Lubricants and Hydraulic Fluids: *Applications*

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CHAPTER 14

Gear Lubrication

14-1. General. Open gears and gear reducers (also referred to as gearboxes and speed reducers) are used extensively on USACE navigation structures. Lubricants are integral to gears and gear reducers and are subject to some unique challenges on navigation structures. This includes extreme temperatures, infrequency of use, high humidity, submersion during floods, and high operating loads and pressures. Open gears and gear reducers are typically custom made and any failure could result in a shutdown of the lock and dam. Lubrication issues are interrelated with open gearing and gear reducer issues. A discussion of lubrication may cross over into gearing and is sometimes the cause of gear failures. The selection of lubricant is important to the long term efficient operation of the gear drive. In addition to considering these factors, the gear lubricant selected for a particular application should match the recommendations of the original equipment manufacturer (OEM). Generally, open gear drives are the most economical type of gear drive alternative for use in applications where high load-carrying capacity and long service life under severe shock load conditions are required. It is these characteristics, in addition to flexibility in the machine's design, that have made the open gear drive a common type of drive used at USACE navigation structures.

a. Energy is transmitted from a power source to a terminal point, through gears that change speeds, directions, and torque. In most cases, this is done through a combination of sliding and rolling motion between gear teeth. Although, for worm gears, the load is transmitted entirely through sliding motion. During the rolling motion, gears are considered to operate in a elastohydrodynamic mode, and during the sliding motion, boundary and/or hydrodynamic lubrication takes place. Gear lubricants are formulated for each application and applied to prevent premature component failure, assure reliable operation, reduce operating cost, and increase service life. The important objectives accomplished by these lubricants include: reduction of friction and wear, corrosion prevention, reduction of operating noise, improvement in heat transfer, and removal of foreign or wear particles from the critical contact areas of the gear tooth surfaces.

b. Gears vary greatly in their design and in their lubrication requirements. Proper lubrication is important to prevent premature wear of gear tooth surfaces. When selecting a lubricant for any gear application, the following issues must be considered: type and materials of gear; operating conditions, including rolling or sliding speed; type of steady load and temperature; method of lubricant application; environment; and type of service. Enclosed gears – those encased in an oiltight housing – usually require an oil with various additives, depending on the operating conditions. Rust, oxidation, and foam inhibitors are common. EP additives are also used when loads are severe.

c. Worm gears are special because the action between the worm and the mating bull gear is sliding rather than the rolling action common in most gears. The sliding action allows fluid film lubrication to take place. Worm gear reducers typically require oil that is approximately twice as heavy as that required for parallel shaft gear reducers. This is due to the nature of the sliding action between the worm gear and the worm wheel. Another significant difference is that worm gears are usually made of dissimilar materials, which reduces the chance of galling and reduces friction. EP additives usually are not required for worm gears and may actually be detrimental to a bronze worm gear because they can cause corrosion. Lubrication can be improved by oiliness additives.

d. In open gear applications, the lubricant must resist being thrown off by centrifugal force or being scraped off by the action of the gear teeth. A highly adhesive lubricant is required for most open gear applications. Most open gear lubricants are heavy oils, asphalt-based compounds, or soft greases. Depending on the service conditions, oxidation inhibitors or EP additives may be added. Caution must be exercised when using adhesive lubricants because they may attract and retain dust and dirt, which can act as abrasives. To minimize damage, gears should be periodically cleaned. Open gear lubricants must possess the following characteristics and properties:

- Tackiness (adhesive/cohesive properties) to impart excellent adhesion to the gears.
- Resistance to water washout and sprayoff.
- Load-carrying capability to protect against friction and wear.
- Protection of the gears against wear and corrosion.
- Cushioning ability (vibration reduction).
- Sprayability and/or ease of dispensability.
- Alleviation of housekeeping and maintenance problems.
- Resistance to fling off.
- No buildup in the roots of the gear teeth.

14-2. Gear Types.

a. Gears are discussed in more detail in EM 1110-2-2610, *Mechanical and Electrical Design of Navigation Locks and Dams* (30 June 2013). Open gears on navigation structures generally are very slow moving and carry large loads and will typically operate in the boundary lubrication regime. Some of the more common open gear types are shown below. These gears tend to be very large and are prone to contamination from dirt and debris. Any lubricant selection for open gears needs to be able to perform under adverse conditions, including submersion. Open gear lubrication has traditionally been petroleum-based lithium-based grease. Gear failures can be traced to mechanical problems or lubricant failure. Lubricant-related failures are usually traced to contamination, oil film collapse, additive depletion, and use of improper lubricant for the application. Water contamination can cause rust on working surfaces and eventually destroy metal integrity. The types of failures are discussed further in Paragraph 14-3.

b. Gear reducers (also called gearboxes or speed reducers) are a common form of power transmission used on a variety mechanical drives. Some more common types of gear reducers include parallel shaft with helical gearing and worm gear reducers. Gear reducers simply are a combination of open gears that are enclosed in a sealed box or housing. They are generally used for speed reduction. Gear reducers can use a number of gear types including worm gears, spur gears, bevel gears, and helical gears. A lubricant is used to control friction and wear between the mating surfaces, and in enclosed gear drive applications, to transfer heat away from the contact area. It also serves as a medium to carry the additives that may be required for special functions. As the oil in a gear reducer heats and cools, it expands and contracts, allowing moist outside air into the gear reducer through the breather. To limit the entrance of moisture into gear reducers, the use of an appropriately sized oil bath or disposable desiccant breather is necessary. Some of the more common gear reducers are shown below. In general, gear lubricants (oils) are formulated to comply with AGMA 9005-E02, "Industrial Gear Lubrication Standard." Gear lubricants complying with AGMA 9005-E02 are also suitable for drive unit bearings in contact with the gear lubricant. Means of lubricating gear boxes include splash lubrication, pressure lubrication, gravity drip, spray systems, and idler immersion systems. Splash lubrication is probably most common at USACE sites.

c. Spur Gears. Spur gears (Figures 14-1 and 14-2), the most common type of gears used, are used at many USACE navigation sites. Design of spur gears is discussed in more detail in EM 1110-2-2610, *Mechanical and Electrical Design of Navigation Locks and Dams* (30 June 2013). Tooth contact is primarily rolling, with sliding occurring during engagement and disengagement. Some noise is normal, but it may become objectionable at high speeds.

d. Rack and Pinion. Rack and pinion gears are essentially a variation of spur gears and have similar lubrication requirements (Figure 14-3).

Figure 14-1. Spur Gears.

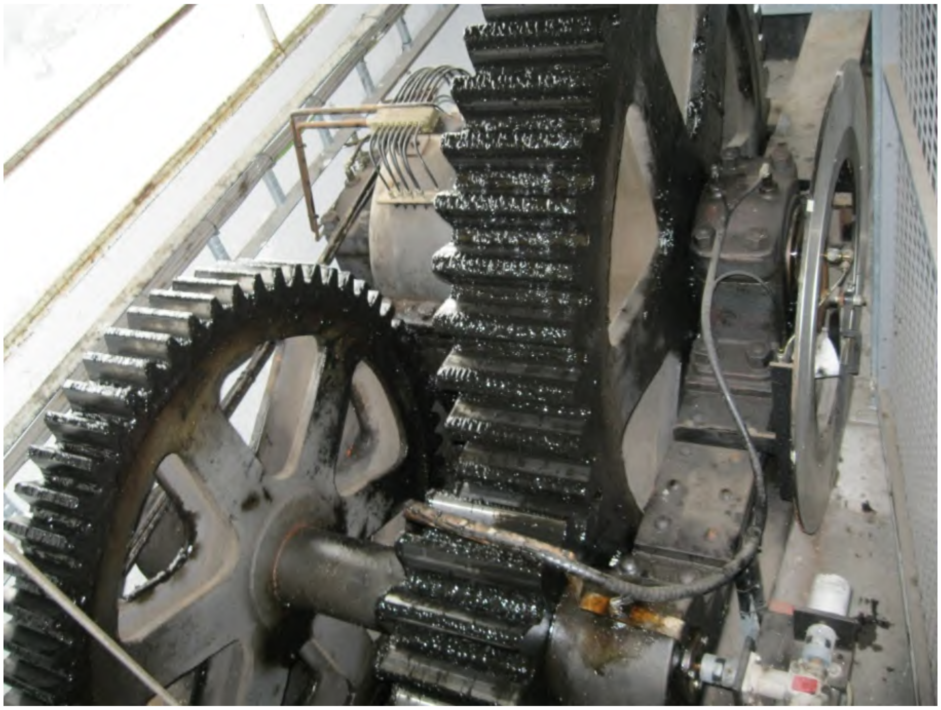

Figure 14-2. Spur Gears, Side View.

Figure 14-3. Sector Gear and Rack (Rack and Pinion).

a. Helical. Helical gears (Figure 14-4) operate with less noise and vibration than spur gears. At any time, the load on helical gears is distributed over several teeth, resulting in reduced wear. Due to their angular cut, teeth meshing results in thrust loads along the gear shaft. This action requires thrust bearings to absorb the thrust load and maintain gear alignment.

Figure 14-4. Helical Gears.

b. Herringbone. Herringbone gears (Figure 14-5) are essentially two side-by-side opposite-hand helical gears. This design eliminates thrust loads, but alignment is very critical to ensure correct teeth engagement.

Figure 14-5. Herringbone Gears.

c. Bevel. Bevel gears (Figure 14-6) are used to transmit motion between shafts with intersecting center lines. The intersecting angle is normally 90 degrees, but may be as high as 180 degrees. When the mating gears are equal in size and the shafts are positioned at 90 degrees to each other, they are referred to as miter gears. The teeth of bevel gears can also be cut in a curved manner to produce spiral bevel gears, which produce smoother and quieter operation than straight cut bevels.

Figure 14-6. Example of Bevel Gear (on Left).

d. Worm. Operation of worm gears is analogous to a screw. The relative motion between these gears is sliding rather than rolling (Figure 14-7). The uniform distribution of tooth pressures on these gears enables use of metals with inherently low coefficients of friction such as bronze wheel gears with hardened steel worm gears. These gears rely on full fluid film lubrication and require heavy oil compounded to enhance lubricity and film strength to prevent metal contact.

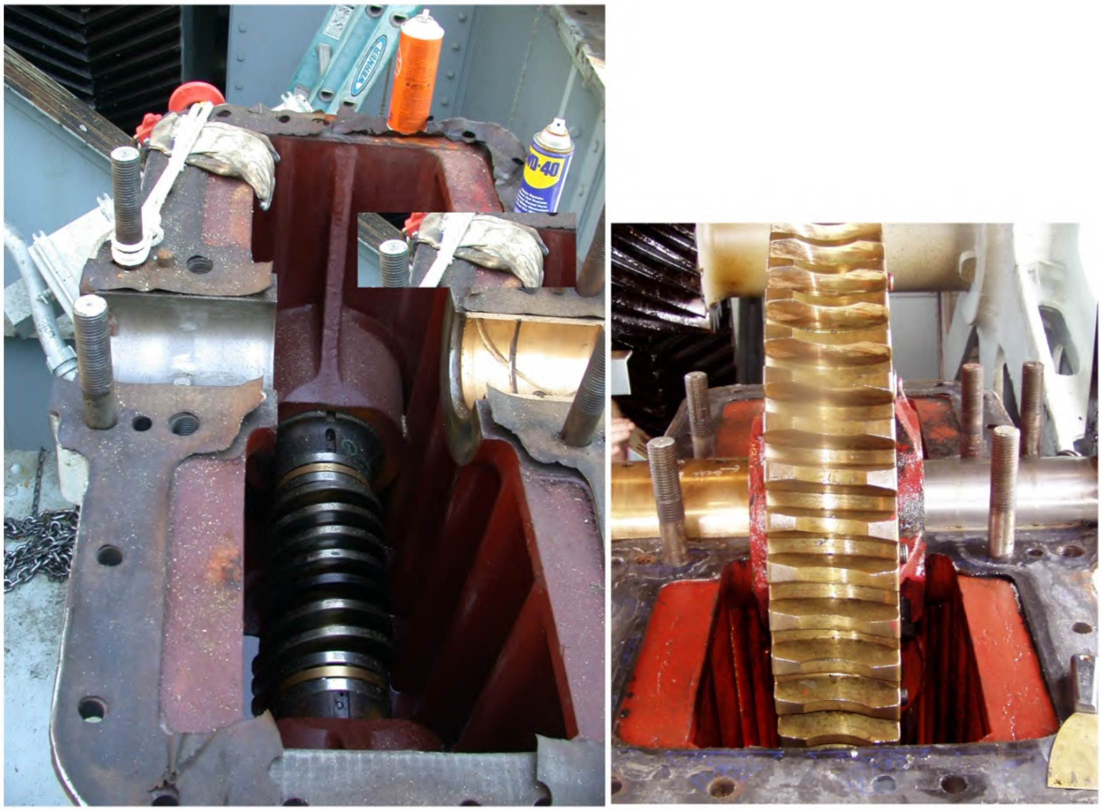

Figure 14-7. Worm Gear Reducer with Worm Wheel Removed (Left) and in Place (Right).

e. Hypoid. Hypoid gears are similar to spiral bevel gears except that the shaft center lines do not intersect. Hypoid gears combine the rolling action and high tooth pressure of spiral bevels with the sliding action of worm gears. This combination and the all-steel construction of the drive and driven gear result in a gear set with special lubrication requirements, including oiliness and antiweld additives to withstand the high tooth pressures and high rubbing speeds.

f. Annular. Annular gears have the same tooth design as spur and helical gears, but unlike these gears, the annular gear has an internal configuration. The tooth action and lubrication requirements for annular gears are similar to spur and helical gears.

14-3. Gear Wear and Failure.

a. The most critical function provided by lubricants is to minimize friction and wear to extend equipment service life. Gear failures can be traced to mechanical problems or lubricant failure. Lubricant-related failures are usually traced to contamination, oil film collapse, additive depletion, and use of improper lubricant for the application. The most common failures are due to particle contamination of the lubricant. Dust particles are highly abrasive and can penetrate through the oil film, causing “ploughing” wear or ridging on metal surfaces. Water contamination can cause rust on working surfaces and eventually destroy metal integrity. To prevent premature failure, gear selection requires careful consideration of the following: gear tooth geometry, tooth action, tooth pressures, construction materials and surface characteristics, lubricant characteristics, and operating environment. The first four items are related to design and application, and further discussion is beyond the scope of this manual. These items may be mentioned where necessary, but discussions are limited to those aspects directly related to and affected by lubrication, including wear, scuffing, and contact fatigue. Refer to ANSI/AGMA Standard 1010-E95, and ASM Handbook Volume 18, for photographs illustrating the wear modes described in the following discussion.

b. Normal Wear. Normal wear occurs in new gears during the initial running-in period. The rolling and sliding action of the mating teeth create mild wear that appears as a smooth and polished surface.

c. Fatigue. Pitting occurs when fatigue cracks are initiated on the tooth surface or just below the surface. Usually pits are the result of surface cracks caused by metal-to-metal contact of asperities or defects due to low lubricant film thickness. High speed gears with smooth surfaces and good film thickness may experience pitting due to subsurface cracks. These cracks may start at inclusions in the gear materials, which act as stress concentrators and propagate below and parallel to the tooth surface. Pits are formed when these cracks break through the tooth surface and cause material separation. When several pits join, a larger pit (or spall) is formed. Another suspected cause of pitting is hydrogen embrittlement of metal due to water contamination of the lubricant. Pitting can also be caused by foreign particle contamination of lubricant. These particles create surface stress concentration points that reduce lubricant film thickness and promote pitting. The following guidelines should be observed to minimize the onset of pitting in gear units:

- Reduce contact stresses through load reduction or by optimizing gear geometry.
- Ensure that steel is properly heat treated to high hardness. Carburizing is preferable.
- Ensure that gear teeth have smooth surfaces produced by grinding or honing.
- Use proper quantities of cool, clean, and dry lubricant with the required viscosity.

d. Micropitting. Micropitting occurs on surface-hardened gears and is characterized by extremely small pits approximately 10 μm (400 μ-inches) deep. Micropitted metal has a frosted or a gray appearance. This condition generally appears on rough surfaces and is exacerbated by use of low viscosity lubricants. Slow speed gears are also prone to micropitting due to thin lubricant films. Micropitting may be sporadic and may stop when good lubrication conditions are restored following run-in. Properly maintaining an adequate lubricant film thickness is the most important factor influencing the formation of micropitting. Higher speed operation and smooth gear tooth surfaces also hinder formation of micropitting. The following guidelines should be observed to reduce the onset of micropitting in gear units:

- Use gears with smooth tooth surfaces produced by careful grinding or honing.
- Use the correct amount of cool, clean, and dry lubricant with the highest viscosity permissible for the application.
- Use high speeds, if possible.
- Use carburized steel with proper carbon content in the surface layers.

e. Wear. The amount of wear that is acceptable depends on the expected life, noise, and vibration of the gear units. Excessive wear is characterized by loss of tooth profile, which results in high loading and loss of tooth thickness, which may cause bending fatigue. New gears contain surface imperfections or roughnesses that are inherent to the manufacturing process. During the initial run-in period, these imperfections are reduced through wear. Smoothing of the gear surfaces is to be expected. Mild wear will occur even when adequate lubrication is provided, but this wear is limited to the oxide layer of the gear teeth. Mild wear is beneficial because it increases the contact areas and equalizes the load pressures on gear tooth surfaces. Furthermore, the smooth gear surfaces increase the film thickness and improve lubrication.

(1) The amount of wear that is acceptable depends on the expected life, noise, and vibration of the gear units. Excessive wear is characterized by loss of tooth profile, which results in high loading and loss of tooth thickness, which may cause bending fatigue.

(2) Wear cannot be completely eliminated. Speed, lubricant viscosity, and temperature impose practical limits on gear operating conditions. Gears that are highly loaded, operate at slow speeds, i.e., less than 100 ft/min (30 m/min), and rely on boundary lubrication are particularly subject to excessive wear. Slow speed adhesive wear is highly dependent on lubricant viscosity. Higher lubricant viscosities provide significant wear reduction, but viscosities must be carefully selected to prevent overheating.

(3) The following guidelines should be observed to minimize the onset of adhesive wear in gear units:

- Ensure that gear teeth have smooth surfaces.
- If possible, restrict the run-in period for new gear units to one-half load for the first hours of operation.
- Use the highest speeds possible. High load, slow speed gears generally operate in the boundary lubrication region and are especially prone to excessive wear. For these applications, nitrided gears should be specified and EP additives used for the lubricant.
- Avoid using lubricants with sulfur-phosphorus additives for very slow speed gears (less10 ft/min [than 3 m/min]).
- Use the required quantity of cool, clean, and dry lubricant at the highest viscosity permissible.

f. Abrasion. Abrasive wear is caused by particle contaminants in the lubricant. Particles may originate internally due to poor quality control during the manufacturing process. Particles also may be introduced from the outside during servicing or through inadequate filters, breathers, or seals. Internally generated particles are particularly destructive because they may become work-hardened during compression between the gear teeth. The following guidelines should be observed to prevent abrasive wear in gear units:

- Remove internal contamination from new gearboxes. Drain and flush the lubricant before initial startup and again after 50 hours of operation. Refill with the manufacturer's recommended lubricant. Install new filters or breathers.

- Use surface-hardened gear teeth, smooth tooth surfaces, and high viscosity lubricants.
- Maintain oiltight seals and use filtered breather vents, preferably located in clean, nonpressurized areas.
- Use good housekeeping procedures.
- Use fine filtration for circulating oil systems. Filtration to 3 μm (120 μ-in.) has proven effective in prolonging gear life.
- Unless otherwise recommended by the gear manufacturer, change the lubricant in oil bath systems at least every 2500 hours or every 6 months.
- When warranted by the nature of the application, conduct laboratory analysis of lubricants. Analysis may include spectrographic, ferrographic, acid number, viscosity, and water content.

g. Polishing. Polishing wear is characterized by a mirror-like finish of the gear teeth. Polishing is caused by antiscuff additives that are too chemically reactive. An excessive reaction rate, coupled with continuous removal of surface films by very fine abrasive particles in the lubricant, may result in excessive polishing wear. The following guidelines should be observed to prevent polishing wear in gearsets:

- Use less chemically active antiscuff additives such as borate.
- Remove abrasives from the lubricant by using fine filtration or by frequent oil changes.

h. Scuffing. The terms scuffing and scoring are frequently interchanged. The following definitions are provided to assist in correctly ascertaining the type of damage observed. The ASM Handbook Volume 18 defines scuffing as localized damage caused by the occurrence of solid-phase welding between sliding surfaces. It defines scoring as the formation of severe scratches in the direction of sliding. The handbook also stipulates that scoring may be caused by local solid-phase welding or abrasion, but suggests that minor scoring be considered as scratching. Gear scuffing is characterized by material transfer between sliding tooth surfaces. Generally this condition occurs when inadequate lubrication film thickness permits metal-to-metal contact between gear teeth. Without lubrication, direct metal contact removes the protective oxide layer on the gear metal, and the excessive heat generated by friction welds the surfaces at the contact points. As the gears separate, metal is torn and transferred between the teeth. Scuffing is most likely to occur in new gear sets during the running-in period because the gear teeth have not sufficient operating time to develop smooth surfaces.

i. Critical Scuffing Temperature. Research has shown that, for a given mineral oil without antiscuffing or extreme pressure additives, there is a critical scuffing temperature that is constant regardless of operating conditions. Evidence indicates that, beyond the critical temperature, scuffing will occur. Therefore, the critical temperature concept provides a useful method for predicting the onset of scuffing. The critical scuffing temperature is a function of the gear bulk temperature and the flash temperature and is expressed as:

$$Tc = Tb + Tf \qquad (14\text{-}1)$$

Where the bulk temperature Tb is the equilibrium temperature of the gears before meshing and the flash temperature Tf is the instantaneous temperature rise caused by the local frictional heat at the gear teeth meshing point. The critical scuffing temperature for mineral oils without antiscuffing or extreme pressure additives increases directly with viscosity and varies from 300 to 570 °F (150 to 300 °C). However, this increased scuffing resistance appears to be directly attributed to differences in chemical composition and only indirectly to the beneficial effects of increased film thickness associated with higher viscosity. Examination of the critical temperature equation indicates that scuffing can be controlled by lowering either of the two contributing factors. The bulk temperature can be controlled by selecting gear geometry and design for the intended application. The flash temperature can be controlled indirectly by gear tooth smoothness and through lubricant viscosity. Smooth gear tooth surfaces produce less friction and heat while increased viscosity provides greater film thickness, which also reduces frictional heat and results in a lower flash temperature. Furthermore, judicious application of lubricant can cool the gears by removing heat.

(1) For synthetics and lubricants containing antiscuff additives, the critical temperature depends on the operating conditions and must be determined experimentally for each case. Antiscuff additives commonly used are iron sulfide and iron phosphate. These additives react chemically with the protected metal gear surface to form very strong solid films that prevent metal contact under extreme pressure and temperature conditions. As previously noted in the discussions of oil additives, the beneficial effects of extreme pressure additives are enhanced as the temperature increases.

(2) The following guidelines should be observed to prevent scuffing in gear units:

- Specify smooth tooth surfaces produced by careful grinding or honing.
- Protect gear teeth during the running-in period by coating them with iron-manganese phosphate or plating them with copper or silver. During the first 10 hours of run-in, new gears should be operated at one-half load.
- Use high viscosity lubricants with antiscuff additives such as sulfur, phosphorus, or borate.
- Make sure the gear teeth are cooled by supplying adequate amount of cool lubricant. For circulating oil systems, use a heat exchanger to cool the lubricant.
- Optimize the gear tooth geometry. Use small teeth, addendum modification, and profile modification.
- Use accurate gear teeth, rigid gear mountings, and good helix alignment.
- Use nitrided steels for maximum scuffing resistance. Do not use stainless steel or aluminum for gears if there is a risk of scuffing.

14-4. <u>Gear Lubrication</u>. The most important property for an oil used to lubricate enclosed gears or gearboxes is correct viscosity. The major variable in viscosity selection is the speed of the gears expressed in pitch line velocity, which is defined as speed of the gear in rpm times the circular pitch diameter in inches. The AGMA publishes viscosity recommendations based on pitch line velocity. AGMA 9005, Appendix B provides charts on viscosity versus pitchline velocity. 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. The following characteristics are applicable to all gear lubricants. The lubrication requirements for specific gears follow this general discussion.

a. Viscosity. Good viscosity is essential to ensure cushioning and quiet operation. An oil viscosity that is too high will result in excess friction and degradation of oil properties associated with high oil operating temperature. In cold climates, gear lubricants should flow easily at low temperature. Gear oils should have a minimum pour point of 9 °F (5 °C) lower than the lowest expected temperature. The pour point for mineral gear oil is typically 20 °F (–7 °C). When lower pour points are required, synthetic gear oils with pour points of –40 °F (–40 °C) may be necessary. The following equation from the ASM Handbook provides a method for verifying the required viscosity for a specific gear based on the operating velocity:

Where:

v = pitch line velocity (ft/min) given by:

$$V=0.262nd \tag{14-2}$$

where n is the pinion speed in rev/min and d is the pitch diameter (inches).

b. Film strength. Good film strength helps prevent metal contact and scoring between the gear teeth.

c. Lubricity (Oiliness). Lubricity is necessary to reduce friction.

d. Adhesion. Helps prevent loss of lubrication due to throw-off associated with gravity or centrifugal force especially at high speeds.

e. Gear speed. The now superseded Industrial Gear Lubrication Standards, AGMA 250.04, used center distance as the primary criterion for gear lubricant selection. The new version of this standard, designated AGMA 9005-E02, *Industrial Gear Lubrication*, has adopted pitch line velocity as the primary selection criterion. As noted above, gear speed is a factor in the selection of proper oil viscosity. The pitch line velocity determines the contact time between gear teeth. High velocities are generally associated with light loads and very short contact times. For these applications, low viscosity oils are usually adequate. In contrast, low speeds are associated with high loads and long contact times. These conditions require higher viscosity oils. EP additives may be required if the loads are very high.

f. Temperature. Ambient and operating temperatures also determine the selection of gear lubricants. Normal gear oil operating temperature ranges from 90 to 100 °F (50 to 55 °C) above ambient. Oils operating at high temperature require good viscosity and high resistance to oxidation and foaming. Caution should be exercised whenever abnormally high temperatures are experienced. High operating temperatures are indicative of oils that are too viscous for the application, excess oil in the housing, or an overloaded condition. All of these conditions should be investigated to determine the cause and to then correct the condition. Oil for gears operating at low ambient temperatures must be able to flow easily and provide adequate viscosity. Therefore, these gear oils must possess high viscosity indices and low pour points.

g. Open Gears. In addition to the general requirements, lubrication for open gears must meet the following requirements:

- Drip resistance. Prevents loss of lubricant, especially at high temperatures, which reduces viscosity.
- Brittle resistance. Lubricant must be capable of resisting embrittlement, especially at very low temperatures.

h. Enclosed Gears. In addition to the general requirements, lubrication for enclosed gears must meet the following requirements:

- Chemical stability and oxidation resistance. Prevents thickening and formation of varnish or sludge. This requirement is especially significant in high speed gears because the oil is subjected to high operating oil and air temperatures. Oxidation stability of the lubricant is critical for gear reducers. Lubricants with low values of oxidation stability will oxide rapidly in the presence of water at high temperatures. When oil oxidizes, it may result in sludge accumulation in the gear reducer. The sludge may interfere with the cooling and lubrication. The oxidized oil will also cause corrosion.
- Extreme pressure protection. Provides additional galling and welding protection for heavily loaded gears when the lubricant film thickness fails. Extreme pressure lubricants are available for mild and severe (hypoid) lubricant applications.

i. Types of Gear Lubricants. For oil lubrication, refer to AGMA 9005-E02 for the specifications for the following lubricants.

(1) R&O oils. These petroleum-based oils are frequently referred to as R&O gear oils. R&O oils are the most common gear lubricants and have been formulated to include chemical additives that enhance their performance qualities. R&O lubricating oils have easy application properties for gear and bearings, good lubrication qualities, and adequate cooling qualities—and they are economical to use. Disadvantages include restriction to enclosed gear applications to prevent contamination.

(2) Compounded gear lubricants. These oils are a blend of petroleum-based oils with 3 to 10% fatty or synthetic fatty oils. They are particularly useful in worm gear drives. Except as noted in the AGMA applicable specifications, compounded oils should comply with the same specifications as R&O oils.

(3) Extreme pressure lubricants. These gear lubricants, commonly referred to as EP lubricants, are petroleum-based and specially formulated to include chemical additives such as sulfur-phosphorus or other similar materials capable of producing a film that provides extreme pressure and antiscuffing protection.

(4) Synthetic oils. Synthetic oils have the advantage of stable application over wide temperature range, good oxidation stability at high temperatures, high viscosity indices, and low volatility. Because gear oils must be changed periodically, the main disadvantage of synthetics is high cost, which can only be justified for applications at high temperature extremes where other lubricants fail. Another disadvantage of synthetics is possible incompatibility with seals and other lubricants. The equipment manufacturer should be consulted before using synthetic oils to ensure that exposed materials will not be damaged or warranties voided. Gear units should be flushed of all mineral oils before the filling with the final synthetic oil.

(5) Residual compounds. These are higher viscosity straight mineral or EP lubricants that are mixed with a diluent to facilitate application. Viscosities range from 1 to 3 sq in./s at 212 °F (400 to 2000 mm^2/s at100 °C) (cST at 212 °F [100 °C]) without diluent. Once applied, the diluent evaporates and leaves a heavy residual lubricant coating on the treated surface.

j. Special Compounds and Greases. These lubricants include special greases formulated for boundary lubricating conditions such as low speed, high-load applications where high film strength is required. These lubricants usually contain base oil, a thickener, and a solid lubricant such as molybdenum disulfide (MoS_2) or graphite. The gear manufacturer should be consulted before using grease. The primary disadvantage of using grease is that it accumulates foreign particles such as metal, dirt, and other loose materials that can cause significant damage if adequate maintenance is not provided. Grease also has a tendency to be squeezed out of the gear tooth meshing zone, and it does not provide satisfactory cooling.

k. Open Gear Lubricants (Oils). Oil lubrication is generally not used within USACE for open gear applications. Open gear oil lubricants are generally reserved for slow speed and low load conditions. Slow speed gears will generally operate in the boundary lubricating regime. Due to the open configuration, the lubricants must be viscous and adhesive to resist being thrown off the gear teeth surfaces. The disadvantages of these lubricants are similar to those noted above for grease.

l. Solid Lubricants. The solid lubricants most commonly used in gear trains are molybdenum disulfide, graphite, PTFE, and tungsten disulfide (WS_2). Because they are expensive to apply, use of these lubricants is reserved for special applications such as high and low temperature extremes where other lubricants fail to perform adequately.

m. Applications. Spur, helical, and bevel gears have similar load and speed characteristics, and similar requirements for antiscuffing and viscosity.

(1) Spur and helical gears. Spur and helical gears usually require mineral oils with R&O inhibitors. Low viscosity R&O oils, such as turbine oils, are commonly used in high speed, low-load gear units. For high speed, low-load gear applications, mineral oils without antiscuff/extreme pressure agents can be used successfully provided the oil viscosity is capable of maintaining the required film thickness. However, low speed gears are usually heavily loaded so antiscuff/extreme pressure agents are necessary to ensure adequate protection.

(2) Hypoid gears. Hypoid gears combine the rolling action and high tooth pressure of spiral bevel gears with the sliding action of worm gears. These severe operating conditions result in high load, high sliding speeds, and high friction. Therefore, hypoid gears are very susceptible to scuffing.

Mineral oils for this application must have high lubricity and high concentrations of antiscuffing/extreme pressure additives.

n. Worm Gears. Worm gears operate under high sliding velocity and moderate loads. The sliding action produces friction that produces higher operating temperatures than those that occur in other gear sets. Normal operating temperature for worm gears may rise to 93 °C (200 °F) and not be a cause for concern. Lubricants for worm gears must resist the thinning due to high temperatures and the wiping effect of sliding action, and they must provide adequate cooling. Mineral oils compounded with lubricity additives are recommended. Extreme pressure additives are usually not required for worm gears. However, when EP protection is required, the additive should be selected with caution to prevent damaging the bronze worm wheel.

o. Gear Combinations. Many applications use different gears in the same gear housing. For these applications, the lubricant must be suitable for the gears with the most demanding requirements. Generally, the other gears will operate satisfactorily with such high performance lubricants.

p. Gear Shaft Bearings. Gear shaft bearings are frequently lubricated by gear oil. In most instances, this condition is acceptable. Bearings in high speed, low-load applications may operate satisfactorily with the gear oil. However, low speed, heavily loaded gears usually require a heavy oil. For these conditions, a low viscosity EP oil may provide adequate lubrication for the gears and bearings. The low viscosity oil will adequately lubricate the bearings while the EP additive will protect the gear teeth from the effects of using a low viscosity oil.

14-5. <u>Applications</u>.

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. The nameplate data on the equipment will often 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/AGMA 9005-E02, *Industrial Gear Lubrication Standard*. Gear lubricants complying with AGMA are also suitable for drive unit bearings in contact with the gear lubricant. Table 14-1 lists common gear oils. Table 14-2 lists gear oil common viscosities. Note that the data in Table 14-2 incorporate the old AGMA system, which has been changed. New tables no longer include the AGMA number, but rather follow the new ISO viscosity classification. Many gearboxes still reflect the old system where viscosity grades were also expressed as a single digit number and the old system is still often used in designating lubrication requirements. Reference to manufacturer's data indicates that an AGMA 3 or 4 grade lubricant will cover most winter applications, and an AGMA 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 AGMA standards no longer recommend EP oils for worm gear drives. Instead, a compounded oil such as AGMA 7 Comp or 8 Comp should be used.

Table 14-1. Common Gear Oils for Gear Reducers.

The Most Common Gear Oils for Enclosed Reducer Gearboxes

Gear Type	ISO Viscosity Range	Oil Type
Spur, Helical, Herringbone	150-320	EP PAO, PAG
Bevel, Spiral Bevel	150-320	EP PAO, PAG
Worm	460-1000	Compounded PAO PAG
Hypoid	460	EP

Table 14-2. Gear Oil Viscosity Classification System.

R&O	Compounded	Extreme Pressure (EP)	Synthetic	AGMA #
32			32 S	0
46			46 S	1
68		68 EP	68 S	2
100		100 EP	100 S	3
150		150 EP	150 S	4
220		220 EP	220 S	5
320		320 EP	320 S	6
460	460 Comp	460 EP	460 S	7
680	680 Comp	680 EP	680 S	8
1000	1000 Comp	1000 EP	1000 S	9

Source: American Gear Manufacturers Association (AGMA)

c. The AGMA 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, AGMA 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.

d. Note that AGMA 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.

e. 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 in Chapter 16.

f. Corps of Engineers facilities should ensure that gear lubricants conforming to the Corps Guide Specification (CEGS) 33 45 00.00 10 are purchased and used for storm water pump gear reducer applications.

14-6. Gear Lubricant Maintenance.

a. Oil Testing. An oil sampling and testing program is recommended to analyze for contamination, viscosity, additive breakdown, and the presence of metallic wear particles. Values that fall out of acceptable ranges for any of these indicate the need for lubricant replacement. The presence of metallic wear particles also indicate the need to further inspect the gears for excessive wear.

b. Cleaning and Flushing Gearboxes. Gear reducer oil that is no longer usable as shown by testing or visual inspection must be replaced (Figure 14-8). At this time, a flushing procedure is recommended to clean the housing of solid contaminants. This flushing procedure can consist of spraying kerosene under pressure on the interior of the case to loosen all deposit. The kerosene is then thoroughly drained from the case. If the interior paint coating of the reducer is flaking and/or rust deposits have formed, a more thorough gear reducer rehabilitation is required consisting of a suitable surface preparation and repainting of the gear reducer interior.

Figure 14-8. Gear Reducer in Need of Cleaning and Flushing.

CHAPTER 15

Bearing Lubrication

15-1. General. Proper lubrication for rolling bearings is essential for reliable operation and long life. The lubricant provides a separating film between the bearing rolling elements, raceways, and cages to prevent metal-to-metal contact. By controlling surface contact, the lubricant is able to minimize the effect of surface contact, namely undesired friction that otherwise would generate excessive heat, metal fatigue, and wear. The lubricant must also prevent corrosion and contamination damage. Rolling element bearings are composed of two races separated by a group of rollers. The shape of these rollers determines the load a particular bearing can hold as well as the lubrication requirements. Bearings can be divided into two subgroups: plain bearings and rolling-contact bearings. Both have their place within USACE and within industry. Each type has some obvious advantages and disadvantages, but there are subtle properties as well that are often ignored. Each type of bearing can be found in multiple applications, and each can be lubricated with either oil or grease. Some specialty bearings are lubricated by water, and some are lubricated by air. Lubricants used in rolling element bearings should have the following characteristics:

- Ability to maintain a stable viscosity over a broad range of temperatures.
- Good film strength that can support loads.
- Stable structure that provides for long service life.
- Noncorrosive property and compatibility with adjacent components.
- Ability to provide a barrier against contaminant and moisture, yet not leak out of the bearing.

15-2. Plain Bearings. EM 1110-2-2610, *Mechanical and Electrical Design of Navigation Locks and Dams* (30 June 2013) also provides extensive discussion on bearing design. Per EM 1110-2-2610, plain bearings, also called sleeve bearings or bushings, should be designed for a maximum normal bearing pressure of 1000 psi (68.95 bar), except for bearings operating below 5 rpm. Plain bearings are typically designed for slower speeds than rolling-contact bearings. Grease grooves should be designed and incorporated into the bearings to provide redundant grease pathways. The pathways should be capable of delivering the grease around the entire circumference of the bearing and mating surface without relying on rotation of the components. Delivery of the grease through the pin to the bearing grease grooves in lieu of delivery through the bearing housing should be the preferred method where feasible. Plain bearings consist of two surfaces, one moving in relation to the other. Plain bearings can be the journal type, where both wear surfaces are cylindrical; thrust type, where there are two planar surfaces, one rotating on the other; and various types of sliding bearings where one surface slides in relation to the other. All depend on a lubricating film to reduce friction. Unless an oil pump is provided to generate the oil film, these bearings rely on shaft motion to generate a hydrodynamic oil wedge. Some advantages of plain bearings include:

- They have very high load-carrying capabilities.
- Their resistance to shock and vibration is greater than rolling-contact bearings.

- The hydrodynamic oil film produced by plain bearings damps vibration so less noise is transmitted.
- They are less sensitive to lubricant contamination than rolling-contact bearings.

a. Types of Plain Bearings.

(1) Journal (sleeve bearings). Journal or plain bearings consist of a shaft or journal that rotates freely in a supporting metal sleeve or shell. There are no rolling elements in these bearings. These are cylindrical with oil distributing or grease distributing grooves. The inner surface can be babbitt-lined, bronze-lined, or lined with other materials generally softer than the rotating journal. On horizontal shafts on motors and pumps, oil rings carry oil from the oil reservoir up to the bearing. In the case of very slow-moving shafts, the bearings may be called bushings. Low speed pins and bushings, which are used extensively in USACE, use a form of journal bearing in which the shaft or shell generally does not make a full rotation. This is typical of tainter gate trunnion bearings (Figure 15-1). The partial rotation at low speed, before typically reversing direction, sometimes does not allow for the formation of a full fluid film; thus metal-to-metal contact does occur within the bearing. Pins and bushings continually operate in the boundary lubrication regime. These types of bearings are typically lubricated with an EP grease to aid in supporting the load. Chapter 16 provides more discussion on tainter gate trunnion bearings.

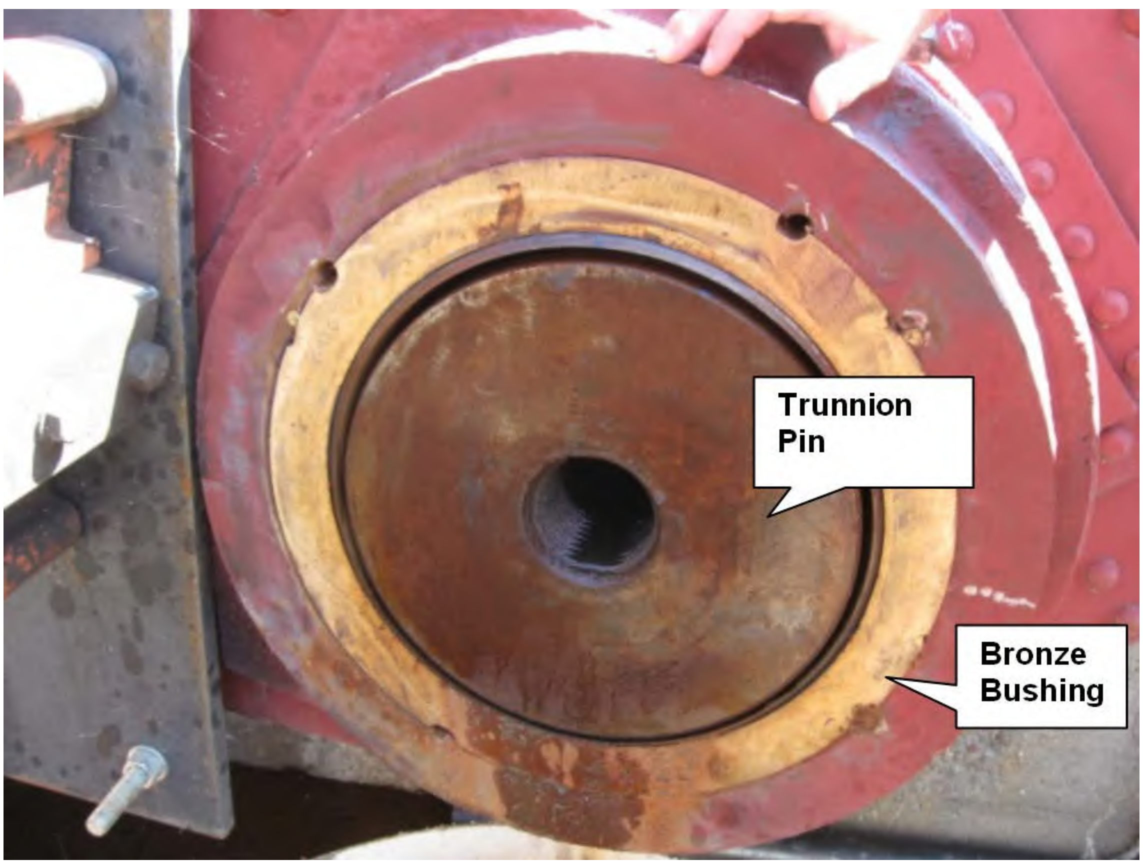

Figure 15-1. Tainter Gate Trunnion Bearing.

(2) Journal bearings (Figure 15-2) are meant to include sleeve, plain, shell, and babbitt bearings. The term “babbitt” actually refers to the layers of softer metals (lead, tin, and copper) that form the metal contact surface of the bearing shell. These softer metals overlay a stronger steel support shell and are needed to cushion the shell from the harder rotating shaft.

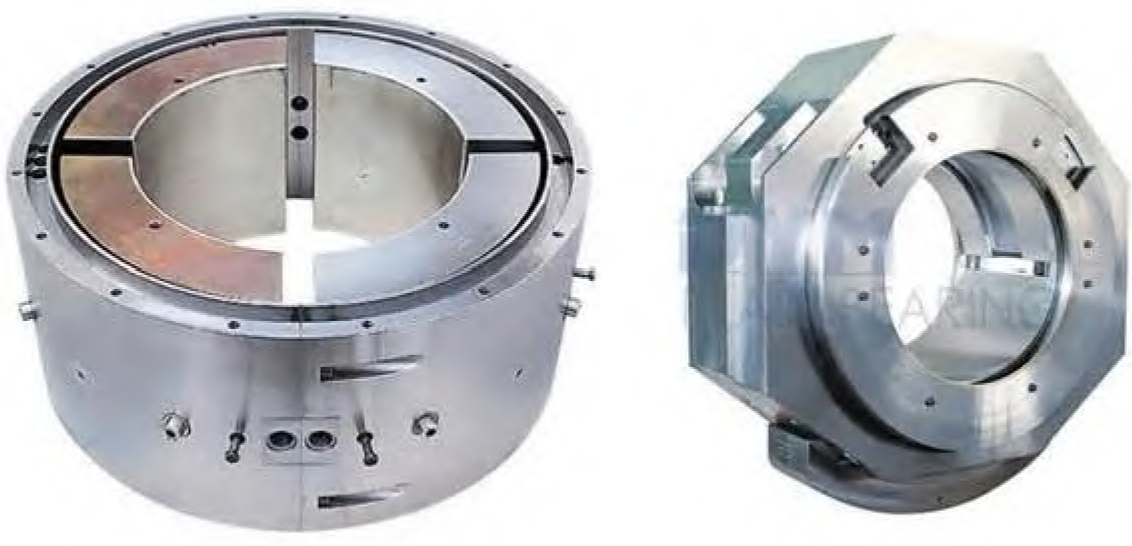

Figure 15-2. Typical Journal Bearings.

(3) The pressures encountered in the contact area of journal bearings are significantly less than those generated in rolling bearings. This is due to the larger contact area created by the conforming (similar curvature) surfaces of the journal and the shell. The mean pressure in the load zone of a journal bearing is determined by the force per unit area, or in this case, the weight or load supported by the bearing divided by the approximate load area of the bearing (the bearing diameter times the length of the bearing). In most industrial applications, these values range from 100 to 300 psi (6.89 to 20.7 bar).

(4) Oils are used in journal bearings when cooling is required or contaminants or debris need to be flushed away from the bearing. High speed journal bearings are always lubricated with oil rather than with grease. Oil is supplied to the bearing either by a pressurized oil pump system, an oil ring, a collar, or a wick. Grooves in the bearing shell (Figure 15-3) are used to distribute the oil throughout the bearings’ surfaces.

Figure 15-3. Typical Plain Bearing.

(5) Segmented journal. These are similar to the journal except that the stationary bearing consists of segments or bearing shoes. Each shoe is individually adjustable. This type of bearing is commonly found in vertical hydroturbine generators and large vertical pumping units. This bearing is usually partially immersed in an oil tub.

(6) Thrust bearings. These bearings (Figure 15-4) support axial loading and consist of a shaft collar supported by the thrust bearing, many times in segments called thrust shoes. The thrust shoes are sometimes allowed to pivot to accommodate the formation of the supporting oil wedges. These bearings, also called “tilting pad” or “pivoting shoe” bearings, consist of a shaft rotating within a shell made up of curved pads. Each pad is able to pivot independently and align with the curvature of the shaft. There are many different configurations of the thrust bearing aimed at equalizing loading and oil wedges. The bearing is immersed in a tub of oil. On large hydroturbine generators and pumps an oil pump is sometimes used to provide an oil film at startup.

Figure 15-4. Radial and Thrust Bearing (Courtesy of Kingsbury Bearings).

(7) Self-lubricated bearings. Chapter 12 provides discussion on self-lubricated bearings. These are journal (sleeve) bearings in which the bearing surface contains a lubricant, usually

solid, that is liberated or activated by friction in the bearing. This type of bearing is gaining popularity as a tainter gate trunnion bearing, wicket gate bearing, or wicket gate linkage bushing.

b. Plain Bearing Lubrication Selection. The most common lubricants for plain bearings are mineral and synthetic oils and greases. Mineral oils are generally used except in extreme hot and cold temperature applications where synthetics provide superior performance. Oil is used for faster rotational speeds where the hydrodynamic oil wedge can be formed and maintained. It is also used in high temperature conditions where grease may melt or degrade. Grease is used for slower rotational speeds or oscillating movements where the hydrodynamic oil wedge cannot form. It is also used in cases of extreme loading where the bearing operates in boundary conditions. Table 15-1 lists some of the important considerations regarding lubricant selection. Generally, oil additives other than extreme pressure additives are not required in plain bearing applications. Some additives and contaminants may cause corrosion so caution should be exercised when using bearing lubricants containing additives or when contaminants may be present.

Table 15-1. Choice of Lubricant.

Lubricant	Operating Range	Remarks
Mineral oils	All conditions of load and speed	Wide range of viscosities available. Potential corrosion problems with certain additive oils (e.g., extreme pressure) (see Table 5-2).
Synthetic oils	All conditions if suitable viscosity available	Good high- and low temperature properties. Costly.
Greases	Use restricted to operating speeds below 3.28 to 6.56 fps (1 to 2 m/s)	Good where sealing against dirt and moisture is necessary and where motion is intermittent.
Process fluids	Depends on properties of fluid	May be necessary to avoid contamination of food products, chemicals, etc. Special attention to design and selection of bearing materials.
Reference: Neale, M.J. 1995. *A Tribology Handbook*. Butterworth-Heinemann Ltd., Oxford, England.		

c. For hydrodynamic bearings to operate safely and efficiently, a suitable lubricant must always be present at the collar and journal surfaces. The lubricant needs to be cooled to remove the heat generated from oil shear, before re-entering the bearing. It must also be warm enough to flow freely, and filtered so that the average particle size is less than the minimum film thickness. Various methods are applied to provide lubricant to the bearing surfaces. The bearing cavities can be flooded with oil such as vertical bearings that sit in an oil bath. The bearings can also be provided with pressurized oil from an external lubricating system. For high speed bearings, the frictional losses from oil shear and other parasitic losses begin to increase exponentially as the surface speed enters a turbulent regime. The amount of lubricant required increases proportionately.

15-3. Rolling-Contact Bearings. These are also referred to as antifriction bearings. EM 1110-2-2610. *Mechanical and Electrical Design of Navigation Locks and Dams* (30 June 2013) also discusses these bearing types. Ball, roller, tapered roller, and spherical roller bearings should be selected in accordance with the manufacturer's published catalog ratings of the group, type, and size required. The manufacturer's ratings for loads and speeds shall be used in determining the bearing capacity. Service and installation factors shall be in accordance with the bearing manufacturer's recommendations. Certain bearing types, such as spherical roller bearings, toroidal roller bearings, tapered roller bearings, and spherical roller thrust bearings, typically have a higher operating temperature than other bearing types such as ball bearings and cylindrical roller bearings, under comparable operating conditions. All bearings shall be equipped with labyrinth seals to exclude foreign matter and retain lubrication without leakage under both static and dynamic operating conditions. In rolling-contact bearings, the lubricant film is replaced by several small rolling elements between an inner and outer ring (Figure 15-5). In most cases, the rolling elements are separated from each other by cages. Basic varieties of rolling-contact bearings include ball, roller, and thrust. Advantages of rolling-contact bearings include:

- At low speeds, ball and roller bearings produce much less friction than plain bearings.
- Certain types of rolling-contact bearings can support both radial and thrust loading simultaneously.
- Rolling bearings can operate with small amounts of lubricant.
- Rolling-contact bearings are relatively insensitive to lubricant viscosity.
- Rolling-contact bearings have low wear rates and require little maintenance.

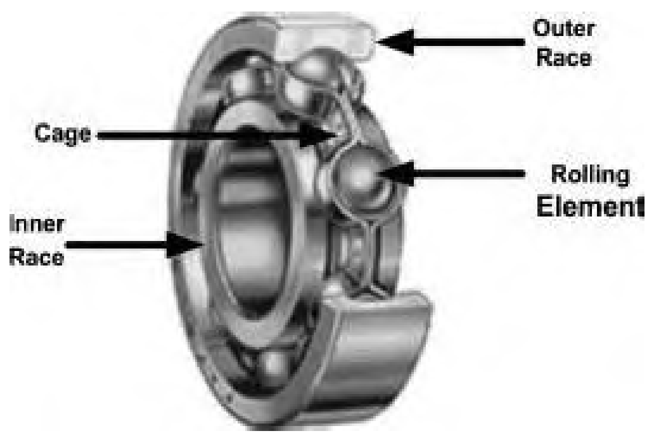

Figure 15-5. Typical Rolling Element Bearing.

a. Types of Rolling-Contact Bearings.

(1) Ball bearing. This bearing has spherical rolling elements in a variety of configurations. It is able to carry both radial and moderate axial loads. A special type, called maximum-type ball bearings, can take an extra 30% radial load, but cannot support axial loads.

(2) Roller bearing. The roller bearing has cylindrical rolling elements and can take much higher radial loads than ball bearings, but can carry no axial loads.

(3) Tapered roller bearing. This type has truncated-cone-shaped rolling elements and is used for very high radial and thrust loads.

(4) Double row spherical. The bearing has a double row of keg-shaped elements. The inner surface of the outer race describes part of a sphere. This bearing can handle thrust in both directions and very high radial loads.

(5) Ball thrust. This type has ball elements between grooved top and bottom races.

(6) Straight roller thrust. This bearing has short segments of cylindrical rollers between upper and lower races. The rollers are short to minimize skidding.

(7) Spherical thrust. This type is also called a tapered roller thrust bearing. The lower race describes part of a sphere. The rolling elements are barrel-shaped and the outside has a larger diameter than the inside. Spherical roller bearings are very similar to cylindrical roller elements with one exception — they are rounded around their midsection. Instead of being a perfect cylinder, spherical roller bearings are rounded so the sides of the cylinder are no longer parallel to each other. This gives them more surface area in contact with the race than a cylindrical element of the same length.

(8) Needle bearing. These bearings have rollers the lengths of which are at least four times their diameter. They are used where space is a factor and are available with or without an inner race. The elements are perfect cylinders, but are stretched to the point that they resemble needles. Although small in diameter, they make up for the surface area in the length they span.

b. Rolling-Contact Conditions. The loads carried by the rolling elements actually cause elastic deformation of the element and race as rotation occurs. The compressive contact between curved bodies results in maximum stresses (called Hertzian contact stresses) occurring inside the metal under the surfaces involved. The repeated stress cycling causes fatigue in the most highly stressed metal. As a result, normal wear of rolling-contact bearings appears as flaking of the surfaces. Lubrication carries away the excessive heat generated by the repeated stress cycles. While lubrication is necessary, too much lubrication, especially with grease lubrication, results in churning action and heating due to fluid friction.

c. Rolling Bearing Lubricant Selection. In most cases, the lubricant type is dictated by the bearing or equipment manufacturer. In practice, there can be significant overlap in applying grease or oil to the same bearing. Often the operating environment dictates the choice of lubricant. For example, a roller bearing on an output shaft of a gearbox will probably be oil-lubricated because it is contained in an oil environment. However, the same bearing with the same rotational speed and loading would be grease-lubricated in a pillow block arrangement. Table 15-2 lists general guidance for choosing the proper lubricant.

Table 15-2. General Guide for Choosing Between Grease and Oil Lubrication.

Factor Affecting the Choice	Use Grease	Use Oil
Temperature	Up to 248 °F (120 °C) - with special greases or short relubrication intervals up to 392/428 °F (200/220 °C)	Up to bulk oil temperature of 194 °F (90 °C) or bearing temperature of 428 °F (200 °C) - These temperatures may be exceeded with special oils.
Speed factor*	Up to *dn* factors of 300,000/350,000 (depending on design)	Up to *dn* factors of 450,000/500,000 (depending on type of bearing)
Load	Low to moderate	All loads up to maximum
Bearing design	Not for asymmetrical spherical roller thrust bearings	All types
Housing design	Relatively simple	More complex seals and feeding devices necessary
Long periods without attention	Yes, depending on operating conditions, especially temperature	No
Central oil supply for other machine elements	No, cannot transfer heat efficiently or operate hydraulic systems	Yes
Lowest torque	When properly packed can be lower than oil on which the grease is based	For lowest torques, use a circulating system with scavenge pumps or oil mist
Dirty conditions	Yes, proper design prevents entry of contaminants	Yes, if circulating system with filtration

* *dn* factor (bearing bore (mm) x speed (rev/min)).
Note: For large bearings (0.65-mm bore) and nd_m (d_m is the arithmetic mean of outer diameter and bore (mm)).
(Reference: Neale, M.J. 1995. *A Tribology Handbook*. Butterworth-Heinemann Ltd., Oxford, England.

15-4. Grease Selection for Bearings. Grease has become a common lubricant choice for rolling element bearings. Grease is easy to apply, can be retained within a bearing's housing and offers protective sealing capabilities.The lubricating properties of greases are significantly affected by the base oil and type of thickeners used. Table 15-4 at the end of this chapter provides general guidelines for selecting the type of grease for bearing lubrications. The temperature range over which a grease can be used depends largely on the type of base oil and thickener as well as the additives. There is both a high temperature limit and a low temperature limit for bearing grease application. Compared to oil, the advantage is that grease is more easily retained in the bearing arrangement, particularly where shafts are inclined or vertical.

a. Grease is used for slower rotational speeds, lower temperatures, and low to medium loads. Grease is used in situations where maintenance is more difficult or irregularly scheduled. It can be used in dirty environments if seals are provided. Grease has the ability to slow the ingress of contaminants into a bearing and can fill the cavities between bearing components. Bearings not sealed for life or factory-filled should be filled with grease with sufficient free space in the housing (up to 50%) to allow room for the excess grease to be ejected from the bearing during startup. Filling the bearing with grease should be one of the last operations completed when mounting a replacement bearing to ensure cleanliness and minimum contamination.

b. Sodium, lithium, and polyurea base greases are normally preferred for general purpose bearing lubrication. Lime base greases are advantageous for high moisture applications, but should not be operated above 150 °F (66 °C). Lithium complex greases have good water resistant characteristics and may be operated through the same temperature range as sodium base greases. Polyurea greases have excellent water resistance and can be used at higher temperatures.

c. Determining an application's grease relubrication intervals will hinge on the influencing conditions, such as temperature, speed, load, bearing arrangement, and type. Environmental considerations can also prompt an increase in relubrication frequency. In applications where manual lubrication is selected, users should confirm that the lubrication fitting is clean, the right type of lubricant is used and the correct quantity of lubricant supply is set. Grease cleanliness is as important as the proper amount. Extra caution should be given to assure contaminant free relubrication. If contaminated grease is placed into a system, it can potentially cause more damage than a lack of lubrication altogether. Pumping new grease into a system can also help purge some of the old grease in a bearing. Over time, the lubricant in a bearing arrangement will naturally lose its lubricating properties. This underscores the necessity for careful attention to original lubricant selection and indicates advantages in partnering with knowledgeable and experienced suppliers from the start.

d. Antifriction Bearings. The most common problem with the grease lubrication of antifriction bearings is overlubrication. Excess grease will churn within the bearing housing and cause excessive heat, which can soften the grease, reducing its effectiveness and leading to bearing damage. The heat can also cause the grease to expand, increasing the temperature further, and creating enough pressure to damage the bearing seals.

(1) Ideally, a grease-lubricated antifriction bearing should be "packed" by hand so that the bearing housing is approximately one-third full of grease. The bearing housing should be opened, the bearing and all of the old grease removed, and the bearing and the housing thoroughly cleaned. Compressed air should not be used for cleaning or drying the bearing because moisture in the air may induce corrosion in the highly polished bearing surfaces. When clean, the bearing should be thoroughly packed in new grease and the bearing housing filled one-third full of grease.

(2) It is not always practical or possible to hand pack a bearing. In these cases, grease guns or other high pressure devices may be used. Caution should be exercised when using high pressure systems to prevent overgreasing or creating excess pressure in the bearing housing. When grease is applied using a grease gun, the relief plug, if so equipped, should be removed so that, as the new grease is applied, all the old grease is purged from the bearing housing. The machine should be

operated approximately 30 minutes before the plug is replaced to allow excess grease to escape. If the bearing housing does not have a relief plug, grease should be added very infrequently to prevent over greasing, and after grease is added, the pressure fitting, or "zerk," should be removed to prevent pressure retention.

e. Grease-lubricated bushings or journal bearings are not as sensitive to over lubrication as antifriction bearings so "hand packing" is not usually necessary. The most common method of applying grease to a journal bearing is by a high pressure system. This may be a centralized, automatic system, as is used on turbine wicket gates, or it may be a simple grease gun. Over greasing with a high pressure system will not normally damage a journal bearing, but it can damage seals, waste grease, and cause a mess. The most common problem encountered with centralized greasing systems is plugging of the lines. All points that are to be lubricated should be checked regularly to ensure they are receiving grease. If clogging of the lines is a persistent problem, switching to a grease with a lighter consistency or less adhesiveness, or adjusting the cycle frequency and the volume of grease per cycle may be necessary.

15-5. Oil Selection for Bearings.

a. Oil is used for higher rotational speeds and higher operating temperatures. It is often used in drive trains and gearboxes. It is used in maximum loading situations and for bearing configurations where a high amount of heat generated in the bearing can be carried away by the oil. Unlike grease, it can be filtered and is used in dirty conditions when the oil is circulated and filtered. Oil is also used for lubrication where the adjacent components (like gear boxes) are lubricated with oil. For moderate speeds, the following viscosities are recommended. The manufacturer of the bearing should always make the final recommendation.

- Ball and cylindrical roller bearings 12 cSt (12 mm^2/s).
- Spherical roller bearings 20 cSt (20 mm^2/s).
- Spherical roller thrust bearings 32 cSt (32 mm^2/s).

b. In general, oils will be the medium to high viscosity index type with R&O inhibitors. EP oils are required for taper-roller or spherical roller bearings when operating under heavy loads or shock conditions. Occasionally EP oils may be required by other equipment or system components.

c. The *Tribology Handbook* (Neale 1995), *Noria Practical Handbook of Machinery Lubrication* (Noria 2011), and the *Machinery's Handbook*, 29th ed. (Oberg et al. 2012) provide a means for selecting bearing oil lubricant viscosity based on the bearing operating temperature, bore diameter, and speed. Bearing manufacturers also provide this information. Table 15-3 lists some of the methods used to supply lubricants to bearings. The lubricant should be supplied at a rate that will limit the temperature rise of the bearing to 68 °F (20 °C).

Table 15-3. Methods of Liquid Lubricant Supply.

Method of Supply	**Main Characteristics**	**Examples**
Hand oiling	Nonautomatic, irregular. Low initial cost. High maintenance cost.	Low speed, cheap journal bearings
Drip and wick feed	Nonautomatic, adjustable. Moderately efficient. Cheap.	Journals in some machine tools, axles
Ring and collar feed	Automatic, reliable. Efficient, fairly cheap. Mainly horizontal bearings.	Journals in pumps, blowers, large electric motors
Bath and splash lubrication	Automatic, reliable, efficient. Oiltight housing required. High initial cost.	Thrust bearings, bath only. Engines, process machinery, general
Pressure feed	Automatic. Positive and adjustable. Reliable and efficient. High initial cost.	High speed and heavily loaded journal and thrust bearings in machine tools, engines, and compressors
Notes: Pressure oil feed: This is usually necessary when the heat dissipation of the bearing housing and its surroundings are not sufficient to restrict its temperature rise to 68 °F (20 °C) or less. Journal bearings: Oil must be introduced by means of oil grooves in the bearing housing. Thrust bearings: These must be lubricated by oil bath or by pressure feed from the center of the bearing. Cleanliness: Cleanliness of the oil supply is essential for satisfactory performance and long life. Reference: Neale, M.J. 1995. *A Tribology Handbook*. Butterworth-Heinemann Ltd., Oxford, England.		

d. There are several oil lubrication methods:

- Oil bath.
- Wick.
- Drip.
- Circulating oil.
- Oil jet.
- Oil-air.

(1) Oil bath. The simplest method of oil lubrication is the oil bath. The oil, which is picked up by the rotating components of the bearing, is distributed within the bearing and then flows back to a sump in the housing. The conventional oil bath system for lubricating bearings is satisfactory for low to moderately high speed applications. Typically, the oil level should almost reach the center of the lowest rolling element when the bearing is stationary. A greater amount of oil can cause churning, increase the fluid friction within the bearing, and result in excessive operating temperatures. Unless

the running level of the oil is known, oil level should be checked only when equipment is shut down as the running level can drop considerably below the static level depending on the speed of the application. Because speed, sealing effectiveness, temperature, and type of oil are factors that influence the refilling cycle, regular inspection is necessary to determine the frequency of refilling. Applications of this type generally employ sight gauges to facilitate inspection.

(2) Wick-feed lubrication. Wick-feed oilers, one of the older methods of applying oil to bearings, still enjoy a certain popularity. Properly designed, applied, and maintained, they are effective and inexpensive. Functioning as a filter and quantity regulator, the wick employs either capillary action, or gravity to transfer the oil from the reservoir to bearing. Paraffinic lubricating oils may also be used with this type oiler although they have a tendency to deposit wax crystals on the wick fibers, destroying the effectiveness of the wick. Because napathetic and synthetic oils do not exhibit this tendency, they are preferred for wick oilers.

(3) Drip-feed system. Another one of the older methods of lubrication of oiling bearings is the drip-feed system. This system has been applied successfully to applications where moderate loads and speeds are encountered. The oil introduced through a filter-type, sight feed oiler has a controllable flow rate that is determined by the operating temperature of the particular application.

(4) Oil splash lubrication. This system of lubrication is used primarily in gear boxes where the bearing and gear lubricant is common. The lubrication of bearings in a gearbox, other than one of slow speed, is usually not critical as the oil splash from gear teeth is sufficient to lubricate the bearings. Because of the constant problem of the oil carrying wear debris, the use of filters and magnetic drain plugs is helpful in reducing the possibility of wear debris contaminating the bearings. In applications where heavy oil flow or splash is encountered, bearings equipped with shields to reduce the quantity of oil reaching the bearings are sometimes necessary to prevent overheating caused by fluid friction where the bearing is flooded. In systems where normal splash or washdown is expected to be marginal, oil feeder trails should be designed into the case to direct case washdown into the bearings.

(5) Circulating oil lubrication. In general, high speed operation increases frictional heat, elevates operating temperatures, and accelerates aging of the oil. To reduce operating temperatures and avoid frequent oil changes, the circulating oil lubrication method is generally preferred. This type of system, which uses a circulating pump to assure a positive supply of lubricant to the bearing, can be used for low to moderately high speed and high temperature power transmission applications. The flow path of the oil in this system is important because bearing churning in a captive amount of oil can generate temperatures capable of causing lubricant breakdown and bearing damage. Due to the inherent possibility of contamination from wear debris in heavy duty applications, suitable oil filters and magnetic drain plugs are necessary to prevent damage to the bearings. After the oil has passed through the bearing, it generally settles in a tank where it is filtered and cooled before being returned to the bearing. Proper filtering decreases the contamination level and extends bearing service life. Cooling the oil can also significantly reduce the operating temperature of the bearing.

(6) Oil jet lubrication. The oil jet lubrication method is an extension of circulating oil systems. A jet of oil under high pressure is directed at the side of the bearing. The velocity of the oil jet should be sufficiently high (≥49.2 ft/s [15 m/s]) to penetrate the turbulence surrounding the rotating bearing. Oil jet lubrication is used for very high speed operation, where a sufficient, but not excessive, amount

of oil should be supplied to the bearing without increasing the operating temperature unnecessarily. In such cases, it is necessary to lubricate each bearing location individually, under pressure, and to provide adequately large scavenging drains to prevent the accumulation of oil after passage through the bearing. In certain high speed applications where the bearing itself creates a pumping action, the flow of oil must be adjusted to assure passage through the bearing. This is extremely important where the flow of oil from the jet opposes the pumping action within the bearing.

(7) Oil-air lubrication (oil mist lubrication). The oil-air or oil mist method, uses compressed air to transport small, accurately metered quantities of oil as small droplets along the inside of feed lines to an injector nozzle, where it is delivered to the bearing. This minimum quantity lubrication method enables bearings to operate at very high speeds with relatively low operating temperature. The compressed air serves to cool the bearing and also produces an excess pressure in the bearing housing to prevent contaminants from entering. Oil mist lubrication systems are used in high speed, continuous operation applications. This system permits close control of the amount of lubricant reaching the bearing. The oil may be metered, atomized by compressed air, and mixed with air, or it may be picked up from a reservoir using a venturi effect. In either case, the air is filtered and supplied under sufficient pressure to assure adequate lubrication of the bearings. Control of this type of lubricating system is accomplished by monitoring the operating temperatures of the bearings being lubricated. The continuous passage of the pressurized air and oil through the labyrinth seals used in the system prevents the entrance of contaminants from the atmosphere into the system. To ensure "wetting" of the bearings and to prevent possible damage to the rolling elements and races, it is imperative that the oil mist system be turned on for several minutes before the equipment is started. The importance of the "wetting" the bearings before starting cannot be overstressed and has particular significance for equipment that has been idle for extended periods of time. The successful operation of this type of system is based on the following factors:

- Proper location of the lubricant entry ports in relation to the bearings being lubricated.
- The proper air pressure and oil quantity ratios to suit the particular application.
- The adequate exhaust of the air-oil mist after lubrication has been accomplished.

e. Types of Oil Lubrication. Straight mineral oils are generally the favored lubricant for lubricating rolling bearings. Oils containing EP or antiwear (AW) additives to improve lubricant properties are generally used only in special cases. Synthetic versions of many of the popular lubricant classes are available. Synthetic oils are generally only considered for bearing lubrication in extreme cases, e.g., at very low or very high operating temperatures.

(1) The thickness of the hydrodynamic film, which prevents metal-to-metal contact in a bearing, plays a major role in bearing fatigue life. The thickness of the hydrodynamic film is determined, in part, by the viscosity index (VI) and the pressure-viscosity coefficient. For most mineral oil-based lubricants, the pressure-viscosity coefficient is similar, and generic values obtained from literature can be used. However, for synthetic oils, the effect on viscosity to increasing pressure is determined by the chemical structure of its base stock. As a result, there is considerable variation in pressure-viscosity coefficients for different types of synthetic base stocks. Due to the differences in the viscosity index and pressure-viscosity coefficient, it should be remembered that the formation of a hydrodynamic lubricant film, when using a synthetic oil, may differ from that of a mineral oil with the same viscosity. For additional information about synthetic oils, contact the lubricant supplier.

(2) In addition, additives play a role in the formation of a hydrodynamic film. Due to differences in solubility, different types of additives are used in synthetic oils that are not included in mineral oil-based lubricants.

(3) Selecting oil is primarily based on the viscosity required to form a sufficiently thick hydrodynamic film at normal operating temperature. The viscosity of oil is temperature dependent, becoming lower as the temperature rises. The viscosity-temperature relationship of an oil is characterized by the viscosity index (VI). For rolling bearings, oils with a viscosity index of at least 95 (little change with temperature) are recommended. To form a sufficiently thick oil film in the contact area between the rolling elements and raceways, the oil must retain a minimum viscosity at normal operating temperature.

15-6. Lubricant Selection, Viscosity, and Speed Considerations.

a. Friction between the lubricant and the bearing components is a function of the characteristics of the lubricant and the design of the bearing. All of these factors contribute significantly to the frictional resistance of the bearing and must be considered when selecting the proper lubricant. Of equal importance when selecting a lubricant for a specific application, are the actual operating conditions in addition to the bearing's characteristics. A shaft system consists of more than just bearings. Associated components like the shaft and housings are integral parts of the overall system. The lubricant and sealing elements also play a crucial role. To maximize bearing performance, the correct amount of an appropriate lubricant must be present to reduce friction in the bearing and protect it from corrosion. Sealing elements are important because they keep the lubricant in, and contaminants out, of the bearing cavity. This is particularly important since cleanliness has a profound effect on bearing service life. There are several factors that influence the selection of a lubricant for a bearing. This includes:

- Bearing speed.
- Bearing size.
- Type of bearing.
- Load.
- Low and high operating temperatures.
- Ambient conditions.
- How the lubricant will be applied.

b. As noted previously, the bearing speed will dictate whether a grease or oil-lubricated bearing will be necessary. Viscosity is the most critical lubricant property for ensuring adequate lubrication of plain bearings. If the viscosity is too high, the bearings will tend to overheat. If the viscosity is too low, the load-carrying capacity will be reduced. The viscosity grade required depends on bearing RPM, oil temperature, and load.

c. Journal Bearings. The required ISO grade number for journal bearings should be coordinated with the manufacturer based on specific application. The load, speed, and temperature range are necessary for proper bearing selection. ISO 68- and 100-Grade oils are commonly used in indoor, heated applications, with 32-Grade oils being used for high speed (10,000 RPM) units and some outdoor low temperature applications. The higher the bearing speed, the lower the oil viscosity that is required. The higher the operating temperature of the unit, the higher the oil viscosity that is required. If vibration or minor shock loading is possible, a higher grade of oil than the one indicated should be considered.

d. It is not the intent of this manual to provide specific design guidance for bearings. All the major bearing manufacturers (Timken, SKF, Kingsbury, etc.) provide detailed design guidance including selection charts for the proper viscosity of lubricating oil and grease. Some frequently used bearing terms are explained here. For a detailed collection of bearing-specific terms and definitions, refer to ISO 5593. Some specific information necessary to properly design rolling bearings include:

A = speed factor [mm/min] = n d_m.

C = bearing load rating [kN].

d_m = bearing mean diameter [mm] = 0.5 (d + D).

F = actual bearing load [kN].

L = life, typically in million revolutions or operating hours.

n = rotational speed [r/min].

P = equivalent bearing load [kN].

P_u = fatigue load limit [kN].

η_c = factor for contamination level.

κ = viscosity ratio: actual versus required.

ν = oil viscosity [mm^2/s].

e. The speed factor in mm/min (also referred to as speed index) is determined by multiplying the pitch diameter of the bearing by the bearing speed as follows:

$$A = n \frac{(D+d)}{2} \qquad (15\text{-}1)$$

where:

D = bearing diameter (mm)

d = the bore diameter (mm)

n = the speed in rev/min.

Speed factors above 200,000 are usually indicative of fluid film lubrication applications.

15-7. <u>Bearing Degradation</u>. Due to the elastohydrodynamic mode in which rolling bearings operate, these bearings are susceptible to water and particle contamination. Water, contaminants, and corrosion can all lead to bearing degradation. Studies have shown that the fatigue life of a bearing can be extended dramatically by reducing the amount of water contained in a petroleum-based lubricant.

a. Particle Contamination. Particle contamination can cause abrasion and surface fatigue in bearings. This greatly shortens the life of a bearing. Rolling elements undergo a lubrication regime known as elastohydrodynamic lubrication. In this regime, the fluid film is usually less than 1 micron, and undergo very high pressures. The oil momentarily turns into a solid and elastically deforms the rolling element and the mating surface. Any contamination can interfere with this process and cause bearing damage. Particles present in the load zone cause surface degradation of the mating surfaces and can lead to the generation of more wear particles. Bearings operating in a contaminated lubricant exhibit much higher levels of wear.

b. Water. Water has a significant effect on bearing life. One study conducted by Timken Bearing Company, "Effect of Water in Lubricating Oil on Bearing Fatigue Life," by Richard Cantley (1976), suggested the following: "The effect of water in an SAE 20 oil on tapered roller bearing fatigue life was evaluated. Full-scale bearing life tests were conducted with water concentrations of 25, 100, and 400 ppm. Good correlation was obtained between fatigue life and water content and the detrimental effects of water on fatigue life at these levels were clearly demonstrated. As a result of the fatigue life findings at the specified water concentrations, the water absorption properties of various oils were evaluated under controlled relative humidity conditions. These results indicated that a lubricant's capacity for water absorption represents an important factor that could significantly affect bearing fatigue life. The evaluation of a water-inhibiting additive was also included in this study." Other studies have shown an exponential drop in bearing life as water content rises from 200 ppm to 500 ppm.

c. Oxidation Resistance. From a quality standpoint, the most important property of an oil is its chemical or oxidation stability. All lubricating fluids are subject to a continual chemical combination with oxygen to form a multitude of compounds. Subsequently, through polymerization and condensation reactions, oil in soluble gum, sludge, and varnish will be formed. This can reduce bearing clearances, plug lines, increase operating temperature, and further accelerate lubricant deterioration, which will end with bearing failure. Lubricating fluids vary in ability to resist oxidation effects.

d. Oxidation stability depends on the fluid type, refining methods, and whether oxidation inhibitors are present. In a circulating or splash system, the oxidation rate is not only a function of the oil, but also of the operating conditions. Temperature, contaminants, water, metal surfaces, and agitation all favor oxidation and all are present in lubrication systems.

Table 15-4. Effect of Environmental Conditions on Choice of a Suitable Type of Grease.

NLGI		Speed Maximum (Percentage Recommended Maximum for Grease)	Environment	Typical Service Temperature				Base Oil Viscosity (approximate values)	Comments
				Maximum		Minimum			
Type of Grease	Grade No.			°C	°F	°C	°F		
Lithium	2	100	Wet or dry	100	210	-25	-13	Up to 140 cSt (140 mm²/s) at 100 °F (37.7 °C)	Multipurpose, not advised at max. speed or max. temperatures for bearings above 65-mm (2.5-in.) bore or on vertical shafts
		75		135	275				
Lithium	3	100	Wet or dry	100	210	-25	-13		
		75		135	275				
Lithium EP	1	75	Wet or dry	90	195	-15	5		Recommended for roll-neck bearings and heavily loaded taper-roller bearings
Lithium EP	2	100	Wet or dry	70	160			14.5 cSt (14.5 mm²/s) at 210 °F (98.8 °C)	
		75		90	195	-15	5		
Calcium (conventional)	1, 2, and 3	50	Wet or dry	60	140	-10	14	140 cSt (140 mm²/s) at 100 °F (37.7 °C)	
Calcium EP	1 and 2	50	Wet or dry	60	140	-5	25	14.5 cSt (14.5 mm²/s) at 210 °F (98.8 °C)	
Sodium (conventional)	3	75/100	Dry	80	175	-30	-22	30 cSt (30 mm²/s) at 100 °F (37.7 °C)	Sometimes contains 20% calcium
Clay		50	Wet or dry	200	390	10	50	550 cSt (550 mm²/s) at (100 °F 37.7 °C)	
Clay		100	Wet or dry	135	275	-30	-22	Up to 140 cSt (140 mm²/s) at 100 °F (37.7 °C)	
Clay		100	Wet or dry	120	248	-55	-67	12 cSt (12 mm²/s) at 100 °F (37.7 °C)	Based on SEs
Silicone/Lithium		75	Wet or dry	200	390	-40	-40	150 cSt (150 mm²/s) at 77 °F (25 °C)	Not advised for conditions where sliding occurs at high speed or load
Reference: Neale, M.J. 1995. *A Tribology Handbook*. Butterworth-Heinemann Ltd., Oxford, England.									

CHAPTER 16

Miscellaneous Lubrication Applications

16-1. 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 from manufacturer data and operation and maintenance manuals. The Bureau of Reclamation has also published a document outlining maintenance and service requirements (including lubrication requirements) of hydropower equipment and pumps. The document, FIST (Facilities Instructions, Standards, and Techniques) Volume 4-1A, *Maintenance Scheduling for Mechanical Equipment* is included in Appendix F. It states, "This document is intended to establish recommended practice as well as to give general advice and guidance in the maintenance of mechanical equipment owned and operated by the Bureau of Reclamation (Reclamation)." The American Society of Civil Engineers (ASCE) has published a book, *Water Control Gates – Guidelines for Inspection and Evaluation*. This book also provides specific inspection and maintenance requirements for a variety of gates including lubrication requirements. 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. Proper selection of a lubricant depends on an understanding of the lubricating regime (i.e., film, mixed, boundary), established conventions of classifications, and an ability to interpret and apply the producer's product data specifications to the equipment.

16-2. Stormwater Pumps and Motors. Stormwater 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 EM 1110-2-3102, *General Principles of Pumping Station Design and Layout* (28 February 1995) and EM 1110-2-3105, *Mechanical and Electrical Design of Pumping Stations* (30 November 1999. EM 1110-2-4205, *Hydroelectric Power Plants, Mechanical Design* (30 June 1995) provides lubrication requirements of hydropower equipment. Lubrication of pumping equipment should follow manufacturer recommendations. Many times the lubrication requirements for pumps are provided in the technical specifications. Detailed lubrication procedures should be provided in the operation and maintenance manuals.

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. R&O

turbine oil with viscosity of 32 cSt (32 mm^2/s) is a common lubricant. Automatic grease lubrication systems (Figure 16-1) are often used on larger vertical pumps (see below). These types of automatic lubrication systems are typically computer (Programmable Logic Controller [PLC]) controlled and provide specific metered amounts of grease to the pump bearings based on operating time.

Figure 16-1. Automatic Grease Lubrication System for a Vertical Pump.

(2) Large units with horizontal shafts use 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 startup. R&O turbine oil with viscosity of 32 cSt (32 mm^2/s) 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 that are 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 use rolling-contact bearings. The upper bearing is a combination of radial and thrust bearing. This is often 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 the 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 R&O turbine oil. For the greased bearings, a lithium-based grease designated NLGI 2 is the most common. The pump and motor manufacturer should provide the recommended oil and grease change intervals.

(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. See Chapter 15 for additional discussion on bearing lubrication.

16-3. Couplings. EM 1110-2-2610, *Mechanical and Electrical Design of Navigation Locks and Dams* (30 June 2013) provides additional discussion on coupling types and design. For new installations, the coupling manufacturer should always be consulted for the proper type of lubricant to use in the coupling. Couplings requiring lubrication are usually spring, chain, gear, or fluid drive type. Table 16-1 lists lubricant recommendations for couplings. Additional recommendations are provided below.

Table 16-1. Recommendations for the Lubrication of Gear, Spring-Type, Chain Couplings

	Limiting Criteria				
	Centrifugal Effects				
Lubricant Type	**Pitch Line Acceleration $d^2/2$ (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	25 max	—	2 years	Soft grease preferred to ensure
	0.5×10^3	25-80	—	12 months	Penetration of lubricant to gear teeth
No. 3 Grease (mineral oil base)	1.5×10^3	80-250	—	9 months	Limitation is loss of oil causing hardening of grease (No. 3 grease is more mechanically stable than No. 1)
	5.0×10^3	250-850	—	6 months	
	12.5×10^3	850-2000	—	3 months	
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
Notes: d = pcd, m; D = pcd, ft; 4> = rads/sec; n = rev/sec; P = hp transmitted Reference: Neale, M.J. 1995. *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 (Figure 16-2) 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 [198 mm^2/s] at 104 °F [40 °C]) 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):

$$n = \frac{200}{\sqrt{d}} \qquad (16\text{-}1)$$

Misalignment and torque are as described for normal conditions in (1) above. For these conditions, an NLGI No. 0 or No. 1 grease with a high viscosity base oil (higher than 198 cSt [198 mm^2/s] at 104 °F [40 °C]) should be used.

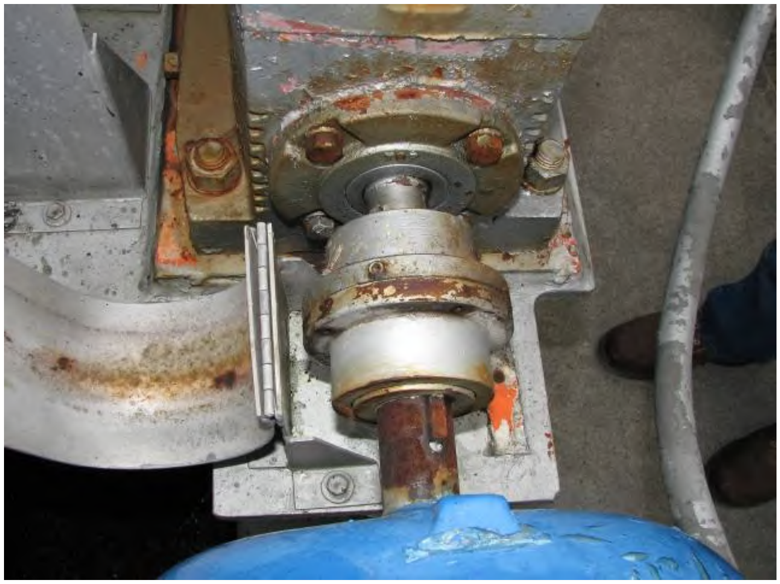

Figure 16-2. Gear Coupling with Grease Fitting.

(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 (212 °F [100 °C]), 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 302 °F (150 °C).

c. Oil-Lubricated Couplings. Most oil-filled couplings are the gear type. Use a high viscosity grade oil not less than 150 SUS at 100 °F (37.7 °C). For high speed applications, a viscosity of 2100 to 3600 SUS at 100 °F (37.7 °C) should be used.

16-4. Hoist and Cranes.

a. General. Various types of hoisting equipment (e.g., Figure 16-3) 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 AGMA requirements for gears discussed in Chapter 14. Hydraulic systems are discussed in Chapter 10. Lubrication of wire ropes and chains used in hoists and cranes is discussed later in this chapter.

Figure 16-3. Pedestal Mounted Crane for Lifting Bulkheads.

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, “Motor Vehicle Brake Fluids” (DOT 3). This includes a dry boiling temperature of 401 °F (205 °C). 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 450 °F (232 °C) dry boiling temperature and containing additional lubrication and anti-oxidation additives.

(b) 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 284 °F (140 °C). If water has separated out, the brake fluid will have a boiling temperature of 212 °F (100 °C). 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 yrs 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 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 1 gallon (3.79 L).

16-5. Wire Rope Lubrication.

a. Lubricant-Related Wear and Failure. Wear in wire ropes (Figure 16-4) 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. Wire rope lubricants have two principal functions. The first is to reduce friction as the individual wires move over each other. The second is to provide corrosion protection and lubrication in the core and inside wires, and on the exterior surfaces of the wire rope. The life of a wire rope can be extended through the proper application of the correct lubricant. Unless the rope is constructed of stainless steel, it is also subject to corrosion damage. Corrosion is especially a problem for wire ropes that are exposed to the elements and submerged in water. Additional information on wire rope selection, design, and lubrication can be found in EM 1110-2-3200, *Wire Rope Selection Criteria for Gate Operating Devices* (02 April 2004).

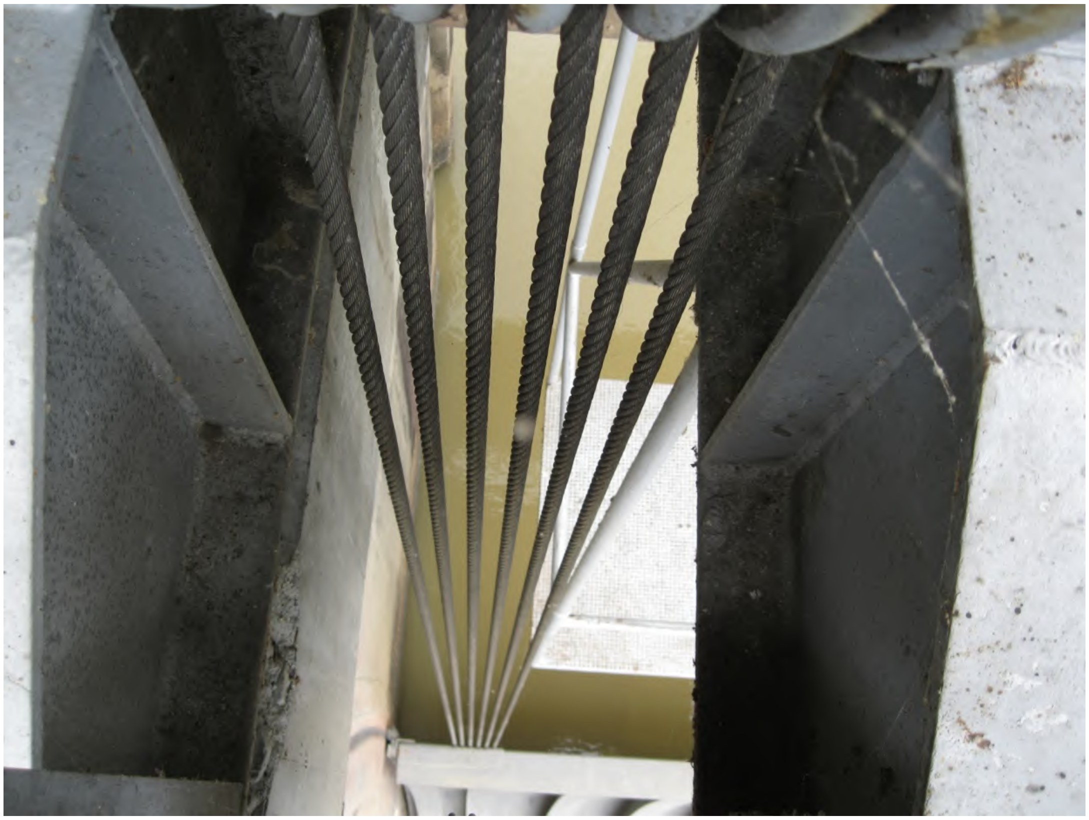

Figure 16-4. Wire Ropes for Lifting a Tainter Gate.

(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%) 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. See EM 1110-2-2610, *Mechanical and Electrical Design of Navigation Locks and Dams* (30 June 2013) for further discussion.

c. Lubricant Functions and Qualities. There are two types of wire rope lubricants, penetrating and coating. Penetrating lubricants contain a petroleum solvent that carries the lubricant into the core of the wire rope then evaporates, leaving behind a heavy lubricating film to protect and lubricate each strand. Coating lubricants penetrate slightly, sealing the outside of the cable from moisture and reducing wear and fretting corrosion from contact with external bodies. Some performance attributes to look for in a wire rope lubricant are wear resistance and corrosion prevention. Some useful performance benchmarks include high four-ball EP test values, such as a weld point (ASTM D2783) of above 350 kg and a load wear index of above 50. For corrosion protection, look for wire rope lubricants with salt spray (ASTM B117) resistance values above 60 hours and humidity cabinet (ASTM D1748) values of more than 60 days. To be effective, a wire rope lubricant should:

- Have a viscosity suitable to penetrate to the rope core for thorough lubrication of individual wires and strands.
- Lubricate the external surfaces to reduce friction between the rope and sheaves or drum.
- Form a seal to prevent loss of internal lubricant and moisture penetration.
- Protect the rope against external corrosion.
- Be free from acids and alkalis.
- Have enough adhesive strength to resist washout.
- Have high film strength.
- Not be soluble in the medium surrounding it under actual operating conditions.
- Not interfere with the visual inspection of the rope for broken wires or other damage.

(1) 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.

(2) Two types of lubricants are generally used: oils and adhesives (greases). 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.

(3) Heavy, adhesive lubricants or grease 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 160 to 200 °F (71 to 93 °C), 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. Various types of greases are used for wire rope lubrication. These coating types penetrate partially, but usually do not saturate the rope core. Common grease thickeners include sodium, lithium, lithium complex, and aluminum complex soaps. Greases used for this application generally have a soft semifluid consistency. They coat and achieve partial penetration if applied with pressure lubricators.

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

- Must not cake, gum, or ball up when contaminated with dust and dirt.
- Must not thin and drip at the highest operating temperature.
- Must not become brittle or chip at the lowest operating temperature.
- Should have inherently high viscosity without adding thickeners or fillers.

d. Lubrication Application.

(1) 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.

(2) Wire rope lubricants can be applied by brush, spray, drip, or preferably by passing the rope through a pressurized lubricator. Before application, the rope must be cleaned of any accumulated dirt, dust, or rust to ensure good penetration. See EM 1110-2-2610, *Mechanical and Electrical Design of Navigation Locks and Dams* (30 June 2013) for further discussion. 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 (Figure 16-5). 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. Pressure lubrication devices for wire rope are available. These can allow lubricant to be applied to the core of the wire rope. If a cable is dirty or has accumulated layers of hardened lubricant or other contaminants, it must be cleaned with a wire brush and petroleum solvent, compressed air, or steam cleaner before relubrication. The wire rope must then be dried and lubricated immediately to prevent rusting. Field lubricants can be applied by spray, brush, dip, drip, or pressure boot.

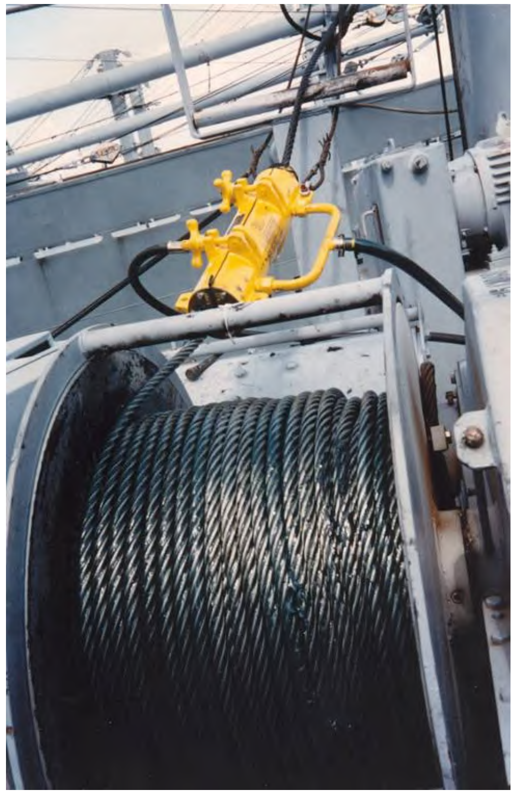

Figure 16-5. Wire Rope Lubricator.

e. 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. Table 16-2 lists these conditions. 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, 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.

Table 16-2. Lubrication of Wire Ropes in Service.

	Operating Conditions				
	(1)	(2)	(3)	(4)	(5)
Parameter	**Ropes working in industrial or Marine environments**	**Ropes subject to heavy wear**	**Ropes working over sheaves where (1) and (2) are not Critical**	**As (3) but for friction drive applications**	**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 preventive leaving a thin, semi-hard 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	• 6 monthly/2 yrs

* 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. 1995. *A Tribology Handbook*. Butterworth-Heinemann Ltd., Oxford, England.

(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 cause of rope deterioration and SAE 30 is 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.

(6) Lubrication of wire ropes in storage. Refer to EM 1110-2-3200,*Wire Rope Selection Criteria for Gate Operating Devices* (02 April 2004) for the storage requirements of wire rope. Wire ropes in long term storage need to be lubricated on a periodic basis.

16-6. <u>Chain Lubrication</u>.

a. Drive chains combine the flexibility of a belt drive with the positive action of a gear drive. Various designs are available the most common being link chain and roller chain. Link chain is the simplest and consists 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 (Figure 16-6) have several moving parts and, except for the self-lubricating type, require periodic lubrication. New roller chain design should be self-lubricated. This is discussed further in EM 1110-2-2610, *Mechanical and Electrical Design of Navigation Locks and Dams* (30 June 2013). The recommendation in EM 1110-2-2610 is to use stainless steel pins and aluminum bronze sidebars. However, many USACE sites have existing roller chain that must be maintained and lubricated. For existing roller chain, lubricants should be applied between the roller and links to ensure good penetration into the pins and inner bushing surfaces.

Figure 16-6. New Roller Chain Using Stainless Steel Pins and Aluminum Bronze Sidebars.

b. 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.

c. 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 a number of specific characteristics. It should:

- Have a viscosity that will enable it to penetrate into the link pins and bearings.
- Lubricate the external surfaces to reduce friction between the sliding link surfaces and chain sprockets.
- Form a seal to prevent moisture penetration.
- Protect the chain against corrosion.
- Be free of acids and alkalis.
- Resist washout.
- Have high film strength.
- Not be soluble in the medium surrounding it under actual operating conditions.
- Displace water.
- Not cake, gum, or ball up when contaminated with dust and dirt.
- Not thin and drip at the highest operating temperature.
- Not become brittle, peel, or chip at the lowest operating temperature.

d. Lubrication Problems. 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. 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.

e. Lubricants. 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 manufacturer's data are not available, recommended lubricants are shown below. For heavily loaded chains, the following EP grades should be used:

- Low speed–0 to 3 m/s (0 to 10 ft/s):
  - below 100 °F (37.7 °C) ISO 100 (AGMA 3).
  - above 100 °F (37.7 °C) ISO 150 (AGMA 4).
- Medium speed—3 to 9 m/s (10 to 30 ft/s):
  - below 100 °F (37.7 °C) ISO 150 (AGMA 4).
  - above 100 °F (37.7 °C) ISO 220 (AGMA 5).

(1) 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.

(2) 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.

(3) 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.

(4) 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.

(5) 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.

f. 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 also on 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.

16-7. 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. If a worm gear reducer is used, ensure that the lubricant does not contain an EP additive as it can be detrimental to a bronze worm gear.

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. Cable or Wire Rope. The lubrication should be selected according to the requirements outlined in the section on wire rope lubrication above.

e. Hydraulic Operated Trashrakes. These trashrakes use a hydraulically operated boom. Bureau of Reclamation projects specify a food grade polymer oil complying with 21 CFR 178.3570 and USDA H1 authorization for food grade quality. The oil must also comply with ASTM D697 for hydraulic pump wear analysis. See Chapter 13 for specific requirements on Environmentally Acceptable lubricants (EA lubricants). EA lubricants are recommended for these applications if possible. Chapter 10 discusses some EA hydraulic oils.

f. 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.

16-8. 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. Appendix C to this manual includes USACE ECB 2006-11, which also discusses this failure. 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. Grease for the slow-moving, highly loaded, bronze bushings such as those found on wicket gates, radial gates, and butterfly valves should be adhesive, water resistant, able to withstand high bearing pressures, and of a consistency that can be pumped at the lowest temperature encountered. 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. (These are most commonly operated with roller chain.)*
- 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). The designer should reference ECB 2006-11, "Tainter Gate Trunnion 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. Also, lubricant suppliers are readily available to recommend a grease, but they should be advised of all conditions for the particular application. Another option for the designer is to consider a self-lubricated trunnion bearing. See Chapter 12 for further discussion on this issue.

(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 16-3 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 16-3 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:

(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 startup 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 eight 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.

(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) Washout resistance. Especially when trunnions are submerged, the grease should be resistant to water washout.

(f) Pumpability. Grease should be non-hardening and flow into the load-bearing clearances of the trunnion bearings. 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.

Table 16-3. Desirable Grease Properties for the Folsom Dam Trunnion Bearings.

Purpose of Grease Property(s)	Examples of Composition					ASTM Test		
			Additives					
	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	D99-95 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, F_k, 0.10)	fs,0.10, (b) F_k, 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	D1743-94	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	D4048 (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	D99-95, bronze pin vs. steel disk	No scuffing, that is, transfer of bronze to steel. "EP" film formation	No scuffing
Resists washout by water	Mineral or synthetic	Polyurea or calcium hydroxystearate	—	—	—	D1264-93	0 washout	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	Lithium or calcium soaps or polyurea	—	—	—	a. D217	a. NLGI 1 or 1.5, cone penetration 340 to 275,	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, iso-butylene or polyethelene	None	Slightly tacky between metals	Slightly tacky
Long life, oxidation stable	Mineral or synthetic	Polyurea	Oxidation inhibitors		Amines, phenols, sulfur compounds	D942-90	Pass, also no acid forma-tion, 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	—	—	D1742-94 and Federal Test	Limited "bleeding" of oil, less than 0.1%	1.6% in 24 hours, 3% in 48 hours

(a) Applied to low carbon (SAE1045) steel pin 812.7 mm (32-in.) diam., rotating in trunnion bronze bushing, at 5.1 mm/min (0.2 in/min) and 816,461 kg (1.8 million lb) load. dam site environment - temperature range 30 to 125 °F (–11 to 51.6 °C), 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 Douglas Godfrey, *Wear Analysis*

Source: "Lubricating Grease Guide," NLGI t4h Ed., 1996

(j) Solid lubricants. The Folsom Dam tainter gate failure investigation recommended that molybdenum disulfide (MoS_2) and polytetrafluoroethylene (PFTE) not be used in greases for the tainter gate trunnion bearings at Folsom Dam. The lowest friction coefficients were achieved with greases that did not have these solid additives. Furthermore, addition of MoS_2 to grease 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 gate trunnions is 2000 to 3000 psi (137.9 to 206.8 bar) for leaded tin bronze bearing surfaces and 4000 to 5000 psi (275.8 to 344.7 bar) for aluminum bronze.

(3) Speed. Relatively speaking, a trunnion pin rotates at extremely low speeds. The tainter gate 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 (this is also noted in EM 1110-2-2610, *Mechanical and Electrical Design of Navigation Locks and Dams* (30 June 2013). A bronze bearing may initially have a lower coefficient of friction. 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 can be considered. There is no USACE mandate or requirement to use these materials, however. The trunnion bushings for the failed gate at Folsom Dam were replaced with self-lubricated 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. See Chapter 12 for more information about self-lubricated bushings. Self-lubricated bearings are also discussed in EM 1110-2-2610, *Mechanical and Electrical Design of Navigation Locks and Dams* (30 June 2013). EM 1110-2-2610 requires using 0.3 for the friction design coefficient on tainter gate trunnion bearings regardless of the material used.

(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% 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 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. Frequencies for lubricating gate and culvert valve trunnions at locks and dams vary across USACE. 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. The ASCE Water Control Gates manual provides some recommendations for frequency of operation and lubrication. 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 includes:

- 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.

(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 gauges 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.
- Measure hoist rope tension with tensiometer to estimate trunnion friction. Subtract allowance for side seal friction.

(f) Review the type of lubricant in use. Consider the lubricant specification recommended for the Folsom Dam trunnions (reference Table 16-3).

(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 3000 to 4000 psi (206.8 to 275.8 bar), 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 washout resistance, copper alloy corrosion protection, and low startup/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 startup/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 contaminated with dirt.

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 startup/running torque for quick startup 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 washout. 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 washout 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% swell in gaskets. Its dropping point should be above 316 °F (158 °C) for temperature ranges of –20 °F to 150 °F (–29 °C to 66 °C). 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.

h. Hydraulic Fluids for Operating Systems. 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 SUS at startup 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 R&O inhibitors. Consideration should also be given to biobased 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 10 of this manual.

16-9. Navigation Lock Gates, Culvert Valves, and Dam Gates. Corps of Engineers navigation facilities use many types of lock gates, including miter, sector, vertical lift, and submergible tainter gates. 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. 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 Section 16-8 (Gates and Valves) for lubrication requirements for culvert valves and dam gate components.

a. Speed Reducers. Chapter 14 also provides some specific discussion of gearboxes. Speed reducers or gearboxes are usually worm, helical, or herringbone-type gear trains in accordance with the applicable AGMA standards. Integral bearings are usually antifriction type. The intermittent and infrequent use of machinery on navigation structures can also contribute to corrosion on the interior of gear reducers (e.g., Figure 16-7). Most of these gear reducers have breathers that are open to the atmosphere and rely on splash lubrication. Long periods of non-use allow any protective film of lubrication to evaporate. Moisture in the air within the gearbox can condense and cause rust and corrosion to form.

Figure 16-7. Gear Reducer for Miter Gate Drive.

(1) As the oil in a gear reducer heats and cools, it expands and contracts, allowing moist outside air into the gear reducer through the breather. To limit the entrance of moisture into gear reducers, the use of an appropriately sized oil bath or disposable desiccant breather is necessary. With this type of breather, not only must they be designed and installed correctly, they must also be replaced when the desiccant is saturated. Gear reducer outdoor exposure to humidity and sunlight will draw water into the gear reducer oil. Fabricated protective covers or roofs are justified to limit the direct exposure to sunlight and the elements.

(2) Lubrication requirements for gear reducers 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 the manufacturer is unknown or no longer in business, a lubricant supplier should be consulted for recommendations. Means of lubricating gear reducers include splash lubrication, pressure lubrication, gravity drip, spray systems, and idler immersion systems. Splash lubrication is probably most common at USACE sites.

(3) A common mistake has been to use the wrong weight of oil in gear reducers. For example, worm gear reducers typically require oil that is approximately twice as heavy as that required for parallel shaft gear reducers. This is due to the nature of the sliding action between the worm gear and the worm wheel. It is not unusual to find that the same weight oil that is appropriate for the parallel shaft gear reducers used in the worm gear reducers. This will lead to accelerated wear.

(4) Oxidation stability of the lubricant is critical for gear reducers. Lubricants with low values of oxidation stability will oxide rapidly in the presence of water at high temperatures. When oil oxidizes, it may result in sludge accumulation in the gear reducer. The sludge may interfere with the cooling and lubrication. The oxidized oil will also cause corrosion. Oxidation stability is discussed further below.

(5) 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 10 watts per square inch. See EM 1110-2-2610, *Mechanical and Electrical Design of Navigation Locks and*

Dams (30 June 2013) for further information. 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 °F (–40 °C) 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.

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

c. 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% of maximum.

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

- Sheave bushings, slow speed, 3500 psi (241 bar).
- Main pinion shaft bearings and other slow-moving shafts, hardened steel on bronze, 1000 psi (68.9 bar).
- Bearings moving at ordinary speeds, steel, or bronze, 750 psi (51.71 bar).

d. Open Gearing. See Chapter 14.

e. 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 startup 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 R&O 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 10 for a more detailed discussion of desirable properties for hydraulic fluids commonly used at locks and dams.

f. 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 graphite-based grease or lubricated with the same grease used on the pintles, depending on type of strut.

g. 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.

h. 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 120 °F (49 °C). Wire ropes are usually 6 x 37, preformed, lang lay, independent wire rope core, 18-8 chrome-nickel corrosion-resistant steel.

i. 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 Section 16-8 (Gates and Valves) for trunnion lubrication requirements.

16-10. <u>Transformer and Circuit Breaker Insulating Oil Degradation</u>.

a. The consequences of oil degradation in a transformer can be even more serious than with other equipment. Combustible gases may form as the transformer develops faults. Some gases are present in a dissolved state while others are found in the free space of the transformer. The type and concentration of gases and the ratio in which they are present are commonly used to assess the serviceable condition of transformers. Under the right conditions, these gases may explode, causing significant damage and injury to personnel. The testing of transformer oils and assessment of transformer serviceable conditions has become a specialty. The Bureau of Reclamation has published manuals that provide detailed procedures and criteria for testing insulating oils. The reader should refer to Reclamation FIST publication Volume 3-30, “Transformer Maintenance, October 2000” and Volume 3-31, “Transformer Diagnostics, June 2003,” for detailed information on transformer and circuit breaker oil maintenance and testing. For information on monitoring, testing, and assessment of transformer serviceability, refer to Institute of Electrical and Electronics Engineers (IEEE) Standard C57.104-2008, “Guide for the Interpretation of Gases in Oil-Immersed Transformers.”

b. Transformer and circuit breaker insulating oils suffer degradation similar to that of lubricating oil and hydraulic fluid including as oxidation, sludge formation, additive depletion, and moisture contamination. Sludge can significantly affect the flow of heat from the oil to the coolant and from the core and coils to the cooling coil. If these conditions are prolonged, the excessive temperature and heat can damage the transformer insulation and eventually cause short circuits and breakdown of the transformer. Moisture can be present in three forms: dissolved, emulsified, or free state. Emulsified water is especially harmful since it has significant influence in reducing the dielectric strength of the oil. Another form of contamination is the presence of dissolved nitrogen, which can cause problems due to corona discharge. Circuit breakers may have all the above problems plus the formation of carbon particles, which can cause short circuits.

CHAPTER 17

Operation, Maintenance, and Selection Considerations

17-1. Introduction. This chapter discusses the maintenance aspects of lubrication, including detailed discussions of maintenance scheduling; relative cost of lubricants; essential oil properties that must be retained to ensure adequate lubrication of equipment; degradation of lubricating oils, hydraulic fluids, and insulating transformer oils; particulate, water, and biological contamination; monitoring programs, including trend monitoring and oil testing; storage and handling; and environmental impacts.

17-2. Maintenance Schedules.

a. Modern maintenance schedules are computer-generated and are frequently referred to as Computer Maintenance Management Systems (CMMSs). The Facility Equipment Maintenance System (FEMS) is a CMMS that has been implemented at many Corps of Engineers facilities. These systems are essential in organizing, planning, and executing required maintenance activities for complex hydropower, pumping, and navigation facilities. A complete discussion of CMMS is beyond the scope of this manual. Some Corps of Engineers and Bureau of Reclamation facilities recognize the value of CMMS and are currently using these systems to document operation and maintenance activities. The following discussion summarizes some key concepts of CMMS.

b. The primary goals of a CMMS include scheduling resources optimizing resource availability and reducing the cost of production, labor, materials, and tools. These goals are accomplished by tracking equipment, parts, repairs, and maintenance schedules.

c. The most effective CMMS are integrated with a predictive maintenance program (PdM). This type of program should not be confused with preventive maintenance (PM), which schedules maintenance and/or replacement of parts and equipment based on manufacturer's suggestions. A PM program relies on established service intervals without regard to the actual operating conditions of the equipment. This type of program is very expensive and often results in excess downtime and premature replacement of equipment.

d. While a PM program relies on elapsed time, a PdM program relies on condition monitoring of machines to help determine when maintenance or replacement is necessary. Condition monitoring involves the continuous monitoring and recording of vital characteristics that are known to be indicative of the machine's condition. The most commonly measured characteristic is vibration, but other useful tests include lubricant analysis, thermography, and ultrasonic measurements. The desired tests are conducted on a periodic basis. Each new measurement is compared with previous data to determine if a trend is developing. This type of analysis is commonly referred to as trend analysis or trending, and is used to help predict failure of a particular machine component and to schedule maintenance and order parts. Trending data can be collected for a wide range of equipment, including pumps, turbines, motors, generators, gearboxes, fans, compressors, etc. The obvious advantage of condition monitoring is that failure can often be predicted, repairs planned, and downtime and costs reduced.

e. All USACE sites should provide a detailed and comprehensive lubrication schedule for their machinery and equipment. This should include a detailed plan for lubricant replacement on a periodic basis. It is important that the lubricants on both hydraulic drives and mechanical drives and hydroturbines have a long service life and durability and not degrade quickly. Maintenance staffing at navigation facilities vary greatly. Operation and Maintenance work is constantly being delayed or cut back due to fiscal constraints. Changing oil in a gearbox or hydraulic system and replacing grease on open gears is a time consuming and costly undertaking. It is important to standardize lubrication requirements to the greatest extent possible. No standardized maintenance procedures are used throughout the Corps of Engineers. The wide variation in the types of machinery make standardized lubrication schedules and practices nearly impossible. The lack of standardization results in a number of lock and dam sites using trial and error for selection of lubricants.

f. The Bureau of Reclamation FIST 4-1A and the ASCE Water Control Gates – Guidelines for Inspection and Evaluation, both provide detailed recommendations for inspection and maintenance of a variety of mechanical equipment. Appendix F to this manual includes Bureau of Reclamation FIST 4-1A.

17-3. Information Sources for Lubricants. There are many valuable information resources on the subject of lubrication.

a. O&M 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. ILSAC and API are other professional societies that classify oil. Reference: http://www.api.org/certification-programs/engine-oil-diesel-exhaust-fluid/service-categories.aspx.

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. Noria publishes a multitude of manuals and guidelines on equipment lubrication. Of particular interest is Plant Engineering's "Lubrication Guide." This guide is updated yearly. This guide cross-references 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. Fluid products in each category are listed within viscosity ranges. Lubricant categories include:

- General purpose lubricants.
- Antiwear hydraulic oil.
- Spindle oil.
- Way oil.
- Extreme pressure gear oil.
- Worm gear oil.

e. The chart for identifies available products from 10 lubricant companies in six categories. Fluid products in each category are listed within viscosity ranges.

f. 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.

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

h. Internet. The Internet offers access to a large amount of information, including lubrication theory, product data, and application information. Since the credentials of individuals publishing information through the Internet are more difficult to ascertain, caution should be used when evaluating information from unverified sites or forums. One useful site is http://www.tribology-abc.com/. This is an online machinery and lubrication and bearing database and unit conversion calculator. Another is http://www.machinerylubrication.com/, a monthly online magazine with a variety of lubrication-related articles. Yet another is available from the STLE. STLE provides detailed information on lubrication engineering: http://www.stle.org/.

i. Specifications. Various lubrication-related specifications are available on the Whole Building Design Guide at http://www.wbdg.org/. The list of ASTM, AGMA, ANSI, ISO, etc. specifications are listed in Appendix A. Military Specifications are available from the ASSIST (Database for Military Specifications and Military Standards) website: https://assist.dla.mil.

17-4. Principles of Lubricant Selection.

a. Equipment Manufacturer Recommendations. The prime considerations are film thickness and wear. Although film thickness can be calculated, the wear properties associated with different lubricants are more difficult to assess. Lubricants are normally tested by subjecting them to various types of physical stress. However, these tests do not completely indicate how a lubricant will perform in service. Experience has probably played a larger role than any other single criterion. Through a combination of testing and experience, machine manufacturers have learned the classes of lubricants that will perform well in their products.

b. Professional societies have established specifications and classifications for lubricants to be used in a given mechanical application. For example, AGMA has established standard specifications for enclosed and open gear systems. These specifications have been developed from the experience of the association's membership for a wide range of applications. Thus, any manufacturer has access to the collective knowledge of many contributors.

c. Note that the equipment manufacturer's recommendation should not necessarily be considered the best selection. Individual manufacturers may have different opinions based on their experience and equipment design. The concept of "best" lubricant is ambiguous because it is based on opinion. Despite this ambiguity, the manufacturer is probably in the best position to recommend a lubricant. This recommendation should be followed unless the lubricant fails to perform satisfactorily. When poor performance is evident, the manufacturer should be consulted for additional recommendations. This is especially critical if the equipment is still under warranty.

d. Although some manufacturers may recommend a specific brand name, they can usually provide a list of alternative lubricants that also meet the operating requirements for their equipment. One of the recommended lubricants should be used to avoid compromising the equipment warranty if it is still in effect. Physical qualities (such as viscosity or penetration number), chemical qualities (such as paraffinic or naphthenic oils), and applicable test standards are usually specified.

e. Lubricant Producer Recommendations. When manufacturers recommend lubricants for their products in terms of specifications or required qualities rather than particular brand names, the user must identify brands that meet the requirements. Following the suggestions given in this chapter may help the user identify appropriate products. When a user is uncertain, lubricant producers should be consulted to obtain advice on products that comply with the required specifications.

f. Many lubricant producers employ product engineers to assist users in selecting lubricants and to answer technical questions. Given a manufacturer's product description, operating characteristics, unusual operating requirements, and lubricant specification, product engineers can identify lubricants that meet the manufacturer's specifications. Viscosity should be the equipment manufacturer's recommended grade. If a recommendation seems unreasonable, the user should ask for verification or consult a different lubricant producer for a recommendation. These products will probably vary in quality and cost. The application should dictate lubricant selection. This will help prevent the unnecessary purchase of high-priced premium quality lubricants when they are not required.

g. User Selection. The user should ensure that applicable criteria are met regardless of who makes the lubricant selection. Selection should be in the class recommended by the machinery manufacturer (R&O, EP, AW, etc.) and be in the same base stock category (paraffinic, naphthenic, or synthetic). Furthermore, physical and chemical properties should be equal to or exceed those specified by the manufacturer. Generally, the user should follow the manufacturer's specification. Additional factors to be considered are shown in Table 17-1. Additional information on selecting additives is found in Chapter 5 and information for selecting lubricants for bearings is found in Chapter 15.

Table 17-1. Factors Affecting Lubricant Selection

Element	**Type**	**Size**	**Material**	**Operating Temperature**	**Operating Conditions**	**Velocity**	**Remarks**
Bearings	Plain, needle roller, ball	Shaft diameter				rev/min	
Chain drives	Links; number and pitch	Pitch Circle Diameter (PCD) of all wheels and distance between centers				Chain speed ft/min	
Cocks and valves	Plug, ball, etc.		Fluid being controlled				Depends on properties of the fluid
Compressors	Brake Horsepower (BHP), manufacturer's name			Gas temperature	Max gas pressure	rev/min	
Couplings	Universal or constant velocity					rev/min	
Cylinders		Bore, stroke	Cylinder, piston, rings	Combustion and exhaust gas temperature	Combustion and exhaust gas pressure	Crank speed, rev/min	
Gears	Spur, worm, helical, hyperbolic	BHP, distance between centers			Radiated heat and heat generated	rev/min	Method of lubricant application
Glands and seals	Stuffing box		Fluid being sealed				Depends on design
Hydraulic systems	BHP Pump type (gear, piston vane)		Hydraulic fluid materials "O" rings and cups, etc.				Lubricant type adjusting to loss rate
Linkages				Environmental heat conditions		Relative link speeds, ft/s, angular vel., rad/s	
Ropes	Steel hawser	Diameter			Frequency of use and pollution, etc.		
Slideways and guides						Surface relative speed, ft/min	
Reference: Neale, M.J. 1995. *A Tribology Handbook*. Butterworth-Heinemann Ltd., Oxford, England.							

h. If the manufacturer's specifications are not available, determine what lubricant is currently in use. If it is performing satisfactorily, continue to use the same brand. If the brand is not available, select a brand with specifications equal to or exceeding the brand previously used. If the lubricant is performing poorly, obtain the recommendation of a product engineer. If the application is critical, get several recommendations. Generally, the user will make a selection in either of two possible situations:

- Substitute a new brand for one previously in use.
- Select a brand that meets an equipment manufacturer's specifications. This will be accomplished by comparing producer's specifications with those of the manufacturer.

i. Product selection starts by using a substitution list maintained by most lubricant producers. A substitution list usually shows the products of major producers and the equivalent or competing product by other producers. Substitution lists are useful, but they have limitations. They may not be subdivided by classes of lubricants. Furthermore, it is difficult to do more than compare a lubricant of one producer with one given by the publishing producer. For example, consider three producers called A, B, and C. Producer A's substitution list may compare B's products with A's, or C's with A's. However, B and C cannot be compared unless A has a product equivalent to both B and C. A user would need substitution lists from many producers to be able to effectively select more than one option. Many producers claim they do not have a substitution list, or are reluctant to provide one.

j. A substitution list or chart is valuable because it correlates the array of brand names used by producers. Furthermore, it eliminates producers who do not have the desired product in their line. A substitution list should be regarded as a starting point to quickly identify potential selections. The lists do not suggest or imply that lubricants listed as being equivalent are identical. The lists do indicate that the two lubricants are in the name class, have the name viscosity, and are intended for the same general use. The chart of interchangeable industrial lubricants lists the following categories:

- General purpose lubricants.
- Antiwear hydraulic oil.
- Spindle oil.
- Way oil.
- Extreme pressure gear oil.
- Worm gear oil.
- Open gear oil.
- General purpose extreme pressure lithium-based grease.
- Molybdenum disulfide extreme pressure grease.

(1) Spindle and way oils are not widely used. One of the last three classes on the list is a special preparation for open gears and the other two are classes of grease. General purpose oils, antiwear hydraulic oils, and EP gear oils are best described by comparison with the nonspecialized industrial oils discussed earlier. AW hydraulic oil is a general purpose oil, but its antiwear properties are sufficient to pass the Vickers vane test for hydraulic applications when this is required.

(2) The EP gear oils should correspond to those described under nonspecialized industrial oils except that EP additives are included and viscosities may be as high as ISO 2200. The EP classification of gear oil should not be confused with the SAE gear oil classification, which is for use in automotive gear systems. SAE gear oils are formulated differently and are not discussed in this manual.

(3) While grease preparation varies among producers, No. 2 lithium EP and molybdenum disulfide EP No. 2 are the two most widely used industrial greases. The name molybdenum disulfide designates lubricant type, and does not reflect the type of soap, but the soap will usually be lithium. While both types are intended to provide extra protection against wear, one contains EP additives and the other contains molybdenum disulfide.

(4) Lithium greases are the most widely used, but calcium, aluminum, polyurea, and sodium-calcium are also used. Furthermore, greases ranging from NLGI 00 to No. 3 are used.

(5) The open gear lubricants are residual oils to which a tackiness agent has been added. They are extremely adhesive and so viscous that solvents are added to permit application. After application, the solvent evaporates leaving the adhesive viscous material. Some products contain no solvent and must be heated to reduce viscosity for application.

(6) Compounded oils are not included in the list as a separate class. When this type of oil is required, producers must be contacted directly.

(7) Ultimately, information brochures provided by the producers must be examined to verify the following:

- Viscosity. The product viscosity meets the manufacturer's recommendation or is the same as a previously used lubricant that performed well. When a grease is considered, the viscosity of the included oil should be the same as the previous lubricant.
- Intended use. The product's intended use, as given by the producer, corresponds to the application in which the lubricant will be used.
- Class of lubricant. The class of lubricant is the same as that recommended by the equipment manufacturer or the same as a previously used lubricant that performed well. If the manufacturer recommended an R&O, AW, or EP oil, or a No. 2 lithium grease, that is what should be used.
- Specification. The product specifications are equal to or better than those recommended by the equipment manufacturer or those of a previously used lubricant that performed well.
- Additives. The product additives perform the required function even though they may not be chemically identical in several possible alternative lubricants.

17-5. Lubricant Consolidation.

a. General. Older machines tend to operate at slow speeds and light loads. These machines also tend to have large clearances and few lubricating points. Lubrication of such older machines is not as critical, comparatively speaking, as for modern machines that operate at higher speeds, under heavier loads, and with closer mechanical tolerances. A common maintenance practice is to have inventories of several types of lubricant to service both older and newer versions of similar equipment (e.g., speed reducers). This problem is further aggravated by the different types of unrelated equipment operating at a complex facility (e.g., turbines, speed reducers, ropes and chains, etc.), each requiring lubrication. Consolidation of lubricants is usually undertaken to reduce inventories, storage requirements, safety and health hazards, and cost. Consolidation, done properly, is a rational approach to handling the lubrication requirements at a facility while reducing the total number of lubricants in the inventory.

b. Manufacturer's Recommendations. Manufacturers may recommend lubricants by brand name or by specifying the lubricant characteristics required for a machine. Depending on the machine, lubricant specifications may be restrictive, or they may be general, allowing considerable latitude. Usually, the manufacturer's warranty will be honored only if the purchaser uses the lubricants recommended by the manufacturer. Voiding the terms of a warranty is not advisable so the specified lubricants should be used until the warranty has expired. After warranty expiration, the machine and its lubrication requirements may be included in the consolidation list for the facility.

c. Consolidation Considerations. Consolidation of lubricants requires careful analysis and matching of equipment requirements and lubricant properties. Factors that influence selection of lubricants include operating conditions, viscosity, viscosity index, pour point, extreme pressure properties, oxidation inhibitors, rust inhibitors, detergent dispersant additives, etc. With a grease, consideration must also include composition of the soap base, consistency, dropping point, and pumpability. There are several precautions that must be followed when consolidating lubricants.

(1) Characteristics. Consideration should be given to the most severe requirements of any of the original and consolidated lubricants. To prevent equipment damage, the selected lubricant must also have these same characteristics. This is true for greases.

(2) Special requirements. Applications with very specific lubricant requirements should not be consolidated.

(3) Compatibility. Remember that some lubricant additives may not be compatible with certain metals or seals.

d. Consolidation Procedure. Consolidation may be accomplished through the services of a lubricant producer or may be attempted by facility personnel who have knowledge of the equipment operating characteristics and lubricating requirements, and an ability to read lubricant producer's product data.

(1) Lubricant supplier. The preferred method for consolidating lubricants is to retain the services of a qualified lubrication engineer. All major oil companies have engineers available to help users with lubrication problems. There are also numerous independent lubricant suppliers with the necessary personnel and background to provide assistance. Ultimately, the knowledge, experience, integrity, and reputation of the lubricant supplier are the best assurance that the products recommended will meet the lubrication requirements for the equipment. The supplier must be given a list of equipment, along with any information about the operating characteristics, ambient conditions, and lubrication requirements. The engineer can use this information to consolidate lubricating requirements where possible, and to isolate equipment with highly specific requirements that cannot be consolidated. The primary disadvantage with this approach is that the lubricant supplier will, in all probability, recommend only those products within the company's product line. If this is a major concern, the services of an independent lubricating engineer or tribologist, not affiliated with any supplier, may be retained.

(2) Consolidation by in-house personnel. In-house personnel should begin the consolidation process by preparing a spreadsheet identifying equipment, lubricating requirements, lubricant characteristics, and brand names. The equipment should be sorted by type of lubricant (oil, hydraulic fluid, synthetics, biodegradable, grease) required. Under each type, the properties of each lubricant should be grouped such as oil viscosity, detergent dispersant requirements, EP requirements, R&O inhibitors, NLGI grade of grease, viscosity of oil component in the grease, pumpability, etc. At this stage, viscosity grouping can be made. For instance, if three similar oils have viscosities of 110, 150, and 190 SUS at 100 °F (37.8 °C), the 150 may be used as a final selection. If one of the original oils was R&O inhibited, the final product should also have this property. A second group of oils with viscosities of 280, 330, and 350 SUS at 100 °F (37.8 °C) could be reduced to one oil having a viscosity in the neighborhood of 315 SUS at 100 °F (37.8 °C). The goal is to identify the viscosity requirements and range for various equipment and see if a single lubricant can span the range. If the range can be covered, then consolidation is possible. However, recall that Paragraph 17-4 included a warning that the lubricant viscosity for a machine must comply with the manufacturer's requirements. Obviously, an exact match of viscosity for all equipment cannot be accomplished with the same lubricant when consolidation is the goal. Lubricants with vastly different viscosity requirements must not be consolidated.

(3) Use higher quality lubricants. Another alternative for consolidation is to use higher grade lubricants that are capable of meeting the requirements of various machinery. Although the cost of high-grade lubricants is greater, this may still be offset by the benefits of consolidation (e.g., reduction in the number of different lubricants needed, reduction in inventory-management requirements, possible price discounts for purchasing certain lubricants in greater quantity, etc.).

(4) Use multipurpose lubricants. Multipurpose lubricants and other general purpose oils can be applied to a wide range of equipment and help reduce the number of lubricants required. Although some lubricants are not listed as multipurpose they may be used in this capacity. For example, assume two lubricants by the same producer: one is listed as an R&O turbine oil and the other as a gear oil. Examination of product literature shows that the R&O turbine oil can also be used in bearings, gear sets, compressors, hydraulic systems, machine tools, electric motors, and roller chains while the gear oil can also be used in circulating system, chain drives, plain and antifriction bearings, and slides. These oils may be suitable for use in a consolidating effort. Producers often have similar application overlaps in their product lines.