9

Lubrication

Section Outline Page

9.1 LUBRICATION OF ROLLING ELEMENT BEARINGS

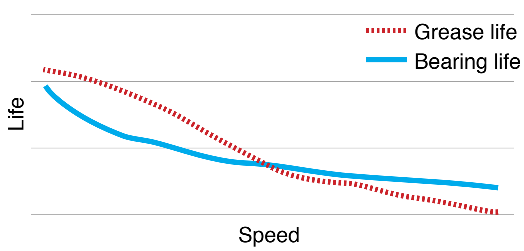
Proper lubrication of rolling element bearings is critical for their successful performance. The major functions of the lubricant include:

- To provide lubricant film for the various sliding and rolling contacts between the bearing elements.
- To protect the surface finish of the raceways and rolling elements from corrosion and rust.
- To seal the bearing from foreign materials.
- To help dissipate heat from the bearing elements.

Grease lubrication is the method most commonly used on small- and medium-size electric motors in the range of 1 to 500 hp (375 kW) for horizontal machines. Sleeve bearings may be used in two-pole or high-speed applications. Vertical motors start to use oil-lubricated bearings at about 50 hp (37 kW). Exceptions to all of the above are special applications using oil mist or bath systems, neither of which is covered in this section.

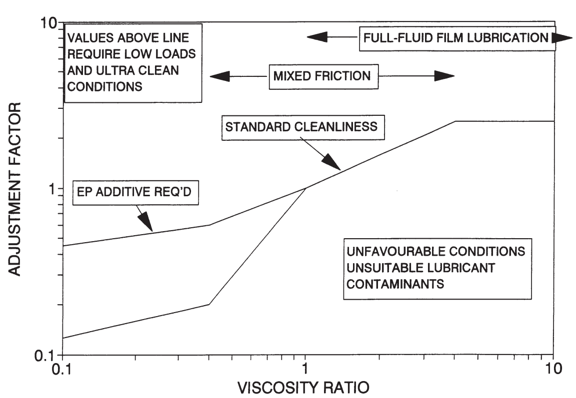
Bearing relubrication requirements depend on loading, temperature and speed. Figure 9-1 shows the relative grease life as it relates to bearing life based on speed. The speed is the average (D) of the inner diameter and the outer diameter in millimeters times the RPM (N) of the inner race; this is the DN speed.

FIGURE 9-1



Relative grease vs. bearing life.

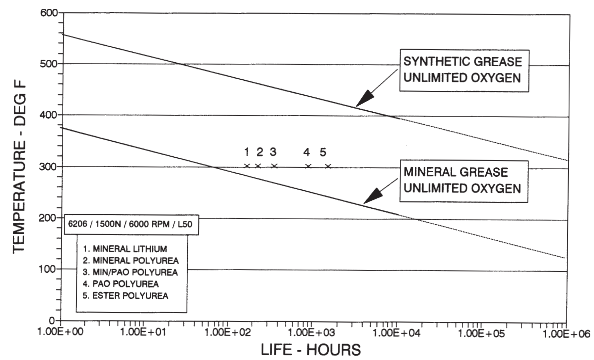
FIGURE 9-2



Life adjustment factor vs. viscosity ratio.

FIGURE 9-3

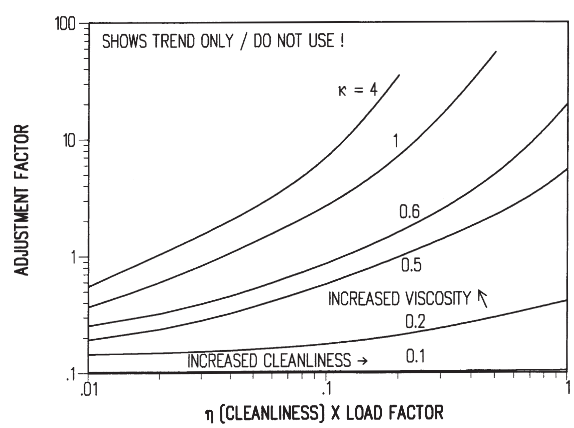
TEMPERATURE VS. OXIDATION LIFE



Grease temperature properties.

FIGURE 9-4

SIMILAR TO ASKF FACTOR



Grease Life adjustment factor vs. contamination load.

The curves intersect at some point as the bearings get larger and the DN speed increases. Below this intersection, relubrication is not required since the expected grease life exceeds that of the bearing and shields or seals can be used to keep out contamination. Above the intersection bearing lubrication must be replenished to realize the full bearing life, and shields or seals should not be used.

Decades of research have produced a family of curves that show how the viscosity ratio, contamination load, temperature and other factors affect the useful life of lubricants (Figures 9-2, 9-3 and 9-4). Figure 9-3, for example, clearly demonstrates that the oxidation characteristics of synthetic greases can significantly extend the lives of these lubricants.

LUBRICANT COMPATIBILITY

The lubricant used for grease applications is usually a mixture of oil impregnated in a soap base. The soap base keeps the oil in suspension until it adheres to the moving surfaces of the bearing elements. The supply of oil is gradually depleted, as it breaks down by oxidation. This process is a function of time, temperature, speed, load and environment.

Selection of the proper grease and relubrication practices are critical for optimum bearing life. Greases are usually made of a combination of soap or non-soap thickening materials mixed with mineral oil and additives. Soaps or chemicals such as sodium, calcium, aluminum, lithium and barium are most commonly used. Polyurea is a synthetic organic thickener that has been widely used for electric motor bearings because it can withstand elevated temperatures in excess of 250°F (120°C). Rust and oxidation inhibitors and tackiness additives are included to enhance performance.

IDENTIFYING LUBRICANT COMPATIBILITY PROBLEMS

A key method for improving the reliability of motor bearings is to use only lubricants that are compatible with what the customer uses. If bearings fail only a few months after repair but the problem did not begin until the machine was relubricated, grease compatibility might be an issue. Check Table 9-1 to confirm that the grease is clearly compatible with what the customer uses. If the table indicates the greases are compatible, investigate further.

TABLE 9-1: GREASE COMPATIBILITY CHART

B = Borderline C = Compatible I = Incompatible	Al complex	Ba complex	Ca stearate	Ca 12 hydroxy	Ca complex	Ca sulfonate	Clay nonsoap	Li stearate	Li 12 hydroxy	Li complex	Polyurea	Polyurea SS
	1	2	3	4	5	6	7	8	9	10	11	12
1. Aluminum complex		I	I	C	I	B	I	I	I	C	I	C
2. Barium complex	I		I	C	I	C	I	I	I	I	I	B
3. Calcium stearate	I	I		C	I	C	C	C	B	C	I	C
4. Calcium 12 hydroxy	C	C	C		B	B	C	C	C	C	I	C
5. Calcium complex	I	I	I	B		I	I	I	I	C	C	C
6. Calcium sulfonate	B	C	C	B	I		I	B	B	C	I	C
7. Clay non-soap	I	I	C	C	I	I		I	I	I	I	B
8. Lithium stearate	I	I	C	C	I	B	I		C	C	I	C
9. Lithium 12 hydroxy	I	I	B	C	I	B	I	C		C	I	C
10. Lithium complex	C	I	C	C	C	C	I	C	C		I	C
11. Polyurea conventional	I	I	I	I	C	I	I	I	I	I		C
12. Polyurea shear stable	C	B	C	C	C	C	B	C	C	C	C	

This information is to be used only as a guide. Consult the manufacturer of each product before mixing different greases.

For example, even though Polyurea Shear Stable and Polyurea Conventional have generally compatible thickeners and perform comparably (i.e., have similar dropping points, viscosities and oxidation resistance), they may contain different, incompatible additives–something the compatibility chart does not cover [1].

POSSIBLE LUBRICANT COMPATIBILITY SOLUTIONS

- **Frequent relubrication.** Besides using greases with similar thickeners that are properly designed and applied for the machine and its environment, one possible solution is to relubricate often [2]. This option acknowledges that the lubricants may not be completely compatible and attempts to compensate by replenishing the lube frequently. Unfortunately, frequent relubrication could lead to over-greasing problems, merely shifting issues from one mode of failure to another.
- **Flushing with new grease.** Another approach is to replace the old grease by flushing new grease through the system. This method cannot replace all the grease hiding in the nooks and crannies of the bearing cavity, so there will always be a mixture of some ratio. Further, this is the very definition of over-greasing, because it fills the grease cavity to capacity under pressure.
- **Lab testing.** Lab testing is a costly, time consuming and often not entirely conclusive [3] way to determine how lubricants mix physically and chemically [4]. The procedure outlined in ASTM Std. D6185, *Standard Practice for Evaluating Compatibility of Binary Mixtures*, mixes various ratios of the greases and subjects them to three tests: dropping point (Test Method D 566), shear stability (Test method D 217), and storage stability (Test Method D 217). Any one of these tests could find a problem that the other two would miss. These tests should be done by a qualified lab with the equipment and experience necessary to perform them properly [1]. Of course, even with this testing, the ultimate proof is the performance and reliability of the machine [5].
- **Ask the manufacturers.** A less-expensive alternative is to ask both grease manufacturers if grease “X” is compatible with grease “Y”. If BOTH state in writing that two greases are compatible, it is reasonably certain they are. If EITHER one replies in the negative or will not commit in writing, avoid mixing the greases. Reputable suppliers will only put it in writing if tests have already been performed. They will also provide the test results.

The above example applies to a grease-lubricated machine, but the same questions apply to oil. If two turbine oils are mixed, one with an acidic rust inhibitor and the other with a basic rust inhibitor, the resulting salt from the acid/base interaction could clog filters and form deposits that interfere with lubrication. Another example is that less than 0.2% engine oil can form emulsions in turbine oil [6].

USE THE SAME GREASE

One definitive way to eliminate lubricant compatibility problems with repaired machines is to use the same grease that was in the bearing. There can be no compatibility issue if there is no mixture of greases. If that grease is comparable in performance to that of the original manufacturer, why not use it? If it is not, help improve overall plant reliability by recommending a better lubrication solution.

The issues/implications associated with this approach include stocking a multitude of lubricants and tracking the which ones customers use for each machine. A practical way of handling this is to label each grease gun and hang it in a designated spot on a pegboard frame with a list of customers or machines that require that particular grease.

HELPFUL REFERENCES FOR LUBRICANT COMPATIBILITY ISSUES

[1] ASTM D6185-97(2008) Standard Practice for Evaluating Compatibility of Binary Mixtures.

[2] Kurosky, J., Anderol, Maximizing Grease Performance through Optimal Compatibility–An Overview of Compatibility Testing, Machinery Lubrication Magazine, July 2003.

[3] Truong, N.H., Noria Corp, Preservation of Grease Quality, Belvac Production Machinery Technical Bulletin, Issue 11, Volume 11, September 2008.

[4] Barnes, M., Compatibility and Switching Suppliers, Reliable Plant, January 2007.

[5] Baker, K.N., PhD, A Tribological Investigation into Grease Mixtures within MIL-G-21164, NLGI White Paper.

[6] Shugarman, A.L., Managing the Risk of Mixing Lubricating Oils, Machinery Lubrication Magazine, September 2001.

9.2 GREASE FILL AND RELUBRICATION INTERVALS

GREASE FILL AND RELUBRICATION INTERVALS

Grease fill. There is a large selection of good bearings to choose from when it is necessary to replace an existing bearing. For closed bearings, a reasonable guideline is to fill them to 30 to 40% of capacity. Open bearings (or single shield bearings) have a much wider range with 50% of capacity being a good target for most normal applications (less for speeds over 1800 rpm and more for speeds below 900 rpm).

For typical applications (Figure 9-5), the bearing (point A) should not normally be filled beyond 40% capacity, and the bearing housing (point B) should be filled to 30 to 50% of capacity. These same practices can also apply to new motors.

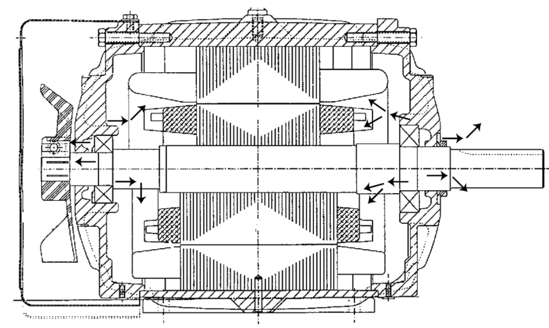
Over-greasing. With the current bearing designs and the quality of lubricants, far more problems are associated with over-greasing than with under-greasing of motors. For this reason, most applications require the addition of only a very small amount of grease during operation of the motor (see Table 9-2).

If the original amount of grease is still present (30 to 50% of cavity is full), it is likely that relubrication will fill the whole bearing cavity with grease (Figure 9-6). Even if the drain plug is removed and cleared of all old grease, some of the excess grease may exit through the running clearances around the shaft. It also is likely that the temperature in the bearing and surrounding areas will temporarily increase, thereby reducing the viscosity of the grease and making it easier to purge through all openings. Be sure to reinstall the drain plug after 30 minutes to prevent too much grease from draining from the motor.

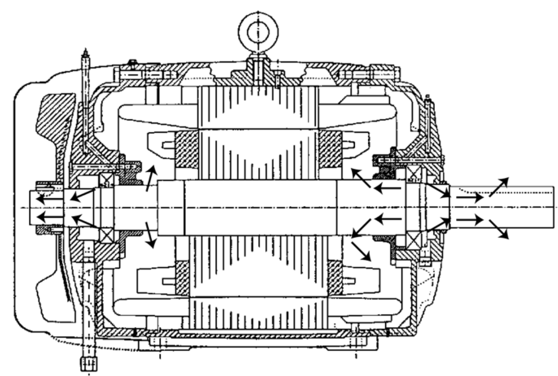
If a motor has been over-greased, schedule an orderly shutdown and have it disassembled to remove all grease from the stator. While there is little danger of a short term failure, prolonged operation in this mode can negatively affect the cooling of the motor and lead to other problems, including premature bearing failure.

FIGURE 9-6

Shown below are possible grease paths when excessive grease is applied. If the grease fails to purge through the drain hole, it will flow into and out of the motor at the running fits as shown by the arrows.

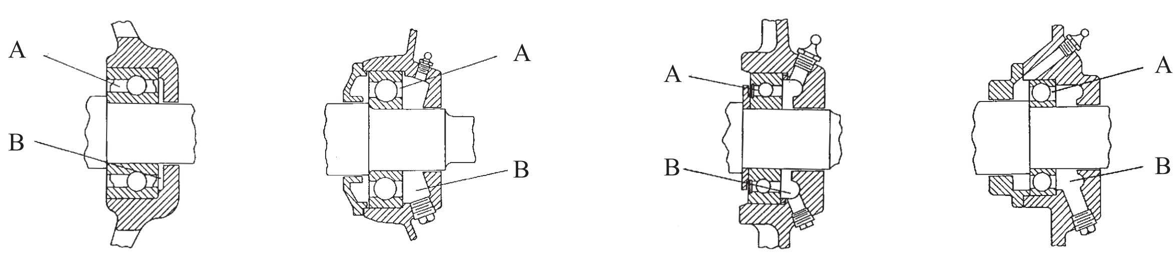


Over-greased motor with bearing caps. The grease will exit all running clearances around the shaft.



Possible grease paths following over-greasing.

FIGURE 9-5



A
Self-contained, double-sealed bearing.

B
Open bearing in regreasable housing.

C
Regreasable housing using single-shielded bearing backed by a shaft slinger.

D
Transverse greasing through bearing.

Bearing and housing arrangements.

TABLE 9-2: RECOMMENDED GREASE REPLENISHMENT QUANTITIES AND INTERVALS FOR GENERAL PURPOSE MOTORS

Bearing number	Grease fluid ounces (milliliters)	Lubrication intervals (for units in service)		
		3600 rpm	1800 rpm	1200 rpm
6203 through 6208	0.2 (6)	2 years	3 years	3 years
6209 through 6309	0.4 (12)	1 year	2 years	2 years
6310 through 6311	0.6 (18)	1 year	2 years	2 years
6312 through 6317	0.8 (24)	1 year	1 year	1year
6218 through 6220	1.0 (30)	6 months	1 year	2 years

For motors mounted vertically or in hostile environments, reduce intervals shown by 50 percent.
Refer to motor nameplate for bearings provided on a specific motor.
For bearings not listed in the table above, calculate the amount of grease required by these formulas:

G Imperial = 0.11 x D x B

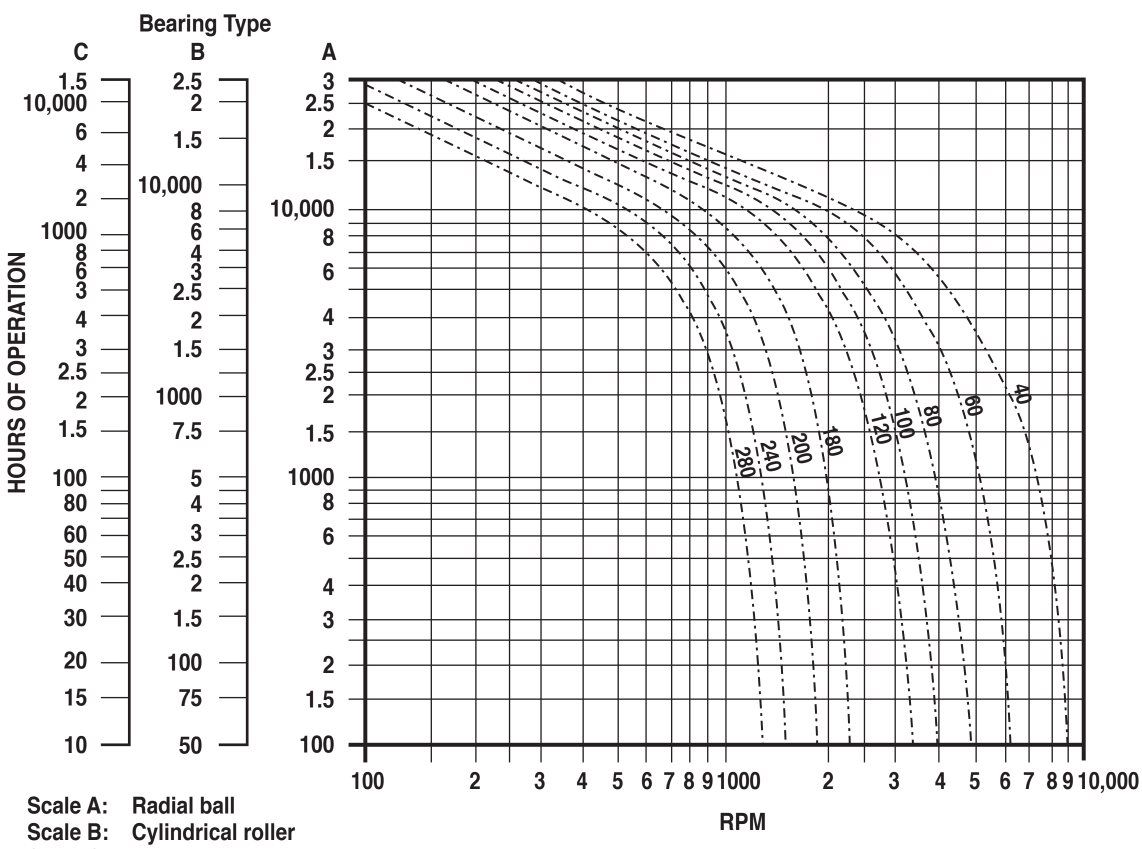
Where:
G = Quantity of grease in fluid ounces.
D = Outside diameter of bearing in inches.
B = Width of bearing in inches.

G Metric = 0.005 x D x B

Where:
G = Quantity of grease in milliliters
D = Outside diameter of bearing in millimeters
B = Width of bearing in millimeters

FIGURE 9-7

Grease relubrication intervals for normal operating conditions can be read as a function of bearing speed and bore. This diagram is valid for bearings on horizontal shafts in stationary machines under normal conditions. The curves represent the internal diameter of the bearings in mm.



Scale A: Radial ball
Scale B: Cylindrical roller
Scale C: Thrust ball and roller

Relubrication intervals for rolling element bearings. Based on information provided by NSK Bearing Corp.

Relubrication intervals. The frequency of relubrication is application and product specific, depending on:

- Operating temperature
- Bearing size
- Critical nature of application
- Vibration levels
- Motor speed
- Duty cycle
- Environmental conditions/contaminants

Determine the appropriate grease relubrication quantities and intervals for general purpose motors under normal operating conditions using Table 9-2.

Relubrication intervals for rolling element bearings can also be determined from Figure 9-7 as follows:

- Find the motor's rpm on the horizontal axis.
- Draw a vertical line from the motor's rpm to the curve that represents the bearing's inside diameter (in millimeters), or the next smaller dimension.
- From that point, draw a horizontal line to intersect the hours of operation (relubrication interval) for the applicable bearing type.
- When a specific application requires a change in lubricant, besides compatibility issues, also consider:
- Noise created by the grease
- Temperature extremes

ROLLING ELEMENT BEARING RELUBRICATION PROCEDURES AND CAUTIONS

- Thoroughly clean all motor housings, shafting, seals and relubrication paths.
- Prevent dirt, moisture, chips or other foreign matter from contaminating the grease.
- Identify the temperature range for the application and select a grease that will perform satisfactorily.
- Over-greasing may cause unacceptable bearing temperatures and elevated winding temperatures, which can lead to premature failures (see Figure 9-6).
- When regreasing, be sure the new grease is compatible with the existing grease and has the desired performance characteristics.
- Some applications, such as shaker motors, may require an extreme pressure (EP) grease.
- Some common greases are not desirable for motor applications. If they are too soft, **slipping** can occur. If they are too stiff, noise and poor bleeding characteristics can occur.

9.3 BEARING LUBRICATION SYSTEM CONSIDERATIONS

The significance of the problem of bearing lubrication varies between "important" and "critical," depending on the application. Furthermore, as in the selection of bearings, there is no simple cure-all solution.

This article describes the importance of proper bearing lubrication. It also presents some associated problems and offer clues to help solve them.

First of all, lubrication is needed to reduce bearing friction resulting from deflection of the balls and races under load. Although points of maximum contact pressures are sufficiently high to break the lubricant film, adjacent points operating under lesser pressures are exposed to some sliding friction and must be protected by lubrication. Lubrication is also used to reduce friction between the balls and the retainer.

By reducing bearing friction, the lubricants also help prevent undue temperature rises and dissipate some heat that is generated. Along quite different lines, lubricants help prevent corrosion on bearing components.

Both oils and greases can be used to lubricate rolling bearings satisfactorily. Oils used should be good grades of pure mineral oil and should have a viscosity suitable to the application. Oils other than mineral oil tend to turn rancid and oxidize more easily. Higher viscosity oils (heavy) are used for heavier loads and lower speeds, while the lower viscosity oils (light) are used for lighter loads and higher speeds.

Grease is basically a combination of soap and oil–roughly 80% oil and the remainder soap. Small quantities of other additives are sometimes included for stabilization, anti-oxidation, etc. Though the statement is not technically correct, soap acts as a sponge to retain oil in the grease.

OIL OR GREASE?

Whether oil or grease would be the best choice for a bearing lubricant will depend on a number of important considerations.

First, thought should be given to the loads and speeds of the application–i.e., the **severity of the application**. This could affect the amount of original lubricant needed, the ease of replenishing used or lost lubricant, and the amount of cooling required.

Basic requirements of **design in the unit** could easily be a determining factor. Lubrication with oil generally is more complicated than grease lubrication–especially in extreme applications. This can be seen by comparing the simplicity of a "sealed-for-life" bearing with the complexity of design required for oil lubrication, where a pump is incorporated to circulate the oil.

The **operating conditions** of the unit should also be considered, including temperature, humidity, cleanliness, horizontal or vertical mounting, and hazards of lubricant spillage that could cause damage.

Finally, consider the relative ease of maintaining a proper supply of lubricant. Questions to answer here would include:

- Is the unit in a fixed position or portable, and is the lubricant apt to be lost easily?
- Is the bearing hard to get at?
- Can the lubricant be thrown out easily?
- Does the relubrication method involve a needless expenditure of manpower?

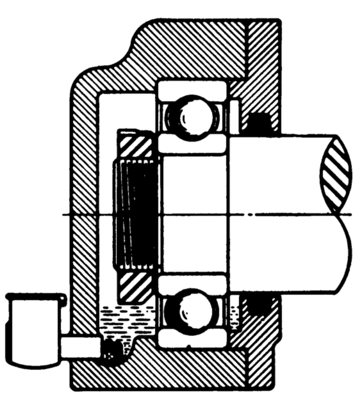
METHODS FOR MAINTAINING A PROPER OIL SUPPLY

A **constant-level system** (Figure 9-8) for maintaining an oil supply requires a reservoir from which a small quantity of oil is constantly trying to work its way into the lower portion of the outer raceway of the bearing.

Constant-level systems are quite satisfactory for slow speed, horizontal applications in stationary units. The most common problems with these systems are difficulty in maintaining the proper level of oil and possible sudden loss of this level.

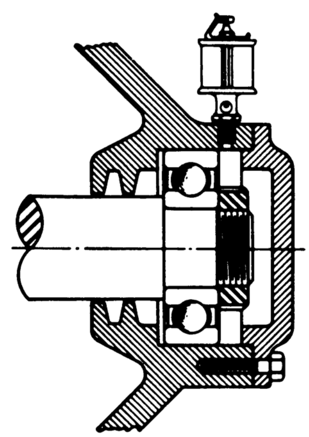
Regulated drip systems (Figure 9-9) are commonly used but run into difficulties in controlling the drip. They may sup-

FIGURE 9-8



Constant level system.

FIGURE 9-9



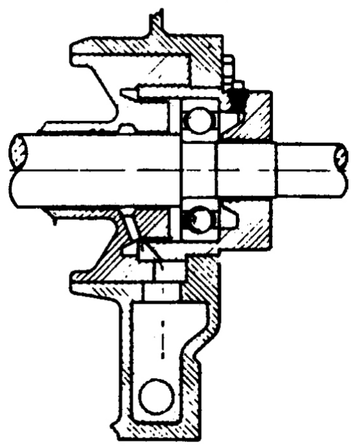
Regulated drip system.

ply too much or too little oil, or the orifice may suddenly plug up. Other problems include excessive oil waste, the associated mess, and possible loss of oil supply.

With **splash systems,** oil is sloshed on adjacent elements and then finds its way into the bearing. This system is practical for many relatively high speed applications with large oil reservoirs (e.g., automobile transmissions).

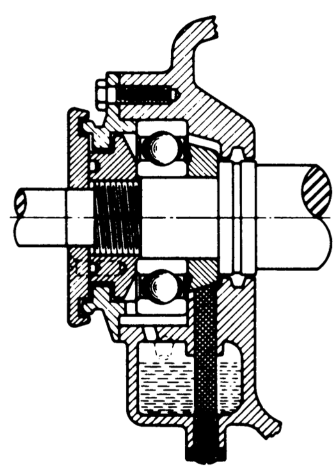
Circulating oil systems (Figure 9-10), although the most complicated to incorporate, are among the most practical. They generally use a wick feed or a circulating pump feed.

FIGURE 9-10



Circulating oil system.

FIGURE 9-11



Wick feed system.

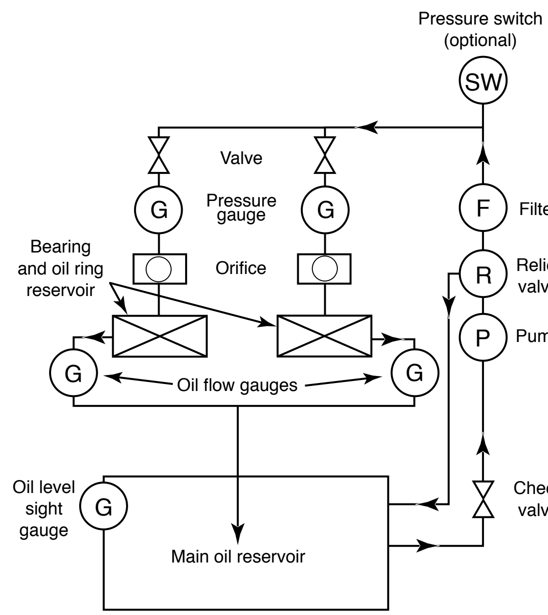
In the wick feed system (Figure 9-11), oil is fed from a reservoir through the wick to a smooth rotating disc, which in turn feeds it into the bearings. Oil leaving the rotating disc is generally in the form of fine droplets.

Oil circulation pumps are usually very elementary, consisting of a screw thread or a coil spring that feeds oil forward or upward into the bearing. Centrifugal force plays an important part in the function of these pumps.

Typical construction incorporates the pump in a vertical application with the end of the hollow shaft in an oil reservoir. As the shaft rotates, the thread on the inside lifts the oil to the top of the shaft, where it is released and drips into the upper bearing. From here the oil circulates through a bypass into the lower bearing, and eventually into the reservoir.

Oil mist systems (Figure 9-12) are usually purchased commercially and installed as a unit on high-speed applications like grinding spindles. These units atomize drops of oil and then force the mist into the bearings using dry, low-pressure air from an external source.

FIGURE 9-12



Oil mist system.

One advantage of these systems is that they supply finely atomized oil to the bearing, so bearings encounter very little interference in high-speed rotation. Another advantage is that surplus air creates a positive pressure inside the spindle, which prevents dirt and other contaminants from entering the unit. The cooling effect of the air also helps keep the bearings and spindle at lower temperatures.

METHODS FOR MAINTAINING A GREASE SUPPLY

Compared with the problems of oil lubrication, maintaining a grease supply in the bearings is relatively simple. Perhaps the easiest method is to use **pre-sealed** or **shielded bearings** that are lubricated for life.

For more severe-duty applications, provision is made in the exterior housing for a **grease reservoir** that is partially filled with suitable grease. Oil dripping from the reservoir continuously travels down a passage to a shield plate and into the bearing to replenish depleted lubricant.

Open bearings with **grease reservoirs on both sides** are used for still more severe applications. Grease is usually retained in the proximity of the bearing by means of external seals incorporated into the basic unit. Care must be exercised to avoid overloading the grease reservoirs. In fact, they normally should not be more than about half full.

In **extremely severe applications**, the grease must be replaced periodically. To accomplish this, suitable orifices are placed so that old and worn grease can be forced out of the cavity as new grease is introduced.

To avoid extreme overheating, it is important not to overload the reservoir. The unit must be run long enough to force out any surplus grease before closing the cavity.

One of the greatest hazards in relubricating bearings is failure to observe rigorous cleanliness procedures.

VARIATION IN GREASES

Grease technology is becoming increasingly complex as new formulations are developed to solve practical problems. Such solutions usually involve varying the type, hardness and percentages of soap; changing the oil types, viscosity and percentage; and modifying other additives.

The **basic types of soaps** used in greases include soda-base soap greases. These are generally used in dry applications, or where it is necessary to absorb and dissipate small quantities of moisture (e.g., condensation) throughout the grease. The absorbed moisture is then expelled with subsequent elevations of temperature.

Lithium or calcium soaps, being water repellent, are used in applications where either no moisture or extreme moisture conditions are encountered. Since they are insoluble in water, they are not easily displaced by water. At the same time, these greases can entrap water, making it difficult to expel.

Other soaps, as well as synthetic materials used as soap replacements, have found their way into the grease field in some special applications with abnormal operating conditions. Some aircraft applications, where a wide range of temperatures and atmospheric pressures are involved, might call for one of these greases.

Variations in oil **viscosity** also affect the penetration value of greases. High viscosity oils tend to make the greases stiffer, so they work well for the heavier loads. The higher viscosity oils in greases are also less susceptible to atomization and thinning at higher temperatures. The low viscosity oils are used for reduced loads and lower temperatures.

Variations in the **percentage of oil** present in the greases also affect their penetration value. The saturation percentages vary with the different soaps.

Additives are used to modify the grease properties. Common additives include anti-oxidants, fillers and wetting agents. Anti-oxidants are used to retard deterioration of greases.

Fillers (e.g., leads, graphites and sulfides) are generally used for special applications. These applications frequently involve extreme pressures resulting from high loads.

Wetting agents are sometimes used in greases to facilitate wetting or lubrication of the ball track, especially in applications involving reciprocating motions.

Special purpose greases are available for low- and high-temperature applications, including **special synthetic greases** for both low temperatures and very high temperatures. These special synthetic greases usually are designed to meet specific problems–primarily very high temperatures. Of these, perhaps the most common are silicone greases, which use silicone oils in place of mineral oils.

Some special greases are used for extremely high-temperature applications, while others are designed for very low-temperature applications. Still others can handle a very wide range of temperatures.

Note that while special greases may do their specific jobs quite well, they usually are less efficient in average temperature ranges and applications.

TESTING GREASES

There are many standardized tests for determining the various properties of grease. One of the foremost of these checks the **lubrication properties** of the grease, including its ability to prevent wear on bearing friction surfaces.

The **penetration test** and the **worked penetration tests** determine stiffness or movability of grease. They are used as a measure of the channeling or the self-leveling properties of the grease.

The **oxidation rate** or aging properties of the grease are checked by accelerated tests. Oxidized greases form poor lubricants and also tend to accelerate corrosion.

The **bleeding rate**, or rate at which oil tends to separate from the soap, is also an important consideration in greases. Judiciously choosing a grease with the appropriate bleeding rate can compensate for the severity of the application.

The **emulsification properties** of greases are also important, especially for humid applications. A grease that is easily emulsified would normally be flushed out of the bearing very easily in wet applications. At the same time, this type of grease would best dissipate small quantities of moisture.

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9.4 GREASE CLASSIFICATIONS

GREASE CLASSIFICATIONS

NLGI* GROUP	TEMPERATURE RANGE °F			°C			APPLICATION
1	-40	to	250	-40	to	121	General purposes
2	0	to	300	-18	to	149	High temperature
3	32	to	200	0	to	93	Medium temperature
4	-67	to	225	-55	to	107	Low temperature
5		to	450		to	232	Extreme high temperature

* NLGI stands for the National Lubricating Grease Institute.

9.5 REFERENCED STANDARDS

The following standard is referenced in this section of the *EASA Technical Manual*.

ASTM Std. D6185-117 (2017): *Standard Practice for Evaluating Compatibility of Binary Mixtures of Lubricating Grease*s. ASTM International, West Conshohocken, PA, 2017, www.astm.