Chapter 11
Lubrication Applications

11-1. Introduction

This chapter discusses lubrication as it applies to specific equipment generally encountered at dams, hydroelectric power plants, pumping plants, and related water conveyance facilities. Lubrication of equipment related to navigation structures is also discussed. Complete coverage of all the auxiliary equipment to be encountered at these various facilities would be too extensive to include in this manual. Furthermore, a significant amount of information related to proper lubrication of this equipment is readily available. Therefore, auxiliary equipment, such as small pumps, air compressors, tools, etc., are not specifically discussed. The following discussions emphasize major equipment such as turbines, pumps, governors, gates, hoists, and gear drives. Much of this equipment is custom designed and constructed according to specifications, at significantly greater cost than off-the-shelf commercial equipment. Appendix B has results of a survey of locks and dams for lubricants and hydraulic fluids used to lubricate and operate lock gates, culvert valves, and navigation dams. Appendix C contains a procurement specification for turbine oil.

11-2. Turbines, Generators, Governors, and Transformers

a. Thrust and journal bearings.

(1) Hydro turbines, whether Francis, Pelton, or Kaplan designs, vertical or horizontal shaft, generally have a minimum of two journal bearings and one thrust bearing. These bearings consist of some form of babbitt surface bonded to a steel backing. The rotating element of the bearing is usually polished steel, either an integral part of the turbine shaft or else attached mechanically to the shaft. The thrust bearing is usually the most highly loaded bearing in the machine. The thrust bearing resists hydraulic thrust developed by the axial component of the force of the water on the turbine wheel. In the case of vertical shafts, the thrust bearing also supports the weight of the rotating parts of the hydro generator. The shaft bearings in the case of horizontal shaft machines support the weight of the rotating parts; in the case of Pelton wheels, they also support the component of the hydraulic thrust that is perpendicular to the shaft. In the case of both horizontal and vertical shaft hydro generators, the shaft bearings support and stabilize the shaft and resist the forces of imbalance.

(2) In general, the manufacturer of the hydro generator supplies, as part of the operation and maintenance data, a list of acceptable lubricating oils for the particular unit. Specifically this recommendation should include a chart of viscosities acceptable for various operating conditions. The oil recommendation will also include whether antiwear (AW) additives are necessary. The manufacturer has selected oils that will assure long life and successful operation of the equipment. The type of oil selected is usually of the general type called turbine oil. Even though this designation refers more to steam and gas turbines than hydro turbines, many of the operating requirements are similar. This makes turbine oil the most common type of commercially available lubricating oil used in hydro turbines.

(3) Most hydro turbines are connected to a plant oil system that has a centrally located oil filtration and moisture removal system. The governor system often uses oil from the same system, so in addition to lubricating the bearings, the oil must function satisfactorily in the governor. The following discussion identifies the requirements for selecting turbine lubricating oils. For additional information on lubrication and oil requirements for hydroelectric applications, refer to Corps of Engineers Engineer Manual

EM 1110-2-4205, “Hydroelectric Power Plants, Mechanical Design.” Also refer to Chapter 13 for sampling, testing, and analysis of turbine oils.

b. Oil requirements.

Specific oil requirements are as follows.

(1) Viscosity.

(a) The viscosity is perhaps oil’s most important quality as it is directly related to film strength. The manufacturer's operation and maintenance instructions usually contain suggested viscosities for specific operating conditions. These suggestions should be followed. In absence of such suggestions, or if the operating conditions have changed materially, or if there is compelling evidence of excessive wear that could be linked to breakdown of the oil film between stationary and moving parts, it may become necessary to revisit the viscosity selection process. Engineers at the oil company supplying the oil should be consulted about this decision. To recommend the proper oil, they will require information on dimensions of all the bearings, including area of the thrust bearing, rotational speed of the shaft, load supported by the bearings, and normal operating temperatures.

(b) Note: *when substituting or ordering lubricating oils, it is very important to use the correct units for the viscosity*. For example, many of the hydro generators in use today were built several years ago, when the most common unit of viscosity was the Saybolt Universal Seconds (SUS). Thus, a generic turbine oil called out in the O&M manual might be "Turbine Oil #44" (SUS). When the oil supplier is called for replacement oil, the closest oil number available would be "Turbine Oil #46" (cSt) if viscosity units are not mentioned. However, when the differing viscosity units are taken into account, the correct equivalent in terms of modern viscosity units would be "Turbine Oil #32" (cSt). This is probably the most common viscosity in use in hydro turbine bearings.

(2) Rust and corrosion inhibitors. The next requirement, which determines the corrosion protection provided by the oil additive package, is often denoted by the letter “R” in the lubricant’s trade name. One function of the oil must be rust protection for steel bearing surfaces because hydro turbine oils are naturally susceptible to water contamination. There is also a risk of the additive packages in the oil reacting with the metal in the bearings. Applicable standards that must be passed by the oil are:

- ASTM D 665 B, Rust Test using synthetic salt water (must be noted “Pass”).

- ASTM D 130, Copper Strip Corrosion Test, 3 hours at 100 °C (212 °F), Results 1B.

(3) Oxidation inhibitors. It is common for the lubricating oil in a hydraulic power unit to be kept in service for 20 years or more. One of the ways that the oil degrades is oxidation, which causes gums and varnishes to form. These contaminants may accumulate in narrow passages or oil system valves and damage the machine. Even though the operating temperatures are moderate, the oil is exposed to the air continuously and the extreme length of time the oil is kept in service makes it necessary to have a high-performance antioxidation package, often denoted by a letter “O” in the trade name. The oil must pass ASTM D 943, Turbine Oil Oxidation Test, and should be over 3500 hours to a 2.0 neutralization number.

(4) Antifoam additives. The oil in the bearing tubs splashes and entrains air. It is extremely difficult to lubricate with small bubbles of air in the oil, so it is important that the lubricating oil release entrained

air quickly. Additives that increase the air release rate are called antifoam additives. The oil must meet ASTM D 892 ," Foam Test," Sequence II.

(5) Water release or (demulsibility). The oil in hydro turbines often becomes contaminated with water. It is important that the oil and water not remain in emulsion as this affects the oil's film strength and causes increased oxidation and corrosion rates. The oil must pass ASTM D 1401, "Emulsion Test," at 54 °C (130 °F).

c. Lubricant maintenance. As there is usually a large amount of oil in the bearing oil system, it is more pertinent to discuss maintenance rather than change intervals. Usually, the facility has a testing laboratory run periodic tests on the oil. It is common for the oil company to offer this service, and this is worth consideration as the company is more familiar with factors affecting the oil's performance -- especially in the additive package. Regular sampling and testing can indicate the timing and effectiveness of filtration, can help pinpoint problem areas, and can indicate when the oil will need to be changed. The lubricant has four different areas of possible degradation: viscosity breakdown, particulate contamination, additive breakdown, and water contamination.

(1) Viscosity breakdown. The oil's ability to maintain separation between the surfaces in the bearing depends on its film strength, which is related closely to viscosity. A loss in viscosity is usually due to shearing stresses in the bearing that reduce the length of the oil molecules. An increase in viscosity usually indicates that the oil temperature is high enough that the lighter molecules are being boiled off. While this may not negatively affect the film strength, the increased viscosity can increase the bearing operating temperature.

(2) Particulate contamination. Unless the bearing surfaces are actually touching, the major cause of wear is through contamination by particles. The sources of particle contamination may be either internal or external. Internal sources may be loose particles created during run-in or oxide particles created by water in the oil. An increase in iron or other metallic oxide particles also may indicate additive breakdown. Particles may also be present in new equipment due to inadequate flushing after system run-in. External contamination may be due to dust and dirt introduced through vents, or poor filters. Contaminants may also be introduced through unclean oil-handling practices, used make-up oil, or contaminated new oil. For this reason, new oil should be tested before it is added to the system.

(3) Additive breakdown. As additives perform their intended functions they are used up. This depletion of additives may increase wear by allowing corrosion to create particles of different oxides that can damage bearings. Over-filtration may actually remove components of the additive system. As stated above, maintaining the additive package is the best reason to use a lubricant maintenance program offered by the manufacturer of the oil.

(4) Water contamination. This is the one form of degradation that can sometimes be observed visually, usually by the oil taking on a whitish, cloudy, or milky cast. This is in some ways a disadvantage. By the time enough water is mixed in the oil to be visible, the oil's film strength has been severely decreased. Thus testing for water should be performed with the other tests even if the oil does not appear to be contaminated with water.

d. Wicket gates.

(1) Wicket gates have two or three journal bearings and one thrust bearing or collar per gate. The journal bearings resist the hydrostatic and hydrodynamic loads involved in regulating the flow of water into

the turbine. They also resist bending in the shaft that results from the thrust of the actuating linkage. The thrust bearing or collar positions the wicket gate vertically between the upper and lower surfaces of the speed ring in the distributor. The thrust collar has to support the weight of the wicket gates but under some conditions must resist an upward thrust as well. Wicket gate bearings are subject to high loads and the shafts do not make complete revolutions, but instead move over an arc, with usually about 90 degrees of motion from completely closed to completely open. This quarter-turn usually takes 5 seconds or more. An improperly adjusted governor may hunt, moving the gates back and forth continually in an arc as small as 1 degree. Even when shaft seals are provided, the grease can come into contact with water. In the worst cases, water can wash the lubricant out of the bearings.

(2) Traditionally, wicket gate bearings have been lubricated with a lithium-based, EP NLGI-2 grease. Auto-lubrication can be used to provide fresh grease every day. Generally the bearings in the wicket gate linkages are lubricated with the same grease and by the same system. Environmental concerns have led to attempts to use environmentally acceptable greases. There are no standards for environmental acceptability, but two areas generally acknowledged to be important are biodegradability and toxicity. These areas are discussed in Chapter 8. It is important to note that greases meeting "food grade" standards do not necessarily meet any of the standards for biodegradability or toxicity.

(3) A way to reduce or eliminate the release of greases to the environment is to use self-lubricating bearings or bushings. There are many suppliers of such bushings, but there are no industry-wide standards to determine quality or longevity of these products. Use of these products should be considered on a case-by-case basis. Refer to Chapter 6, paragraph 6-3, for a description of Corps of Engineers and Bureau of Reclamation experience using greaseless bearings for this and similar applications.

e. Governors. A governor consists of a high-pressure pump, an accumulator tank, an unpressurized reservoir, control valves, hydraulic lines, filters, and actuators called servomotors. Servomotors develop the force that is used by the wicket gates to regulate the flow of water through the turbine, and thus the amount of power generation it generates. Governors generally utilize the same oil as is used in the hydro generator guide and thrust bearing system. Governors that operate at over 68.9 bar (1000 psi) may require an antiwear additive to the oil, but these are not common. Turbine oils operate successfully in the governor system because the requirements for the oils are very similar. For example, antifoam characteristics prevent compressible foam from being introduced into the high-pressure lines. Also RO characteristics are needed because the high-pressure pumps and the pilot valve assembly have very small clearances. Rust or other oxidation products could be transported into those clearances and cause the pump to wear or the pilot valve to stick or be sluggish, resulting in a degradation or loss of governor function. Auxiliary filters are sometimes used to keep the governor oil supply free of particulates.

f. Transformers and oil circuit breakers. Mineral-based insulating oil for electrical equipment functions as an insulating and cooling medium. This oil usually is produced from naphthenic base stocks and does not contain additives, except for an oxidation inhibitor. New electrical insulating oil, either provided in new equipment or purchased as replacement oil, must meet the following standards:

(1) ASTM D 3847, "Standard Specification for Mineral Insulating Oil Used in Electrical Apparatus - Type II Mineral Oil." This is the general specification for mineral insulating oil and contains references to more than 20 other ASTM standards that are used to determine the functional property requirements. The appendices to the standard explain the significance of the physical, electrical, and chemical properties for which the various tests are performed. One of the objectives of the standard is to specify insulating oils that are compatible and miscible with existing oils presently in service.

(2) ASTM D 4059, "Analysis of Polychlorinated Biphenyls in Insulating Liquid by Gas Chromatography Method." No detectable PCB content is permitted.

11-3. Main Pumps and Motors

Main pumps and motors come in various shapes and sizes, but can be divided into categories. The first dividing criterion is the orientation of the shaft. Pumps are available in vertical-shaft and horizontal-shaft configurations. The second criterion is the size of the unit. Large units are similar in layout and component size to hydro generators. Some parts are embedded, and the pump appears to be built into the pumping plant. Small units have a wide range of size, but generally have an identifiable pump and motor and often are mounted on skids or plates. For additional information on pumps and lubrication refer to Corps of Engineers Engineer Manual EM 1110-2-3105.

a. Large units.

(1) Large units with vertical shafts typically use journal bearings and a sliding contact thrust bearing. These units sometimes are dual-purpose, being used both as pumping units and turbine generators. There may be a plant oil system that has oil storage and filtering capabilities. RO turbine oil with viscosity 32 (cSt) is a common lubricant.

(2) Large units with horizontal shafts utilize journal bearings Each bearing has its own oil reservoir. Oil rings that rotate with the shaft pick up oil from the reservoir, and it runs or drips down into holes in the top of the bearing. Very large units may have an oil pump to provide an oil film before start-up. RO turbine oil with viscosity 32 (cSt) is a common lubricant.

b. Small units.

(1) Smaller vertical-shaft machines may have a variety of pumps attached to the motor, such as propeller, vertical turbine, or mixed flow. These pumps normally have a grease-lubricated suction bushing, and the rest of the bearings in the pump itself are sleeve-type -- either lubricated by the fluid being pumped (product-lubricated) or else by oil dripped into a tube enclosing the shaft bearings (oil-lubricated). There are also vertical-pumps with bronze bearings or bushings that are grease-lubricated by individual grease lines connected to grease points at floor level.

(2) Motors for the smaller vertical units generally utilize rolling-contact bearings. The upper bearing is a combination of radial and thrust bearing -- many times a single-row spherical bearing. Because of the large heat loads associated with these bearing types and conditions, they are usually oil-lubricated. The lower bearing is either a ball or roller bearing and is lubricated by grease. This bearing provides radial support and is configured in the motor to float vertically so it is not affected by axial thrust.

(3) Smaller horizontal units often have rolling-contact bearings in both pump and motor, and can be lubricated by either grease or oil. Oil-lubricated bearings will have an individual oil reservoir for each bearing that is fed by an oil-level cup that maintains the level of the oil. Grease-lubricated bearings can have grease cups that provide a reservoir with a threaded top that allows new grease to be injected into the bearing by turning the top a prescribed amount at set intervals of time. In some cases, grease nipples are provided. These receive a prescribed number of strokes from a manual grease gun at specified time intervals.

c. Maintenance. For all of the bearing types that use oil, the most common type of oil found is RO turbine oil. For the greased bearings, a lithium-based grease designated NLGI 2 is the most common. Maintenance problems with these machines center around oil changes and grease changes.

(1) Oil changes sometimes do little good if the oil is cold and particulate matter has been allowed to settle out. This problem is resolved by changing the oil after the pump has been running at normal operating temperature. Running the pump helps mix particles into the oil before it is drained. Another method that may work is to drain the oil, then flush the oil reservoir with warmed oil, discard the oil, then fill the bearing. This can help to dislodge foreign matter that has settled to the bottom.

(2) Another problem is condensation caused by thermal cycling of the motor as it starts and stops. A desiccant air breather on the bearing equalizing air intake will prevent extra moisture from being taken into the reservoir. Proper flushing of the oil reservoir can help carry out water that has collected in the low spots.

(3) Having adequate grease in rolling element bearings is important, but too much grease can cause overheating and bearing failure. Maintenance procedures must be followed to avoid over greasing.

(4) Bearing housings need to be disassembled and all the old grease cleaned out and replaced at intervals.

11-4. Gears, Gear Drives, and Speed Reducers

a. General. Lubrication requirements for gear sets are prescribed by the equipment manufacturers, based on the operating characteristics and ambient conditions under which the equipment will operate. Often the nameplate data on the equipment will indicate the type of lubricant required. If no lubricant is specified on the nameplate, recommendations should be obtained from the equipment manufacturer. If the manufacturer is unknown or no longer in business, a lubricant supplier should be consulted for recommendations.

b. Gear drives. In general, gear lubricants are formulated to comply with ANSI/AGA 9005-D94, “Industrial Gear Lubrication Standard.” Gear lubricants complying with AGA are also suitable for drive unit bearings in contact with the gear lubricant.

(1) The AGA standard is intended for use by gear designers and equipment manufacturers because it requires knowing the pitch line velocity of the gear set to select a lubricant. Because this information is rarely known, except by the gear manufacturer, the standard provides little assistance for equipment operators trying to select a gear lubricant. The superseded standards, AGA 250.01 and 250.02, require that the operators know the centerline distance for the gear sets. The centerline distance can be calculated or approximated by measuring the distance between the centerline of the driver and driven gear. Although updated standards have been in use for several years, many gear unit manufacturers and lubricant producers continue to publish selection criteria based on the old standard. Therefore, equipment operators may want to save the old standard for reference until manufacturers and producers update all their publications. When the pitch line velocity is unknown or cannot be obtained in a timely manner, an educated guess may be necessary. A lubricant can be selected by referring to the old standard and subsequently verified for compliance with the latest standard.

(2) Reference to manufacturer’s data indicates that an AGA 3 or 4 grade lubricant will cover most winter applications, and an AGA 5 or 6 will cover most summer applications. EP oil should be used for

heavily loaded low-speed equipment. Unlike the old standard, the new AGA standards no longer recommend EP oils for worm gear drives. Instead, a compounded oil such as AGA 7 Comp or 8 Comp should be used.

(3) Note that AGA provides recommended gear lubricants for continuous and intermittent operation. Inspection of some gear sets in radial gate applications at Bureau of Reclamation facilities found wear that may be attributable to use of improper oil due to runoff that left the tooth surfaces dry. The intermittent lubricant recommendations are especially important for these applications where water flow regulation requires that the gates remain in a fixed position for prolonged periods. Gear lubricants formulated for continuous operation are too thin and may run off during the standing periods, resulting in inadequate lubrication and possible gear tooth damage when the gate moves to a new position.

(4) Gear oils should be selected for the highest viscosity consistent with the operating conditions. When very low ambient temperatures are encountered, the oil viscosity should not be lowered. A reduced oil viscosity may be too low when the gears reach their normal operating temperature. If possible, oil heaters should be used to warm the oil in cold environments. The heater should be carefully sized to prevent hot spots that may scorch the oil. Another alternative is to switch to a synthetic oil that is compatible with the gear materials.

(5) Environmental concerns will have a growing impact on the development and use of lubricants. Although some lubricants are identified as food grade and have been FDA-approved and are subject to ASTM standard testing procedures, there is no worldwide standard definition or specification for environmental lubricants intended to replace standard lubricants. U.S. regulations are becoming more restrictive with regard to the contents, use, and disposal of lubricants. Four are of particular interest at the Federal level.

- Comprehensive Environmental Response Compensation and Liability Act (CERCLA), which imposes liability for cleaning up contamination caused by hazardous substances.

- Resource Conservation and Recovery Act (RCRA), which regulates hazardous waste and solid waste.

- Superfund Amendments and Reauthorization Act (SARA) - Extended and amended CERCLA to include toxicological profiles of hazardous substances.

- Toxic Substance Control Act (TSCA), which governs the manufacturing, importing, distribution, and processing of all toxic chemicals. All such chemicals must be inspected and approved by the Environmental Protection Agency (EPA) before entering the market.

(6) As environmental regulations become more restrictive, finding environmentally acceptable lubricants that comply with gear drive manufacturers' specifications is becoming increasingly difficult. Product users should exercise caution when evaluating and accepting alternative lubricants to ensure that the product selected complies with the gear manufacturer's requirements.

(7) Lubrication of gear drives, such as "limitorques" used to operate gates and valves, are grease-lubricated and are covered under the lubricating requirements for gates and valves.

(8) Corps of Engineers facilities should ensure that gear lubricants conforming to the Corps Guide Specification CEGS 15005 are purchased and used for storm water pump gear reducer applications.

11-5. Couplings

Couplings requiring lubrication are usually spring, chain, gear, or fluid drive type. Table 11-1 provides lubricant recommendations for couplings. Additional recommendations are provided below.

Table 11-1
Recommendations for the Lubrication of Gear, Spring-Type, Chain Couplings

	Limiting Criteria				
	Centrifugal Effects				
Lubricant Type	***Pitch-line Acceleration*** $d\omega^2/2$ ***(m/sec^2)***	***Range in Practical Units*** Dn^2 ***(ft/sec^2)***	**Heat Dissipation Pn**	***Lubricant Change Period***	***Remarks***
No. 1 Grease (mineral oil base)	0.15×10^3 0.5×10^3	25 max 25-80	- -	2 years 12 months	Soft grease preferred to ensure penetration of lubricant to gear teeth
No. 3 Grease (mineral oil base)	1.5×10^3 5.0×10^e 12.5×10^3	80-250 250-850 850-2000	- - -	9 months 6 months 3 months	Limitation is loss of oil causing hardening of grease; No. 3 grease is more mechanically stable than No. 1
Semifluid polyglycol grease or mineral oil	45.0×10^3	3000-5000	230×10^3 max	2 years	Sealing of lubricant in coupling is main problem

d = pcd, m; D = pcd, ft; ω = rads/sec; n = rev/sec; P = hp transmitted
Reference: Neale, M. J., Lubrication: A Tribology Handbook. Butterworth-Heinemann Ltd, Oxford, England

a. General lubrication. Lubrication should follow the manufacturer's recommendations. When no suitable recommendations are available, NLGI No 1 to 3 grease may be used for grid couplings. Gear and chain couplings may be lubricated with NLGI No. 0 to 3 grease.

b. Grease-lubricated couplings.

(1) Normal applications. This condition is descriptive of applications where the centrifugal force does not exceed 200 g (0.44 lb), motor speed does not exceed 3600 rpm, hub misalignment does not exceed three-fourths of 1 degree, and peak torque is less than 2.5 times the continuous torque. For these conditions, an NLGI No. 2 grease with a high-viscosity base oil (higher than 198 cSt at 40 °C (104 °F) should be used.

(2) Low-speed applications. This application includes operating conditions where the centrifugal force does not exceed 10 g (0.2 lb). If the pitch diameter "*d*" is known, the coupling speed "*n*" can be estimated from the following equation (Mancuso and South 1994):

$$n = \frac{200}{\sqrt{d}}$$

Misalignment and torque are as described for normal conditions in (1) above. For these conditions an NGLI No. 0 or No. 1 grease with a high-viscosity base oil (higher than 198 cSt at 40 °C (104 °F)) should be used.

(3) High-speed applications. This condition is characterized by centrifugal forces exceeding 200 g (0.44 lb), misalignment less than 0.5 degrees, with uniform torque. The lubricant must have good resistance to centrifugal separation. Consult a manufacturer for recommendations.

(4) High-torque, high-misalignment applications. This condition is characterized by centrifugal forces less than 200 g (0.44 lb), misalignment greater than 0.75 degrees, and shock loads exceeding 2.5 times the continuous torque. Many of these applications also include high temperatures (100 °C (212 °F), which limits the number of effective greases with adequate performance capability. In addition to the requirements for normal operation, the grease must have antifriction and antiwear additives (polydisulfide), extreme pressure additives, a Timken load greater than 20.4 kg (40 lb), and a minimum dropping point of 150 °C (302 °F).

c. Oil-lubricated couplings. Most oil-filled couplings are the gear type. Use a high-viscosity grade oil not less than 150 SUS at 36.1 °C (100 °F). For high-speed applications, a viscosity of 2100 to 3600 SUS at 36.1 °C (100 °F) should be used.

11-6. Hoist and Cranes

a. General. Various types of hoisting equipment are used in hydroelectric power plants and pumping plants, including gantry cranes, overhead traveling cranes, jib cranes, monorail hoists, and radial gate hoists. The primary components requiring lubrication are gear sets, bearings, wire ropes, and chains. The lubrication requirements for gear sets should comply with the same AGA requirements for gears discussed above. Lubrication of wire ropes and chains used in hoists and cranes is discussed later in this chapter.

b. Hydraulic brakes. Hydraulic brakes are commonly found on cranes and hoists. Both drum and disk brakes are used in these applications. Components closely resemble automotive parts and similar brake fluids are used. Brake fluid is glycol-based and is not a petroleum product. Hydraulic brake fluid has several general requirements:

! It must have a high boiling temperature.

! It must have a very low freezing temperature.

! It must not be compressible in service.

! It must not cause deterioration of components of the brake system.

! It must provide lubrication to the sliding parts of the brake system.

(1) Hydraulic brake fluids are acceptable for use if they meet or exceed the following requirements:

(a) Federal Motor Vehicle Safety Standard (FMVSS) No. 116 (DOT 3). This includes a dry boiling temperature of 205 °C (401 °F). This is commonly known as DOT 3 brake fluid. Some industrial braking systems require Wagner 21B fluid, which is a DOT 3 fluid with a 232 °C (450 °F) dry boiling temperature and containing additional lubrication and antioxidation additives.

(b) Society of Automotive Engineers (SAE) Specification J1703 - Motor Vehicle Brake Fluid. This standard assures all the necessary qualities of the brake fluid and also assures that fluids from different manufacturers are compatible.

(2) SAE Recommended Practice J1707, “Service Maintenance of SAE J1703, Brake Fluids in Motor Vehicle Brake Systems.” This guidance provides basic recommendations for general maintenance procedures that will result in a properly functioning brake system. The largest problem with glycol brake fluids is that they absorb moisture from the atmosphere. If left in service long enough, the brake fluid will become contaminated with water, and this can cause brake failure. Water can collect in the lowest part of the system and cause corrosion, which damages seals or causes leak paths around them. DOT 3 brake fluid that is saturated with water will have its boiling temperature reduced to 140 °C (284 °F). If water has separated out, the brake fluid will have a boiling temperature of 100 °C (212 °F). Under heavy braking, the temperature of the brake fluid can become so high that the brake fluid will boil or the separated water will flash into steam and make the brake fluid very compressible. This will result in loss of braking capacity, from spongy brakes to a complete loss of braking function. Brake fluid should be completely replaced every 3 years unless the manufacturer's recommended interval is shorter. Also if brake fluid deterioration is noticeable due to a high-humidity working environment it should also be replaced more frequently. Because brake fluid so readily absorbs moisture from the air, only new dry fluid from unopened containers should be used as a replacement. This means that brake fluid left over from filling or refilling operations should be discarded. For this reason it is recommended that the user purchase brake fluid in containers small enough that the fluid can be poured directly from the original container into the brake system fill point. Under no circumstances should brake fluid be purchased in containers larger than 3.7 liters (1 gallon).

11-7. Wire Rope Lubrication

a. Lubricant-related wear and failure. Wear in wire ropes may be internal or external. The primary wear mode is internal and is attributed to friction between individual strands during flexing and bending around drums and sheaves. This condition is aggravated by failure of the lubricant to penetrate the rope. Additional information on wire rope selection, design, and lubrication can be found in Corps of Engineer Engineer Manual EM 1110-2-3200, “Wire Rope Selection.”

(1) Corrosion. Corrosion damage is more serious than abrasive damage and is usually caused by lack of lubrication. Corrosion often occurs internally where it is also more difficult to detect. Corrosion of wire ropes occurs when the unprotected rope is exposed to weather, to corrosive environments such as submergence in water (especially salt water), or to chemicals. Corrosion results in decreased tensile strength, decreased shock or impact-load resistance, and loss of flexibility. Unprotected wire ropes that are used infrequently have a greater potential for rust damage due to moisture penetration. Rust may prevent relative sliding between wires, creating increased stresses when the rope is subsequently placed in service.

(2) Abrasion. A common misconception among facility operators is that stainless steel ropes do not require lubrication. This misconception is probably due to corrosive operating conditions. This misconception is easily corrected by considering a wire rope as a machine with many moving parts. The typical wire rope consists of many wires and strands wrapped around a core. A typical 6 x 47 independent wire rope core (IWRC) rope, is composed of 343 individual wires that move relative to each other as the rope is placed under load or wrapped around a drum. During service these wires are subject to torsion, bending, tension, and compression stresses. Like all machine parts, ropes also wear as a result of abrasion and friction at points of moving contact. Therefore proper lubrication is essential to reduce friction and wear between the individual wires and to ensure maximum performance.

b. Lubrication. During operation, tension in the rope and pressure resulting from wrapping around drums forces the internal lubricant to the rope surface where it can be wiped or washed off. Tests conducted on dry and lubricated rope operating under similar conditions provide ample evidence of the beneficial effects of lubrication. The fatigue life of a wire rope can be extended significantly (200 to 300 percent) through the application of the correct lubricant for the operating conditions. However, under certain operating conditions lubrication may be detrimental. Unless recommended by the rope manufacturer, wire rope operating in extremely dirty or dusty environment should not be lubricated. Abrasives may combine with the lubricant to form a grinding compound that will cause accelerated wear. In applications where ropes undergo frequent and significant flexing and winding around a drum, the rope should be lubricated regardless of whether the wire rope is constructed from stainless steel. However, Corps of Engineers experience has shown that wire ropes used in fairly static applications, where flexing and winding are minimal, should not be lubricated. Tests have shown that lubricated ropes may actually experience more severe corrosion than unlubricated ropes because the lubricant tends to tap and seal moisture in the voids between the wires.

c. Lubricant qualities.

(1) To be effective, a wire rope lubricant should:

(a) Have a viscosity suitable to penetrate to the rope core for thorough lubrication of individual wires and strands.

(b) Lubricate the external surfaces to reduce friction between the rope and sheaves or drum.

(c) Form a seal to prevent loss of internal lubricant and moisture penetration.

(d) Protect the rope against external corrosion.

(e) Be free from acids and alkalis.

(f) Have enough adhesive strength to resist washout.

(g) Have high film strength.

(h) Not be soluble in the medium surrounding it under actual operating conditions.

(i) Not interfere with the visual inspection of the rope for broken wires or other damage.

(2) New wire rope is usually lubricated by the manufacturer. Periodic lubrication is required to protect against corrosion and abrasion and to ensure long service life. Wire rope lubricants may require special formulations for the intended operating conditions (for example, submerged, wet, dusty, or gritty environments). The rope manufacturer's recommendations should always be obtained to ensure proper protection and penetration. When the manufacturer's preferred lubricant cannot be obtained, an adhesive-type lubricant similar to that used for open gearing may be acceptable.

(3) Two types of lubricants are generally used: oils and adhesives. Often mineral oil, such as an SAE 10 or 30 motor oil, is used to lubricate wire rope. The advantage of a light oil is that it can be applied cold with good penetration. However, the light oil may not contain adequate corrosion inhibitors for rope applications. Also, it tends to work out of the rope just as easily as it works in, necessitating frequent applications.

(4) Heavy, adhesive lubricants or dressings provide longer lasting protection. To ensure good penetration, these lubricants usually require thinning before applying. Thinning can be accomplished by heating the lubricant to a temperature of 71.1 to 93.3 °C (160 to 200 °F), or by diluting with a solvent. A properly applied heavy lubricant will provide both internal lubrication and a durable external coating to prevent corrosion and penetration of dust and abrasives.

(5) In addition to the qualities noted above, good adhesive lubricants or rope dressings:

(a) Must not cake, gum, or ball up when contaminated with dust and dirt.

(b) Must not thin and drip at the highest operating temperature.

(c) Must not become brittle or chip at the lowest operating temperature.

(d) Should have inherently high viscosity without adding thickeners or fillers.

(6) When damp conditions prevail, or when severe flexing under heavy loads is encountered, a two-stage lubricant application may be the most effective. Application of a lighter adhesive followed by a very heavy adhesive lubricant to seal in the oil provides the best protection. In certain ropes subjected to highly corrosive environments such as acids, alkalis, or salt water, providing a heavy impervious exterior lubricant coating to guard against corrosion may be more important than ensuring adequate penetration.

(7) Wire rope lubricants can be applied by brush, spray, drip, or -- preferably -- by passing the rope through a heated reservoir filled with the lubricant. Before application the rope must be cleaned of any accumulated dirt, dust, or rust to ensure good penetration. The lubricant should be applied to the entire circumference of the rope and the rope slowly wound on and off the drum several times to work the lubricant into the rope. If the lubricant is being applied by hand it may be helpful to apply the lubricant as it passes over a sheave where the rope's strands are spread by bending and the lubricant can penetrate more easily.

d. Rope applications and lubricant requirements. There are five general rope application categories based on operating conditions: industrial or outdoor, friction, low abrasive wear and corrosion, heavy wear, and standing. These conditions are summarized in Table 11-2. Each of these conditions has its own lubrication requirements.

(1) Industrial or outdoor applications. This category includes mobile, tower, and container cranes. Internal and external corrosion are possible, but external corrosion is the more serious and deserves primary consideration. Desirable lubricant qualities include good penetration into the wires and core, moisture displacement, corrosion protection, resistance to washout and emulsification, and freedom from buildup due to repeated applications. The best lubricants for these applications are solvent-based that leave a thick, semidry film after evaporation of the solvent. A tenacious semidry film will minimize adhesion of abrasive particles that cause wear. Thin-film lubricants such as MoS_2 and graphite are not recommended because they tend to dry, causing surface film breakdown and subsequent exposure of the wires.

(2) Friction applications. This category includes elevators, friction hoists, and capstan winches. Fatigue and corrosion are the primary considerations. Desirable lubricant qualities include corrosion protection, internal lubrication, moisture displacement, lubricant buildup prevention, and minimizing loss of friction grip. Note that unlike other lubrication applications, where efforts are made to reduce friction,

Table 11-2
Lubrication of Wire Ropes in Service

	Operating Conditions				
	(1) Ropes working in industrial or marine environments	**(2) Ropes subject to heavy wear**	**(3) Ropes working over sheaves where (1) and (2) are not critical**	**(4) As (3) but for friction drive applications**	**(5) Standing ropes not subject to bending**
Predominant cause of rope deterioration	Corrosion	Abrasion	Fatigue	Fatigue - corrosion	Corrosion
Typical applications	Cranes and derricks working on ships, on docksides, or in polluted atmospheres	Mine haulage, excavator draglines, scrapers, and slushers	Cranes and grabs, jib suspension ropes, piling, percussion, and drilling	Lift suspension, compensating and governor ropes, mine hoist ropes on friction winders	Pendant ropes for cranes and excavators. Guys for masts and chimneys
Dressing requirements	Good penetration to rope interior. Ability to displace moisture. Internal and external corrosion protection. Resistance to "wash off." Resistance to emulsification	Good antiwear properties. Good adhesion to rope. Resistance to removal by mechanical forces	Good penetration to rope interior. Good lubrication properties. Resistance to "fling off."	Non-slip property. Good penetration to rope interior. Ability to displace moisture. Internal and external corrosion protection	Good corrosion protection. Resistance to "wash off." Resistance to surface cracking.
Type of lubricant	Usually a formulation containing solvent leaving a thick (0.1 mm) soft grease film	Usually a very viscous oil or soft grease containing MoS_2 or graphite. Tackiness additives can be of advantage	Usually a good general purpose lubricating oil of about SAE 30 viscosity	Usually a solvent-dispersed temporary corrosion preventative leaving a thin, semihard film	Usually a relatively thick, bituminous compound with solvent added to assist application
Application technique	Manual or mechanical	Manual or mechanical	Mechanical	Normally by hand	Normally by hand
Frequency of application*	Monthly	Weekly	10/20 cycles per day	Monthly	Six monthly/2 years

* The periods indicated are for the general case. The frequency of operation, the environmental conditions, and the economics of service dressing will more correctly dictate the period required.
Reference: Neale, M. J., Lubrication: A Tribology Handbook. Butterworth-Heinemann Ltd, Oxford, England

in this instance a desirable quality includes increasing the coefficient of friction. A solvent-based dressing that deposits a thin slip-resistant semidry film offers the best protection.

(3) Low abrasive wear and corrosion applications. This category includes electric overhead cranes, wire rope hoists, indoor cranes, and small excavators. Internal wear leading to fatigue is the primary

consideration. Maximum internal and external lubrication are essential. Mineral-oil-base lubricants such as SAE 30 are commonly accepted as the best alternative, but these oils provide minimal corrosion protection and tend to run off. The best alternative is to use a lubricant specifically designed for wire rope applications. These lubricants contain corrosion inhibitors and tackiness agents. Thin-film dry lubricants such as MoS_2 and graphite are also commonly used, but claims of increased fatigue life attributed to these lubricants have been questioned by at least one wire rope manufacturer.

(4) Heavy wear applications. This category includes ropes used in excavators, winches, haulage applications, and offshore mooring systems and dredgers. Protection against abrasion is the primary consideration. Desirable lubricant qualities include good adhesion, crack and flake resistance, antiwear properties, resistance to moisture, emulsification, and ultraviolet degradation, and corrosion-resistance --especially in offshore applications. The best lubricants are those with thixotropic (resistance to softening or flow under shear) characteristics to ensure good lubricity under shearing action. These lubricants offer good penetration, and they resist cracking and ultraviolet degradation. Viscous oils or soft grease containing MoS_2 or graphite are commonly used. Tackiness additives are also beneficial.

(5) Standing rope applications. This category includes guy and pendant ropes for onshore use, and towing cables, cranes, derricks, and trawl warps for offshore applications. Corrosion due to prolonged contact in a corrosive environment is the primary consideration. Desirable lubricant qualities include high corrosion protection, long-term stability over time and temperature, good adhesion, and resistance to wash-off, emulsification, and mechanical removal. The best lubricants are thixotropic oils similar to those required for heavy-wear applications, except that a higher degree corrosion-resistance additive should be provided.

11-8. Chain Lubrication

Drive chains combine the flexibility of a belt drive with the positive action of a gear drive. Various designs are available. The simplest consist of links that are rough cast, forged, or stamped. These chains are seldom enclosed and therefore exposed to various environmental conditions. They are generally limited to low-speed applications and are seldom lubricated. Roller chains have several moving parts and, except for the self-lubricating type, require periodic lubrication. Lubricants should be applied between the roller and links to ensure good penetration into the pins and inner bushing surfaces.

a. Lubricant-related wear and failure.

(1) Like wire ropes, chains experience both internal and external wear. Internal wear generally occurs on the pins and adjacent bearing surface of the roller bushing, and at the link surfaces. Wear is attributed to friction between metal contacting surfaces. Use of improper lubricant, inadequate lubricant penetration into the pin and bushing clearances, poor lubricant retention, and inadequate or infrequent lubrication are the primary causes of premature wear. Poor chain designs, such as those that provide no grease fittings or other lubricating schemes, also contribute to premature wear.

(2) Corrosion damage is a serious problem and often occurs internally where it is difficult to detect after the chain is assembled and placed in service. Corrosion occurs when the unprotected chain is exposed to weather or corrosive environments such as prolonged submergence in water. Corrosion results in decreased tensile strength, decreased shock or impact-load resistance, and loss of flexibility.

b. Lubricant characteristics. The most important considerations in chain lubrication are boundary lubrication and corrosion. Chain life can be extended through the proper selection and application of lubricant for the operating conditions. An effective chain lubricant should possess the following characteristics:

(1) Have a viscosity that will enable it to penetrate into the link pins and bearings.

(2) Lubricate the external surfaces to reduce friction between the sliding link surfaces and chain sprockets.

(3) Form a seal to prevent moisture penetration.

(4) Protect the chain against corrosion.

(5) Be free of acids and alkalis.

(6) Resist washout.

(7) Have high film strength.

(8) Not be soluble in the medium surrounding it under actual operating conditions.

(9) Displace water.

(10) Not cake, gum, or ball up when contaminated with dust and dirt.

(11) Not thin and drip at the highest operating temperature.

(12) Not become brittle, peel, or chip at the lowest operating temperature.

c. Lubrication problems.

(1) Most chains, such as those used on conveyors, transporters, and hoists, are accessible and easily lubricated while in service. Lubrication of these chains is generally accomplished through oil baths, brushing, or spray applications.

(2) Lubrication of tainter (radial) gate chains poses an especially difficult challenge. Chain design, construction, application, and installation often render them inaccessible. The operating constraints imposed on these gates include water flow regulation, changing water surface elevations, poor accessibility, and infrequent and minimal movement. These gates may remain in fixed positions for prolonged periods. The submerged portions of chains have a significantly greater potential for rust damage due to exposure to corrosive water, lubricant washout, and moisture penetration into the link pins and bearings. Infrequent movement and inaccessibility adversely affect the frequency of lubrication.

d. Lubricants.

(1) Typical chain lubricants include light general purpose mineral oils, turbine oils, gear oils, penetrating fluids, and adhesives. Light oils may be adequate for continuous chains exposed to oil baths. Synthetic sprays employing solid lubricants such as graphite, MoS_2, and PTFE are also common. When the potential for environmental contamination or pollution is a major concern, food-grade lubricant may be required to prevent contamination of water supplies. When manufacturer’s data are not available,

recommended lubricants are shown below. For heavily loaded chains, the extreme pressure (EP) grades should be used.

- Low speed--0 to 3 m/s (0 to 10 ft/s) :
  below 38 °C (100°F) ISO 100 (AGMA 3).
  above 38 °C (100 °F) ISO 150 (AGMA 4)

- Medium speed--3 to 9 m/s (10 to 30 ft/s):
  below 38 °C (100 °F) ISO 150 (AGMA 4)
  above 38 °C (100 °F) ISO 220 (AGMA 5)

(2) Chain lubricants may require special formulation or incorporation of multiple lubricants to cope with severe operating conditions including submerged, wet, dusty, and gritty environments. When possible, the chain manufacturer should be consulted for lubricant recommendations. If the recommended lubricant is not available, a lubricant manufacturer can recommend a substitute lubricant for the application provided the operating conditions are accurately described. When necessary, an adhesive-type lubricant similar to that used for open gearing may be acceptable.

(3) Heavy roller chains such as those used in radial gate applications require heavier lubricants to ensure adequate protection over prolonged periods of submergence without benefit of periodic lubrication. Chain lubricants used in this application must be especially resistant against washout.

(4) New or rebuilt gate chains are usually lubricated during assembly, but periodic lubrication is required to protect against corrosion and abrasion and to ensure long service life. A properly applied lubricant will provide both internal lubrication and a durable external coating to prevent corrosion and penetration of dust and abrasives.

(5) The following example is provided to stress the complex nature of certain lubricant applications, such as heavily loaded roller chains. In a 1996 radial gate rehabilitation at Folsom Dam, a three-stage lubricant application was used during assembly of the new lift chains. The procedure was recommended by Lubrication Engineers, Inc., based on their experience with similar applications. The Folsom chains were not fitted with grease fittings , so once reassembled, the pins and bushings could not be lubricated. An initial coat of open gear lubricant was applied to the pins and bushings. This coating provided primary protection for the internal parts of the chain which would be inaccessible after the chain was placed in service. After assembly, the entire chain received a coat of wire rope lubricant. This is a penetrating fluid that will lubricate assembled areas of the chain that the final coat will not penetrate. The final coat consisted of open gear lubricant similar to initial coating except that the product contained a solvent for easier application -- especially at low temperatures. After evaporation of the solvent, the remaining lubricant has characteristics similar to the initial coating. The top coat must be reapplied as necessary to ensure lubrication and corrosion-protection between the sliding links.

(6) Although the multistage lubricant application described above was conducted on new chain, it may also be possible to extend the service life of existing chains by using this procedure. However, since this work is labor-intensive and requires placing the affected gate out of service, the economics and logistics must be considered.

e. Lubricant application. The need for lubrication will be evident by discoloration appearing as reddish-brown deposits. Often bluish metal discoloration can be detected. Chains can be lubricated by various methods including brush, oil can, spray, slinger, dip, pump, or oil mist. The method of application depends on operating conditions such as load, speed, and size and whether the components are exposed or enclosed. Lubricant should be applied to the lower strand of the chain immediately before engaging the gear or sprocket. Centrifugal action will force the lubricant to the outer areas.

11-9. Trashrake Systems and Traveling Water Screens

a. Gear drives. The most common drive units are standard speed-reducers using helical gears, although worm gears are also used. Lubrication requirements for these gear drives are similar to those discussed in the gear lubrication section above.

b. Couplings. All types may be used. The lubrication requirements are similar to those discussed above.

c. Chains. Roller chains are the most common type used. The lubrication should be selected according to the requirements outlined in the section on chain lubrication above.

d. Hydraulic operated trashrakes. These trashrakes use a hydraulically operated boom. Bureau of Reclamation projects specify a food-grade polymer oil complying with Code of Federal Regulations 21 CFR 178.3570 and USDA H1 authorization for food-grade quality. The oil must also comply with ASTM D 2882 for hydraulic pump wear analysis.

e. Bearings. Trashrake conveyor belts or systems are commonly provided with rolling contact bearings, either in the ends of the rollers or in pillow block bearings. These bearings are normally manually lubricated with NLGI 2 lithium-based grease.

11-10. Gates and Valves

Various gates and valves and essential lubricated components for each are listed and discussed below. The lubricated components discussed below also apply to unlisted gates and valves that incorporate these same components. Hydraulic fluids for operating systems are also discussed. The discussion of gate trunnions provides more detail as it encompasses “lessons learned” from the investigation of a 1995 tainter gate failure at Folsom Dam. Recommended frequencies of lubrication are noted, but frequency should be based on historical data. Each component has its own effect on lubricants, and each facility should pattern its frequency of lubrication around its own particular needs. For example, lock culvert valves such as tainter gates are lubricated more frequently than tainter gates on spillways of water storage dams because culvert valves are operated much more often. The manufacturer’s schedule should be followed until operating experience indicates otherwise. Gates and valves, and their lubricated components (shown in italics), are:

- Tainter (radial) gates and reverse tainter gates. *Trunnions.*

- Other lubricated hinged gates. *Same lubricant as trunnions*.

- Bonneted gates, including outlet, ring-follower, and jet-flow gates. *Seats, threaded gate stems, gears for electrically and manually operated lifts.*

- Unbonneted slide gates. *Threaded gate stems, gears for electrically and manually operated lifts.*

- Roller-mounted gates, including stoney. *Roller trains and roller assemblies.*

- Ring-seal and paradox gates. *Roller trains and roller assemblies.*

- Wheel-mounted, vertical-lift gates. *Wheel bearings.*

- Roller gates. *See chains.*

- Butterfly, sphere, plug valves. *Trunnions. Gears for electrically and manually operated lifts.*

- Fixed cone valves. *Threaded drive screws, gears for electrically and manually operated lifts.*

a. Trunnions. Grease for trunnions should be selected for high-load, low-speed applications (boundary lubrication). Other considerations include frequency of operation, trunnion friction, temperature range, condition of bearing surfaces (rust, scuffing, etc.), whether the trunnions are exposed to sunlight or submerged, and contaminants such as moisture and debris. During the warranty period, specific greases are recommended by equipment manufacturers and should be used. If another grease is desired, the testing of a number of greases by a qualified lubricant expert to the exacting conditions of the application will determine the optimal grease. However, testing can be expensive and is not necessary unless highly unusual conditions exist. Suitable greases can be identified by finding out what works at other facilities that use the same equipment under similar conditions. . Commonly used greases and lubrication frequencies for trunnions on gates and culvert valves at navigational dams and locks are noted in the survey in Appendix B. Also, lubricant suppliers are readily available to recommend a grease, but they should be advised of all conditions for the particular application.

(1) Recommended greases and desirable properties from field experience.

A spillway tainter gate failure at Folsom Dam in 1995 led to an investigation and testing of greases for trunnions. Table 11-3 lists desirable grease properties for the Folsom Dam trunnion bearings. Details of the investigation may be found in the report "*Folsom Dam Spillway Gate 3 Failure Investigation Trunnion Fixture Test,*" prepared by the U.S. Bureau of Reclamation Mid-Pacific Regional Office, July 1997. The properties compiled for the trunnions at Folsom Dam are applicable to trunnions in general. Table 11-3 shows the purpose of the grease property, base oils for grease, grease gelling (thickening) agents, additives, and ASTM grease test and properties. Further explanation of desirable trunnion grease properties are as follows:

(a) Lubricity. Low breakaway (static) and running (kinetic) friction and no stick-slip are necessary for smooth gate and valve operation. The grease should possess good lubricity for low start-up and running torque.

(b) Rust prevention. Rust on a trunnion pin thickens with time. This thickening takes up bearing clearance, soaks up the oil from grease, prevents film formation, causes high friction, and abrades bronze bushing material. Since rust takes up about 8 times the volume of the iron from which it is formed, it is very important for trunnion pin grease to inhibit rust.

(c) Low corrosion of leaded bronze. Grease degradation products such as organic acids and chemically active sulfur and chlorine compounds used in gear oils can corrode leaded bronze bushings. Some light tarnishing is acceptable, but excessive corrosion is indicated by stains, black streaks, pits, and formation of green copper sulfate from sulfuric acid.

Table 11-3
Desirable Grease Properties for the Folsom Dam Trunnion Bearings. (Reference: "Lubricating Grease Guide," NLGI 4th Ed., 1996)

Purpose of Grease Property (a)	Examples of Composition		Additives				ASTM Test	
	Base Oil	Gelling Agent	Type	%	Chemical	Number	Desired Result	Maximum
Lubricity, that is, low static and kinetic friction for bronze on steel	Mineral or synthetic including polyol ester, jojoba oil, vegetable oils	Lithium or calcium soaps, or polyurea	Lubricity (reduction of friction)	2.5	Fatty materials, oleic acid, oleyl amine, jojoba oil	D 99-95 Pin-on-disk apparatus applicable	Coefficient of static friction, fs, (breakaway), 0.08, (b) Coefficient of kinetic friction at 5.1 mm/min (0.2-inch/ min, fk, 0.10)	fs,0.10, (b) fk, 0.12
Prevent rusting of steel	Mineral, or synthetic	Calcium, lithium or aluminum complex soaps, or calcium sulfonates, or polyurea	Rust inhibitors, calcium sulfonate	0.2 to 3	Metal sulfonates, amines	D 1743-94	Pass- no rusting of steel after 48 hours in aerated water	Pass
Low corrosion of leaded bronze (Cu 83, Sn 8, Pb 8%)	Mineral, or synthetic	Lithium or calcium sulfonate and soaps, or polyurea	Corrosion inhibitors, metal deactivators	0.2 to 3	Metal sulfonates phosphites	D 4048 (copper strip)	1 to 1B	4C
Prevent scuffing of steel vs bronze	Mineral or synthetic	Lithium or calcium soaps, or polyurea	Antiscuff (EP)	1 to 2	Sulfur and phosphorous compounds, sulfurized fats, ZDDP	D 99-95, bronze pin vs steel disk	No scuffing, that is, transfer of bronze to steel. "EP" film formation	No scuffing
Resists wash-out by water	Mineral or synthetic	Polyurea or calcium hydroxystearate	-	-	-	D 1264-93	0 wash-out	1.9%
Does not "harden" in pipes	Mineral or synthetic	Lithium or calcium soaps or polyurea	-	-	-		No change in consistency with aging	No change
Easy to pump and distribute through tubing and grooves in bronze bushing	Mineral or synthetic, ISO 100 to 150	Polyurea, lithium or calcium soaps	-	-	-	a. D 217	a. NLGI 1 or 1.5, cone penetration 340 to 275, b. Pumps through 7.62 m to 0.0762 m (25' to 1/4") copper tubing	NLGI 2
Adherence to metal, and retention in areas of real contact of trunnion	Mineral or synthetic	Lithium or calcium soaps or polyurea	Tackiness agent		Polymers, isobutylene or polyethelene	none	Slightly tacky between metals	Slightly tacky
Long life, oxidation stable	Mineral or synthetic	Polyurea	Oxidation inhibitors		Amines, phenols, sulfur compounds	D 942-90	Pass, also no acid formation, odor, or discoloration.	Pass
Low bleeding, oil does not separate from grease excessively	Mineral or synthetic	Lithium or calcium soaps or polyurea	High-viscosity base oil	-	-	D 1742-94 and Federal Test	Limited "bleeding" of oil, less than 0.1%	1.6% in 24 hr, 3% in 48 hr.

(a) Applied to low carbon (SAE1045) steel pin 812.7 mm (32") diam., rotating in trunnion bronze bushing, at 5.1 mm/min (0.2 in/min) and 816,461 kg (1.8 million pounds) load.
dam site environment - temperature range -11°C to 51.6 °C (30 to 125 °F), wet, long periods of no sliding under load.
(b) Only known bench test with Pin (bronze pad)-on-Disk (1045 steel) tribometer, at Herguth Laboratories, P.O. Box B, Vallejo, CA 94590 run at 50 N (11-2 lb of force) load, 5.1 mm (0.2 inch) per minute sliding velocity, and room temperature.

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(d) Scuff prevention. Scuffing causes serious damage to surfaces in the form of metal transfer, melting, and tearing. Antiscuffing additives are activated by the heat of friction and form a surface film. If used in a trunnion grease, sulfur concentrations must be low to prevent chemical corrosion of sliding surfaces.

(e) Wash-out resistance. Especially when trunnions are submerged, the grease should be resistant to water wash-out.

(f) Pumpability. Grease should be nonhardening and flow into the load-bearing clearances of the trunnion. A grease should easily pump and flow through piping and tubing. The grease should retain its NLGI grade over long periods during any temperature fluctuations.

(g) Adherence to metal. Tackiness agents provide this characteristic

(h) Oxidation resistance. Grease oxidation will occur over long periods at dam environment temperatures. Symptoms of oxidation are discoloration, hardening, and bronze corrosion. An effective oxidation inhibitor will increase grease longevity.

(I) Low oil separation. Oil separation or “bleeding” from the gelling agent should be minimized during inactivity and storage. Excessive bleeding hardens the remaining grease because of the decreased oil-to-thickener ratio. However, some separation -- especially under pressure -- is desired so the oil and its additives can flow into the molecular-scale clearances between pin and bushing for boundary lubrication.

(j) Solid lubricants. The Folsom Dam tainter gate failure investigation recommended that molybdenum disulfide ($MoSO_2$) and polytetrafluoroethylene (PFTE) not be used in greases for tainter trunnions at Folsom. The lowest friction coefficients were achieved with greases that did not have these solid additives. Furthermore, addition of $MoSO_2$ to greases is shown to reduce their ability to prevent corrosion. Although not a factor in the Folsom Dam tainter gate failure, graphite is not recommended as an additive for lubricating trunnions because it has been found to promote corrosion.

(2) Load. Tainter gate trunnions operate under high loads and extremely low speeds. The load on the trunnion is the water-level pressure plus a portion of the gate weight. Typical design loading on tainter trunnions is 137.9 to 206.8 bar (2000 to 3000 psi) for leaded tin bronze bearing surfaces and 275.8 to 344.7 bar (4000 to 5000 psi) for aluminum bronze.

(3) Speed. Relatively speaking, a trunnion pin rotates at extremely low speeds. The tainter trunnion pins at Folsom Dam rotate at 0.002 rpm. Trunnions in reverse tainter gates at locks have faster rotational speeds than those in dam gates.

(4) Friction. Trunnion friction increases during operation as the bearing rotates. Friction increase is caused by lubricant thinning at the loaded bearing surfaces. Trunnion friction is especially critical at high water levels and low gate openings, but lessens as the gate is opened and the reservoir level drops. Typical design coefficient of friction for grease-lubricated trunnion bearings is 0.3. There was no trunnion coefficient of friction calculated into the design of the failed Folsom gate, but the friction coefficient rose to 0.3 over a long period of time, perhaps the entire life of the gate, due to rust on the trunnion pin. When new equipment is purchased or existing bushings are replaced, self-lubricated bushings are recommended. The trunnion bushings for the failed gate at Folsom Dam were replaced with self-lubricated bushings. Modern gates such as the clamshell gate are specified exclusively with self-lubricated trunnion bushings.

Typical design coefficient for self-lubricated trunnion bushings is 0.15, which translates into less structural support (to keep gate arms from buckling under friction) than for grease-lubricated bearings.

(5) Lubrication regime. Two grease lubrication regimes are applicable to trunnions operating under high-load, low-speed conditions. They are hydrostatic lubrication and boundary lubrication.

(a) Hydrostatic lubrication. Hydrostatic lubrication may be used when bearing surface velocities are extremely slow or zero. Under hydrostatic lubrication, a pressurized grease physically separates the bearing surfaces to produce a thick film. Trunnion friction can be reduced by about 40 percent if a grease film can be maintained during operation by an automatic greasing system.

(b) Boundary lubrication. Boundary lubrication occurs when bearing surfaces are separated by a lubricant film of molecular thickness and there is momentary dry contact between asperities (microscopic peaks). Friction is caused by contact of bushing and pin surface asperities. Since viscosity depends on film thickness, when boundary lubrication occurs, friction is not affected by of the grease viscosity and can only be reduced through additives.

(6) Grease selection based on boundary lubrication. Grease should be selected based on its performance specifically for boundary lubrication, whether for manual lubrication or automatic greasing system. Manual hydrostatic lubrication on stationary equipment under load reduces trunnion friction for the next operation, but as the pin rotates, the lubricant film thins until pure boundary lubrication results. With rust on the trunnion pins, the preferred method of trunnion lubrication is hydrostatic lubrication during gate operation using an automatic greasing system. However, automatic systems are subject to occasional breakdown which could produce catastrophic results.

(7) Frequency of lubrication.

(a) Frequency of lubrication depends on many factors, such as frequency of operation, trunnion friction, temperature, condition of bearing surfaces (rust, pitting, etc.), whether the equipment is submerged, replacement of grease lost to leakage or oxidation, and the need to flush out moisture or other contaminants. An example of two different lubrication frequencies based on factors and gate conditions are as follows:

- The Folsom Dam spillway tainter gate investigation suggests that, in general, if the allowable gate trunnion friction in the design is at least 0.5 and the bearing is well protected from its given environment, the Bureau of Reclamation standard of lubricating tainter gates twice a year is adequate.

- The same Folsom investigation found there was no allowable trunnion friction in its gate design. The trunnion pins were rusted, scuffed, and had inadequate protection from rain and spray. Based on these factors, it was concluded that a reasonable lubrication schedule would be to grease once a month when the lake level is below the gates; grease once a week when the lake level is above the gate sill; and employ automatic greasing while the gate is in motion. Frequent applications can remove moisture from trunnion surfaces and decelerate rust progress.

(b) Frequencies for lubricating gate and culvert valve trunnions at locks and dams are shown in the survey in Appendix B. These vary from weekly to twice a year, indicating that there is no set frequency of lubrication. Aside from recommendations for new equipment, lubrication frequencies become individualized based on the factors and conditions noted above and operating experience.

(8) General suggestions for tainter gates. Some of the recommendations made for Folsom Dam, such as the automatic greasing system and the lubricant type, are made partly due to existing rust of the trunnion pins and bushings. Other tainter gates may have different conditions such as local climate, frequency of gate operation, the designed allowable trunnion friction, and the lubrication system. The following procedures are suggested to determine the requirements for tainter gate trunnions at other locations:

(a) If exposed to water, air, and abrasive dust and debris, install weather protection seals on the edges of the trunnions to protect the bearing. Seals will protect against rusting of the pin while protecting the grease from oxidation and contamination.

(b) Determine the allowable trunnion friction. An allowable friction coefficient below 0.3 would be considered low.

(c) Carefully review the design of the trunnion assembly and lubrication system.

(d) Review the frequency of gate operations.

(e) Inspect the trunnions using some of the techniques listed below to determine the presence of rust and to estimate the existing trunnion friction. (These techniques have been established as a result of the investigation. Their effectiveness or feasibility has not been extensively determined and may depend on local conditions.) If corrosion is suspected, determine trunnion friction. Friction coefficients above design value may require a change of lubricants and/or lubrication frequency. Techniques are:

- Send used grease that is pumped out of the trunnions to a laboratory to test for contaminants such as rust.

- Measure the gate's hoist motor current as an indication of possible increased trunnion friction.

- Attach strain gages to the gate arms to measure induced stresses caused by trunnion friction.

- Attach a laser and target to the gate structure to measure deflections caused by trunnion friction.

- Fabricate probes that can access the trunnion pin through the lubrication ports to determine the presence of rust.

(f) Review the type of lubricant in use. Consider the lubricant specification recommended for the Folsom Dam trunnions (reference Table 11-3).

(g) Rotate trunnion pins 180 degrees. Loading is typically on one side of the pin, and the pin will corrode first on the side with the thinnest lubricant film.

(h) If pins are rusted, use new steel pin, because previously rusted steel is susceptible to rapid rusting.

b. Seats for bonneted gates. With design loading on the bronze sliding surfaces of these gates at 206.8 to 275.8 bar (3000 to 4000 psi), seats are typically lubricated with a multipurpose lithium, lithium complex, or lithium 12 hydroxystearate-thickened grease with EP additives. The grease must be suitable for the temperature range intended. Desired grease properties are good water wash-out resistance, copper alloy corrosion protection, and low start-up/running torque. Recommended greasing frequency is every 6 months, however, but chattering or jerking during operation is a sign of inadequate lubrication and indicates the need for more frequent lubrication. Greases recommended by gate manufacturers are usually NLGI grade 2. However, it has been noted that cold seasonal temperatures may dictate a lower NLGI grade for better flow through piping to the seats.

c. Threaded gate stems. The same multipurpose EP greases recommended by gate manufacturers for seats are recommended for stems. The grease must be suitable for the temperature range intended. Good water resistance and low start-up/running torque are also desired grease properties for stems. Cold seasonal temperatures may necessitate a lower NLGI grade if the grease accumulates excessively at the lift nut during operation due to low temperature. Keeping threaded stems clean and greased is critical. When excess dried grease or other foreign material is carried into the threads of the lift nut, extremely hard operation will result. If the foreign material is not cleaned from interior threads, seizure can result. Moreover, if the foreign material is abrasive and the stem is coated with this grit, frequent use of the gate will wear the threads in the thrust nut creating a potentially dangerous situation. An excessively worn thrust nut may not support the weight of the gate and may cause it to fall. Use of pipe covers will protect stems above the deck. Plastic stem covers will allow visual inspection. Recommended cleaning and greasing frequency is at least every 6 months or 100 cycles, whichever occurs first, and more often if the grease becomes dirty.

d. Threaded drive screws. The lubricant should have good water-separating characteristics and must be suitable for the temperature range intended. It should have extreme pressure characteristics and low start-up/running torque for quick start-up and smooth operation. The same multipurpose EP greases used for threaded gate stems can be used on drive screws.

e. Roller trains and roller assemblies for roller-mounted gates. When chains are part of roller assemblies, they should be lubricated according to the requirements discussed below for chains. Grease for roller trains should contain an EP additive and generally be NLGI grade 2. It should be formulated for rust and corrosion protection and be resistant to water wash-out. It should be suitable for the temperature range intended and for the shock loading of wave action. Frequency of lubrication depends on factors such as frequency of operation and accessibility, but roller trains should be lubricated a minimum of twice a year. When possible, the equipment manufacturer should be consulted for lubricant and frequency recommendations.

f. Wheel bearings. Grease should be suitable for boundary lubrication of a high-load, low-speed journal bearing and contain EP additives. It should be noncorrosive to steel and resistant to water wash-out conditions. It must be suitable for the temperature range intended. The grease should conform to the recommendations of the bearing manufacturer. Bearings should be lubricated at least once a year. When this is not possible they should be lubricated whenever accessible.

g. Grease-lubricated gears for electrically and manually operated lifts.

(1) Grease for the main gearboxes of operating lifts should contain an EP additive and be suitable for the temperature range intended. It should be water- and heat-resistant, and be slightly fluid (approximating NLGI grade 1 or 0). It should not be corrosive to steel gears, ball, or roller bearings, and should not create more than 8 percent swell in gaskets. Its dropping point should be above 158 °C (316 ° F) for temperature ranges of -29 °C (-20 °F) to 66 °C (150 °F). It should not contain any grit, abrasive, or fillers.

(2) Frequency of lubrication varies among manufacturers. One lift manufacturer recommends pressure greasing through fittings after 100 cycles or every 6 months, whichever comes first. The frequency of inspections and/or lubrication should be based on historical data. The manufacturer's schedule should be followed unless operating experience indicates otherwise. Grease should be inspected at least every 18 months. It should contain no dirt, water, or other foreign matter. Should dirt, water, or foreign matter be found, the units should be flushed with a noncorrosive commercial degreaser/cleaner that does not affect seal materials such as Buna N or Viton. All bearings, bearing balls, gears, and other close-tolerance parts that rotate with respect to each other should be recoated by hand with fresh grease. The operator should then be repacked with fresh grease. Different lubricants should not be added unless they are based on the same soap (calcium, lithium, etc.) as the existing lubricant and approval has been given by the lubricant manufacturer. (Oil-lubricated gears are discussed in paragraph 9.4).

h. Hydraulic fluids for operating systems. Commonly used hydraulic fluids for gates at locks and dams and culvert valves at locks are tabulated in Appendix B. An oil with a high viscosity index should be selected to minimize the change in pipe friction between winter and summer months. The oil selected must have a viscosity range suitable for the system components and their expected operating temperature and pressure ranges. Generally, the maximum viscosity range is between 4000 Saybolt Universal Seconds (SUS) at start-up and 70 SUS at maximum operating temperature. However, this range will vary between manufacturers and types of equipment. Hydraulic systems containing large quantities of fluid should include rust and oxidation inhibitors. Consideration should also be given to biodegradable fluids composed of vegetable-base oils with synthetic additives. These fluids should be used with caution to ensure that they are compatible with the components used in the hydraulic system. A more detailed discussion of hydraulic fluids properties can be found in Chapter 4 of this manual.

11-11. Navigation Lock Gates, Culvert Valves, and Dam Gates

a. General requirements.

(1) Corps of Engineers navigation facilities use many types of lock gates, including miter, sector, vertical lift, and submergible tainter. The machinery required to operate these gates consists of speed reducers, gear couplings, bearings, open gearing, wire ropes, and chains. Most of this equipment is heavily loaded and operates at low speeds. Consequently, hydrodynamic lubrication cannot be established and boundary lubricating conditions predominate.

(2) The general lubricating requirements for this equipment have already been discussed. The following discussion is limited to the lubricating requirements specific to the lock gate noted. Refer to paragraph 11-10 (gates and valves) for lubrication requirements for culvert valves and dam gate components. Refer to the survey (Appendix B) discussed in the next paragraph for commonly used lubricants and hydraulic fluids.

b. Survey of locks and dams for lubricants. About 45 Corps of Engineers locks and dams around the country were surveyed for lubricants and hydraulic fluids used for lock gates, culvert valves, and navigation dams. Twenty-three survey responses showed lubricant products from more than 25 different lubricant companies. Each product appears suitable for the particular application. Information on frequency of lubrication and method of application was also included in the responses. Respondents expressed interests in environmentally acceptable lubricants, but use has been limited. Responses also covered lubricants for equipment not specifically queried for on the survey. These responses and comments on environmentally acceptable lubricants are included with the survey results in Appendix B.

c. Speed reducers. Speed reducers are usually worm, helical. or herringbone-type gear trains in accordance with the applicable American Gear Manufacturers Association (AGMA) standards. Integral bearings are usually antifriction type. Gear oil must be suitable for the expected ambient temperatures. Where ambient temperature ranges will exceed the oil producer's recommendations, a thermostatically controlled heater should be provided in the reducer case. The surface area of the heater should be as large as possible to prevent charring of the oil. The density of heating elements should not exceed 21.44 hp/m^2 (10 watts per square inch). If possible, insulate the reducer case to minimize heat loss. If heaters are impractical, synthetic gear oils should be considered. A number of locks are using synthetic oils in gearboxes. One reason given is that in cold weather, heaters have scorched petroleum oils, requiring additional maintenance. Synthetic oils eliminate the need for heaters. A synthetic gear lubricant with a -40 °C (-40 °F) pour point is recommended if acceptable to the reducer manufacturer. Lubricant selection should be based on published manufacturer's data for the required application and operating conditions. Gear oils used at locks and dams are listed in the survey in Appendix B.

d. Couplings. Flexible couplings are usually the gear type. The lubrication requirements for these couplings were discussed above.

e. Bearings.

(1) Antifriction bearings should be selected in accordance with manufacturer's published catalog ratings. Life expectancy should be based on 10,000 hours B-10 life with loads assumed equal to 75 percent of maximum.

(2) Bronze sleeve bearings should have allowable unit bearing pressures not exceeding the following:

- Sheave bushings, slow speed, 3500 psi.

- Main pinion shaft bearings and other slow-moving shafts, hardened steel on bronze, 1000 psi.

- Bearings moving at ordinary speeds, steel or bronze, 750 psi.

f. Open gearing. Open gears are usually the spur teeth involute form, complying with AGMA 201.02 ANSI Standard System, "Tooth Proportions For Coarse-Pitch Involute Spur Gears" (Information Sheet A). Lubricants used at Corps of Engineers locks and dams are noted in the survey in Appendix B.

g. Hydraulic fluid. A petroleum oil with a high viscosity index should be selected to minimize the change in pipe friction between winter and summer months. The oil selected must have a viscosity range suitable for the system components and their expected operating temperature range. Generally, the maximum viscosity range is between 4000 SUS at start-up and 70 SUS at maximum operating temperature. However, this range will vary among manufacturers and types of equipment. Hydraulic systems containing large quantities of fluid should include rust and oxidation inhibitors. Consideration should also be given to biodegradable fluids composed of vegetable-base oils with synthetic additives. These fluids should be used with caution to ensure that they are compatible with the components used in the hydraulic system. Refer to Chapter 8 for a more detailed discussion of desirable properties and the survey in Appendix B for hydraulic fluids commonly used at locks and dams.

h. Miter gates. There are various types of operating linkages for miter gates. Generally these gates are operated through electric motors, enclosed speed reducers, a bull gear, sector arm, and spring strut. Alternatively, the gates may be hydraulically operated. Miter gate gudgeon pins and pintles are grease-lubricated with automatic and manual greasing systems. Spring struts are lubricated with graphite-based grease or lubricated with the same grease used on the pintles, depending on type of strut. Refer to the survey in Appendix B for commonly used lubricants and frequency of application.

i. Sector gates. The operating machinery for sector gates is similar to that used in miter gate and may consist of a hydraulic motor, or an electric motor, a herringbone gear speed reducer, and a specially designed angle drive gear unit. In some applications a system consisting of a steel wire rope and drum arrangement replaces the rack and pinion assembly, and is used to pull the gates in and out of their recesses. Sector gates gudgeon pins and pintles are lubricated with the same grease used on miter gate gudgeon pins and pintles.

j. Vertical-lift gates. The hoisting equipment for vertical-lift gates consists of a gear-driven rope drum. The actual gear drive depends on the gate use. Emergency gates use two-stage open-spur gearing, a herringbone or helical gear speed reducer, and an electric motor. The downstream gate is wheel-mounted. These wheels may be provided with self-lubricating spherical bushings. Tide gate drums are operated by a pinion gear driven by a triple-reduction enclosed gear unit. Vertical gates are also equipped with a hydraulically operated emergency lowering mechanism. The hydraulic fluid is used to absorb heat so a heat exchanger is required to ensure that the oil temperature does not exceed 49 °C (120 °F). Wire ropes are usually 6 x 37, preformed, lang lay, independent wire rope core, 18-8 chrome-nickel corrosion-resistant steel.

k. Submergible tainter gates. Submergible tainter gates are operated by two synchronized hoist units consisting of rope drum, open gear set, speed reducer, and hoist motor. Due to continuous submergence, stainless steel wire ropes are commonly used. Refer to paragraph 11-10 (gates and valves) for trunnion lubrication requirements.

11-12. Information Sources for Lubricants

There are many valuable information resources on the subject of lubrication.

a. Operations and maintenance manuals. The primary information sources are the manufacturer's installation, operation, and maintenance manuals. The information contained in these manuals applies specifically to the equipment requiring servicing.

b. Industry standards. Industry standards organizations such as ANSI, ASTM, AGMA, and IEEE publish standard specifications for lubricants and lubricating standards for various types of equipment.

c. Journals. Engineering and trade publications and journals such as Lubrication, Lubrication Engineering, and Wear specialize in the area of lubrication or tribology. Articles featured in these publications are generally technical in nature and describe the results of current research. Occasionally research results are translated into practical information that can be readily applied.

d. General trade publications. Magazines such as Power, Power Engineering, Hydraulics and Pneumatics, Machine Design, Pump and Systems, and Plant Engineering Magazine frequently contain practical articles pertaining to lubrication of bearings, gears, and other plant equipment. Of particular interest is Plant Engineering's "Chart of Interchangeable Industrial Lubricants" and "Chart of Synthetic Lubricants." Each of these charts is updated every 3 years. These charts cross-reference lubricants by application and company producing the product. Chart users should note that Plant Engineering Magazine product names are provided by the manufacturers, and that publishing of the data does not reflect the quality of the lubricant, imply the performance expected under particular operating conditions, or serve as an endorsement. As an example of the information contained in the interchangeable lubricant chart, the 1995 chart identifies available products from 105 lubricant companies in nine categories. Fluid products in each category are listed within viscosity ranges. Greases are NLGI 2 only. Included is a chart entitled “Viscosity/Grade Comparison Chart” that tabulates viscosity equivalents for ISO viscosity grade, kinematic viscosity (CSt), Saybolt viscosity (SUS), gear lubricant (AGMA) specification, EP gear lubricant, and worm gear lubricant (Comp). Lubricant categories include:

- General-purpose lubricants
- Antiwear hydraulic oil
- Spindle oil
- Way oil
- Extreme pressure gear oil
- Worm gear oil
- Cling-type gear shield (open gears)
- General-purpose extreme pressure lithium-based grease
- Molybdenum disulfide extreme pressure grease.

The 1997 chart for synthetic lubricants identifies available products from 69 lubricant companies in eight categories. Fluid products in each category are listed within viscosity ranges. Greases are NLGI 2 only. Included is a table entitled “Performance Characteristic of Various Synthetic Lubricants” that shows the relative performance characteristics of seven types of synthetic lubricants and a paraffinic mineral oil. Lubricant categories are:

- Gear and bearing circulation oil
- Extreme pressure gear oil
- High pressure (antiwear) hydraulic oil
- Fire-resistant hydraulic fluid
- Compressor lubricant
- Multipurpose extreme pressure grease (without molybdenum)
- Multipurpose molybdenum disulfide extreme pressure grease
- Multipurpose high temperature grease (without molybdenum).

Plant Engineering Magazine notes that the synthetic lubricant products presented in each category are not necessarily interchangeable or compatible. Interchangeability and compatibility depend on a variety of interrelated factors, and each application requires an individual analysis.

e. Hydropower industry publications. Hydro Review and Water Power and Dam Construction are widely known publications throughout the hydropower industry. Hydro Review tends to be more research-oriented and, therefore, more technical. Water Power and Dam Construction includes technical and practical information. Occasionally, lubrication-related articles are published.

f. Lubricant producers. Lubricant producers are probably the most valuable source for information and should be consulted for specific application situations, surveys, or questions.

g. Internet. The Internet offers access to a large amount of information, including lubrication theory, product data, and application information. The Internet also provides a means for communicating and sharing information with personnel at other facilities. Problems, causes , and solutions are frequently described in great detail. Since the credentials of individuals publishing information through the Internet are more difficult to ascertain, caution should be used when evaluating information obtained through the Internet. The amount of information located depends on the user's ability to apply the most pertinent keywords on any of the search engines. Hyperlinks are usually available and lead to other information sources. Users should note that broad search categories, such as "lubrication," will provide the greatest returns but will undoubtedly include much extraneous data. Alternatively, searching on a phrase such as "lubrication of hydroturbine guide bearings" may be too restrictive. Generally, inserting too many words in the search field narrows the scope of the search and may produce little or no useful information. The search field must be adjusted until the desired information is obtained or the search is abandoned for another reference source.

h. Libraries. In a manner similar to Internet searches, librarians can also help locate information within their collections or outside their collections by conducting book and literature searches. Unlike the Internet, literature searches rely on large databases that require password entry not available to the general public. Therefore, these searches are usually conducted by a reference librarian. The search process is a very simple method used for locating books an a specific subject, or specific articles that have been included in technical publications. Usually, searches begin with the current year to find the most recent articles published. The search is expanded to previous years as necessary until useful articles or information are located. All that is required is the subject keyword and the time period to be searched. For example: locate all articles on "guide bearing lubrication" written over the past 2 years. If this does not return the desired information, two options are available: extend the time period further into the past or change the search title to "journal bearing lubrication" and try new search. Again, the amount of information located depends on using the proper search keywords. Searches can be expanded or contracted until the desired information is obtained.