, loose slot sticks, end turns, and coil ties, can be repaired or replaced. The rotors should also be carefully inspected, making sure there are no cracked squirrel cage bars, broken fan blades, or loose components.

5.9.6.3.2. Inspections and Replacement

A thorough visual inspection is one of the best maintenance procedures on large motors. Replace aged or damaged components such as brushes and bearings according to manufacturer's instructions. Use qualified trained personnel and proper equipment. In larger motors, pay special attention to:

- **Bearings.** Approximately 80 to 90 percent of motor failures occur because of a failure of mechanical components within the pump-motor system such as bearing failure. Bearings can fail from overheating, grit and abrasion, and lack of lubrication. The mechanical failure can then involve the motor windings, leading to complete failure and a very costly complete motor rewind. Maintenance, inspections, and replacement for bearings depend on the type of bearing, so follow manufacturer instructions carefully.

- **Stator coils**. The condition of the insulating varnish should be inspected; it should have a good gloss and not be cracked or crazed. Slot sticks should also be firmly in place. Make sure the coil ties, at the end turns, are tight and there is no looseness at all, especially where the coils enter the stator iron. Looseness, and the resultant movement, in this area is the source of most motor failures.

- **Slip rings, commutators, and brushes**. A smooth dark-colored patina on these components is normal. Never clean slip rings unless they are badly pitted, scored, or burned. The slip rings naturally build up a layer of carbon within the pores of the metal surface, which will help lengthen the life of the brushes and promote good current flow to the motor. Badly worn commutators or slip rings should be resurfaced, cleaned, and repaired.

Perform these electrical tests for large motors:

- Conduct Insulation Resistance Testing and Hipot testing (generally only performed on medium voltage motors)
- Conduct motor stator resistance tests (generally only performed on medium voltage motors)
- Verify tightness of bolted electrical connections
- Measure resistance through the bolted connection
- Verify the operation of motor accessory devices, like space heaters, instrumentation, etc.

5.9.7. Motor Starters / Motor Circuit Protectors

There are many names for motor starters in the industry. The terms "motor starters," "motor circuit protectors (MCP)" and NEMA combination starters" can all refer to the same type of equipment that controls the motor. These are the devices that let the motor be turned on and off by an electrical signal.

Motor starters can be highly customizable, and manufacturers can provide a variety of options from a loose starter (Figure 35) to motor control centers (Figure 36). A common configuration includes a circuit breaker, motor contactor, overload relay, start/stop push buttons, and indicating lights. A common option is a potential transformer (PT) to provide 120 V control power to the motor starter.

Figure 35. Loose starter.

Figure 36. Motor starters in a motor control center.

Perform periodic inspection of the motor starter to check its condition and to ensure the electrical connections are tight. Inspect the condition and operation of contacts. Verify proper operation of the control circuits for the motor starter, including operation of the indicating lights and accessory devices.

Perform circuit breaker inspection in accordance with the recommendations in FIST 4-1B. *Maintenance Scheduling for Electrical Equipment*.

5.9.8. Switchgear

Switchgear distributes power to the electrical system (Figure 37). Electrical switchgear operates like a panel of circuit breakers to distribute power to secondary panels that distribute power to the electrical components. Switchgear generally consists of an enclosure about 4 to 5 feet wide with vertical sections that are often about 1.5 to 2 feet wide each. The switchgear is the heart of the electrical distribution system, as the panelboards, motor control centers, and electrical distribution components get power from the switchgear. Some smaller systems may simply use a motor control center or power panels.

The failure of a small, seemingly insignificant component in the switchgear can force a pump or the entire facility out of service. Yet the switchgear is one piece of equipment where maintenance has historically been ignored. Furthermore, many circuit breakers on the switchgear are rarely operated, so the contacts can become pitted, and the mechanical parts of the breaker become stiff. This will lead to the breaker not being able to operate as designed when needed, which is a very perilous situation for both the equipment and personnel.

Figure 37. 480 volt switchgear.

5.9.8.1. Maintenance

Switchgear maintenance includes other maintenance on the overall enclosure and bus work inside and on the circuit breakers. The overall installation should be periodically inspected, including the condition of the interior buss work, cable terminations, circuit breaker compartments, and control compartments. The switchgear enclosure should be in good condition and free of dust, moisture, and any signs of visible damage. Electrical connections, specifically bolted bus and power termination connections, should be tight and show no signs of damage. This should be checked by either checking the tightness of the bolt with a calibrated torque-wrench, verifying the resistance across the bolted connection, or performing a thermal survey. Correct operation of auxiliary components like heaters, meters, etc., should be checked for proper operation and readout.

Circuit breaker racking mechanisms should be operated and checked for alignment and circuit breakers should be operated. Use a vacuum cleaner to clean the switch gear cabinet. Do not use compressed air to blow dirt out of switch gear cabinets, as this can drive dirt into delicate mechanisms.

If switchgear has not been maintained in the past and a significant amount of time has elapsed since switchgear components have been operated, consider taking special precautions when restarting switchgear maintenance cycles. This situation represents a higher-than-normal hazard for circuit breaker or racking mechanism misoperation.

Special attention should be given to the contact points and the trip element. When the contactor closes, the points should come together simultaneously and have equal spring tension. Replace any contact points that are badly pitted, burned, or worn. Spare contact points and main holding coils for all the makes and sizes of contactors used in the facility should be available within the facility's warehouse.

> Perform circuit breaker maintenance in accordance with the recommendations in FIST 4-1B. *Maintenance Scheduling for Electrical Equipment*.

5.9.8.2. Inspections

Qualified personnel should perform regular inspections and replace damaged parts.

A special test set is required to test the circuit breaker trip unit. This test is very important because there will be no sign that a trip unit has failed, and if the trip unit has failed then the breaker will never trip if there is a fault. At one pumping plant where breaker maintenance was never performed on the switchgear, the first time the trip units were checked, 7 out of 16 trip units were bad, and the breakers would never have tripped. If breakers do not trip, then system components can fail or be severely damaged.

One of the most dangerous pieces of equipment in any facility is the 480-V station service switchgear since it has more power flowing through it than most of the other electrical equipment at the facility. The power available in the switchgear can cause large electrical arc flash, with the most dangerous time being when a circuit breaker is being operated or mechanically moved within the enclosure. Mechanical movement allows for component failure or breakage within the enclosure, which might cause an arc flash. Arc ratings are indicated on the switchgear ratings nameplate. Unless the switchgear enclosure is arc-rated to contain the arc, a closed panel door will not provide sufficient protection. Staff should be located as far from the switchgear as possible when either operating the circuit breakers or the racking mechanisms—if switchgear configuration allows. Modern switchgear has options like remote racking devices and control set up to allow the circuit breakers to be remotely opened and closed. See Section 6.6 *Electrical Safety* for more information about arc flash labeling.

5.9.9. Transformer Maintenance

Qualified personnel should regularly inspect and perform transformer tests according to FIST 3-30 Transformer Maintenance and FIST 3-31 Transformer Diagnostics.

5.9.9.1. Oil Filled Transformers

Oil filled transformers use oil to provide electrical insulation in and around the transformer windings. A transformer maintenance program must be based on thorough routine inspections. At least monthly maintenance rounds should check to ensure gages and levels are within normal ranges. Annual inspections are also needed.

Figure 38. Side view of a transformer, looking at the transformer cooling fans.

One of the best indicators of what is going on inside a distribution transformer is the insulating oil. Periodically take an oil sample for a lab to perform a dissolved gas analysis (DGA). The company that analyzes the oil will produce a valuable report that will show the results of the analysis. These results should be recorded and trended, since this can indicate developing problems within the transformer.

Test results can vary based on outside factors such as humidity, barometric pressure, and material of sample bottles. Try to keep all factors for the test the same (e.g., same time of day, same procedures). It is critical the sample be drawn so that it is not contaminated with gases and moisture from the outside air. Carefully seal the sample and protect against contamination as much as possible.

Annual DGA tests of oil samples can tell a myriad of information, such as if there is excess heating or if there is arcing inside the transformer. It is an excellent indication of the health of the transformer as well as a good indicator that things are starting to go bad. Qualified personnel should compare annual results to determine long-term trends.

Gauges and instrumentation on the transformer should be routinely inspected against normal operating values. These values should be periodically recorded to track operation of the transformer over time.

5.9.9.2. Dry Type Transformers

Dry type transformers do not contain insulating oil and are often used for indoor transformers and for small transformers. The gauges and instrumentation on the transformer should be routinely inspected against normal operating values. These values should be periodically recorded to track operation of the transformer over time.

> Information on transformer testing and maintenance requirements is in FIST 3-30. *Transformer Maintenance.*

6. Safety

Performing maintenance on mechanical and electrical equipment can be hazardous. Electrical and mechanical energy can cause injury and death if not managed properly.

6.1. Hazardous Energy Control Program

You must have a Hazardous Energy Program that includes written procedures, personnel training, and periodic inspections to ensure the machine and/or equipment is isolated from all hazardous energy sources before any maintenance. This can prevent unexpected energizing, startup, or release of stored energy that could cause injury or death.

Your program should consider specific Job Hazard Analysis (JHA) and Lock Out Tag Out (LOTO) processes for energy sources.

> See FIST 1.1 *Hazardous Energy Control Program* and *Reclamation Safety and Health Standards* Section 15.

6.2. Job Hazard Analysis

Before anyone begins any work, a responsible supervisor, in consultation with a safety or health professional, must assess a workplace or work activities to determine what potential hazards are present or are likely to be present.

The conclusion of the assessment will determine if a JHA is warranted based on all possible hazards that will be encountered. Potential hazards may include but are not limited to:

- Ambient conditions
- Atmospheric conditions
- Confined space
- Extreme working conditions
- Various types of equipment to be used
- Environment and surrounding work conditions
- Electric shock
- Arc Flash
- Potential encounter with various species of plants, animals and insects
- Terrain where work is to be performed
- Access to work site
- Slip, trips, falls

A health hazard assessment is to be performed if there is any potential hazard exposure. Consider:

- Chemical
- Physical
- Biological

A JHA is the thought process needed to identify risks to health, how to avoid them and actions to take if an accident should occur. Thinking through possible hazards and threats can reduce or eliminate the chances of something happening before anyone gets hurt and equipment or facilities are damaged. The JHA will identify what course of action or actions can be performed to mitigate potential hazards. A JHA should have information that covers:

- How everyone will communicate
- What work is to be done
- Where is the work to be done: physical address and site access
- Who will be doing the work
- When is the work to be performed
- How long the work will take (expected time for completion)
- What training is required
- What equipment will be needed
- What PPE will be required
- Who will be affected (e.g., downstream or upstream activities, neighbors)
- What the potential hazards are
- Where the first aid kit is
- Contacts for medical services (local health clinic, hospitals)

- Contacts for emergency services – rescue, fire, law enforcement, etc.
- Plans if something goes wrong (Safety plan and precautions)

The JHA is an ongoing process. Even though there may be a standard JHA on file for a particular task, such as mowing along a canal, the JHA needs to be revisited every time to assess changes in conditions (e.g., dew, canal levels). Involve the entire staff to identify these risks—as everyone will have a different perspective. Explain the purpose of a JHA is to study dangers associated with the task, and not employee performance.

The JHA will be reviewed and signed with all of the involved workers prior to the start of work and anyone that enters the work area after work is in progress.

> *Reclamation Safety and Health Standards* prescribe the safety and health requirements for all Reclamation activities and operations. Section 4. *Work Planning* explains how to develop a Job Hazard Analysis.

6.3. Lock Out Tag Out

The purpose of LOTO is to isolate all potentially dangerous energy sources from a designated work area (work boundary). Typical examples of energy sources are:

- **Electrical:** motors, power generation, switchgear, distribution panels
- **Mechanical:** pumps, hoists
- **Hydraulic:** hydraulic power units
- **Pneumatic:** air systems, air compressors
- **Stored:** accumulator systems, hydrostatic (such as water behind a gate)
- **Chemical:** batteries

The work boundary may be exposed to one or more energy sources. Each energy source (including automatic operating systems) will need to be identified, isolated, and physically locked out to prevent potential damage to the work crew. Proper isolation from the energy sources in the area to be worked in will provide a safe work boundary.

An established procedure should be followed to provide for a project wide LOTO program. Follow the minimum requirements of Reclamation's FIST 1.1 *Hazardous Energy Control Program*. If your facility does not have this documentation, work with Reclamation to develop these procedures.

The LOTO process includes administrative, supervisory, and O&M personnel. Each person involved should have a working understanding of the LOTO process and responsibilities of the people involved. Proper training of personnel in LOTO is important in preventing worker injuries or death. Persons who are to work in or around areas that have dangerous energy sources—as well as anyone who supervises these staff—should be fully trained to understand the LOTO process.

Proper training based on the level of involvement of everyone participating should be conducted on a regular basis. Reclamation can help institute a LOTO program.

6.4. Confined Space

A confined entry space is any space:

- Large enough to enter and perform work
- With limited entries and exits
- Not designed for continuous occupancy
- Where any body part may be exposed to a hazard upon entry

Pump sumps, enclosed chambers, outlet works, outlet pipes, inlet pipes, underground vaults, instrumentation vaults, ditches, and trenches are some examples of confined entry spaces or permit-required confined spaces (Figure 39). Confined spaces should only be entered with the proper training, ventilation, and safety equipment. These areas should be monitored for proper atmospheric conditions before and during entry.

Figure 39. Example of confined space work (inside the pipe). Attendants outside the pipe can hoist people from a confined space but they cannot enter.

A confined space differs from a permit-required confined space, which has one or more of the following characteristics:

- A hazardous or potentially hazardous atmosphere
- Contains a substance that could engulf and asphyxiate anyone who enters
- An internal configuration that could trap or asphyxiate anyone who enters by inwardly converging walls or by a floor that slopes downward and tapers to a smaller cross section
- Contains any other serious safety or health hazard

When hazards exist within a confined space, that space must have a label that reads: "Permit Required," and it must have controlled access (Figure 40). Entry documents are required to be on hand detailing the steps and conditions required for entry into the labeled areas. If there is any doubt in the proper classification of a space, contact Reclamation.

Figure 40. All locations on the project should be examined, evaluated, and labeled as "Confined Space" or "Permit Required" areas.

Training is required for:

- **Anyone entering the space**
- **Attendants**
- **Managers**

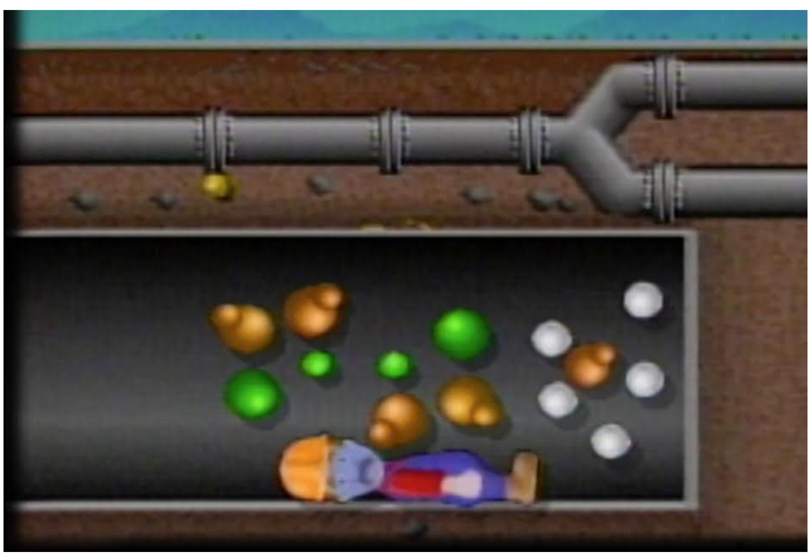

Figure 41. Persons entering confined spaces MUST have proper training and proper safety equipment to allow for a safe entry. (Figure courtesy of WorkSafeBC [Workers' Compensation Board], from the video *Confined Spaces: Deadly Spaces*. Used with permission, all rights reserved.)

Evaluation of the areas should be made under the guidelines in 29-CFR 1910.146, *Permit-required Confined Spaces* and *Reclamation Safety and Health Standards*, Section 14.

6.5. Personal Protective Equipment

Proper clothing for the job to be performed is a must. As part of the JHA, assess each workplace to determine if hazards are present (or likely to be present) that would make it necessary to use PPE.

6.5.1. General Equipment

Each job may require a specific type of PPE to be used. General PPE required on most jobs includes:

- Required helmets (hard hats)
- Gloves
- Hearing protection
- Safety shoes
- Eye protection
- Fall protection
- Respirators
- High-visibility apparel

Equipment or locations where electrical shock hazards or arc flash hazards exist may require special PPE. Often the electrical equipment will have an arc flash (incident energy) hazard label which identifies the arc flash boundary and information on the energy of the potential arc flash or the required level of PPE. Staff inside the shock boundary or arc flash boundary should have the appropriate PPE for the shock or arc flash hazard that exists. This can include arc rated clothing, gloves, face shields, or other type of PPE. Qualified personnel should identify the PPE required for the tasks and conditions.

Types of AR clothing are classified in terms of the clothing's energy breakthrough threshold. AR clothing ratings are calculated to determine the amount of energy the clothing can withstand to limit the burn damage to the wearer. Some electrical equipment can generate a very powerful arc flash and can require significantly more PPE than a standard set of AR clothing. Thus, PPE used for one location may not provide enough protection at another location. This means it is always important to understand the arc flash hazard label when working on or around energized electrical equipment. If an arc flash analysis has not been performed on a piece of equipment where work is needed, then a task based assessment must be performed.

AR clothing, arc flash suits, gloves, and other types of electrical PPE must be inspected before each use. Many types of electrical PPE require periodic testing, re-certification, or replacement. Discard and do not use damaged PPE. Do not use PPE items contaminated with grease, oil, or flammable or combustible materials and clean them immediately. PPE must be cleaned and maintained as specified by the manufacturer. Cleaning AR clothing, if performed according to manufacturer's requirements, has been shown to be very effective in removing contaminants and returning the garments to near original condition.

See FIST 5-14.*Electrical Safety Program* for shock hazards, performing task based assessments, appropriate levels of PPE, and guidelines for applying PPE for electrical hazards (specifically for arc flash hazards and shock hazards).

See NFPA 70E. *Standard for Electrical Safety in the Workplace* for codes for shock hazards and appropriate levels of PPE.

See OSHA 1910. *Occupational Safety and Health Standards* for standards on work spaces and conditions, exits, hazardous materials, noise, PPE, first aid, etc.

6.6. Electrical Safety

Working around energized electrical equipment is inherently dangerous and complacency is a significant contributing factor to many electrical workplace accidents. It is always important to maintain an awareness of your surroundings and the activities occurring at the facility for O&M activities on electrical components. While some electrical hazards are only present when physical contact is made with the equipment other hazards, like arc flash, do not require physical contact with energized components to cause injury.

The dangers represented by this equipment can be partially mitigated by having a robust facility safety program. This includes implementing a hazardous energy control program and acting within Reclamation standards and requirements, industry codes, guidelines of the FIST manuals, industry codes, and OSHA regulations.

De-energize equipment and components before working on them or entering the enclosure or housing. This is one of the most important elements of an electrical safety program and cannot be emphasized enough. All of the maintenance procedures discussed in this guide are easy to accomplish while the switchgear is de-energized. Working on hot equipment is much more complex and dangerous. Only highly qualified personnel should attempt to work on energized equipment, and then it should only be done in extreme situations.

FIST manuals with electrical safety requirements include:

- FIST 1-1. *Hazardous Energy Control Program*
- FIST 4-1B. *Maintenance Scheduling for Electrical Equipment*
- FIST 5-1. *Personal Protective Grounding for Electric Power Facilities and Power Lines*
- FIST 5-14. *Electrical Safety Program*

Electrical safety standards include *NFPA 70E* and *OSHA 1910*.

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Appendix: Sample Gate Test Report Form

UNBALANCED HEAD GATE TESTING PROGRAM
GROUP 1 and 2 FACILITIES
REPORT OF RESULTS

General Information:

1) Facility Name:

2) Project Name:

3) Region:

4) Date of Last Test:

5) Date of Current Test

6) Size and Type of Emergency Gate: (Use a separate form for each gate tested and describe exactly which gate it was)

7) Gate Manufacturer:

8) Gate Operator Type:

9) For Hydraulic Systems: Design Operating Pressure: psi

   - Normal Operating Pressure: psi
   - Design Relief Valve Setting:__psi
   - Normal Relief Valve Setting:__psi
   - Pressure Switch Setting: psi

10) Reservoir Elevation:
   - Maximum Reservoir Elevation: . ft.
   - Centerline Elevation Emergency/Guard Gate: . ft.
   - Maximum Head on Emergency/Guard Gate: . ft.
   - Actual Head on Emergency/Guard Gate: . ft.
   - Percentage of Full Head on Emergency/Guard Gate: %

Air Venting:

11) Proper operation of Air Vacuum/Air Release Valve verified?
12) At the time of the test or otherwise (please explain)?
13) Air valve piping inspected both inside and out?

Regulating Gate/Valve and Operating System Description:

14) Were the operating instructions for the gate posted in an accessible location and were they legible?

15) Percent of full travel gate operated through under unbalanced conditions:

16) Operation during site visit:
    Opening: *AMPS:*
    Closing: *AMPS:*
    Date gate last operated using backup system:

Emergency Gate (balanced operation):

17) Is there a gate hanger used for the emergency gate? If so, what type? Was the operator proficient in its use and did he have an understanding of its function?

18) Were the operating instructions for the gate posted in an accessible location and were they legible?

19) Gate operated through a full-cycle under balanced conditions?

20) Operation during site visit?

21) System operating pressure or current during balanced operation:
    - Opening: Pressure: psi Running: - psi Time: :
    - Closing: Pressure: psi Running: - psi Time: :

Emergency Gate (unbalanced operation):

22) Type of gate position indicator used:

23) Ten percent gate operation successful?

24) System pressure (or current and voltage) recorded during unbalanced operation:

    - Opening: Operating Pressure: psi Time: :
    - Closing: Operating Pressure: psi Time: :

25) Gate position at maximum reading percent open.

Provide narrative of test procedure if warranted for any unusual conditions or anomalies.