Lubrication of Anti-Friction Bearings

Introduction

Although the basic principle of ball and roller bearings is the rolling of one element over another, some sliding friction is generated during operation of anti-friction bearings. Successful operation of an anti-friction bearing requires a lubricating film in the areas of sliding contact. In cageless bearings, the rolling elements slide against each other. When a cage is present the rolling elements slide against this and under some operating conditions, the cage slides against ring guiding surfaces. When a ball under load rolls in a curved bearing raceway, pure rolling occurs only along two lines in the contact area; other contact points on the ball slide or spin along areas of the raceway. This is because the effective diameter of the ball is smaller at points distant from the bottom of the race-groove. See Figure 1.

a. The forces of slippage between zone #1 and the two zones #2 are equal in magnitude.

b. The slippage in zone #1 is in opposite direction from that in zone #2.

c. Technically the zones of pure rolling in #3 are very narrow but there are larger areas that approach pure rolling.

d. These conditions exist, although less obvious, even when loads are lighter and the ball paths narrower.

Without lubrication in the highly loaded contact areas, very high friction will be encountered in ball bearings. High friction generally creates high heat and thermal expansion, usually concentrated in the rolling elements and inner ring races which may cause a loss of internal clearance and radial preloading. This frequently causes surface degeneration and early fatigue. Cage breakage may also result from extreme stresses.

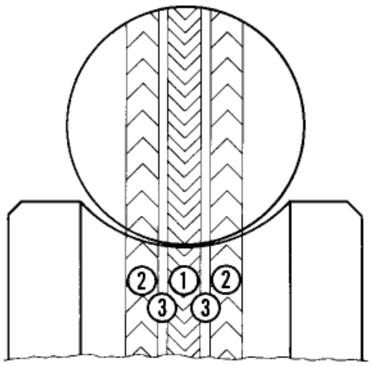


Figure 1

Bearing Construction

An anti-friction bearing is a precision device and a marvel of engineering. It is unlikely that any other mass produced item is machined to such close tolerances. While boundary dimensions are usually held to tenths of a thousandth of an inch, rolling contact surfaces and geometries are maintained to millionths of an inch. It is for this obvious reason that very little surface degradation can be tolerated.

Bearing steels are hard, durable alloys, highly free of impurities in order to withstand the high unit stresses which occur at the point of contact between a rolling element and the race. Also, they must be sufficiently elastic to quickly regain their original shape after deformation through loading.

Race and rolling element finish are also critical since even minute surface imperfections can cause high stress concentrations resulting in premature failure.

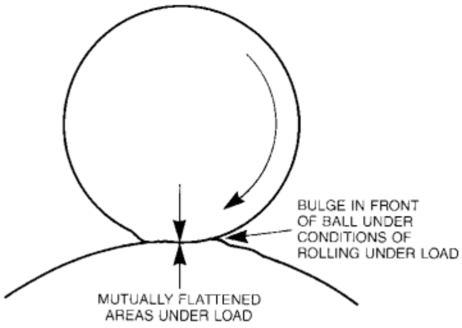


Figure 2

Principle of Operation

When a ball in a bearing is subjected to load, an elliptical area of contact results between the ball and the race. In operation, as each ball enters the loaded area, slight deformation of both the ball and the race occurs. The ball flattens out in the lower front quadrant and bulges in the lower rear quadrant. (See Figure 2) The amount of deformation is a function of the magnitude and direction of load, ball size, race geometry, and elasticity of the bearing materials. Any particular point on the race goes through a cycle of these stress reversals as each ball passes it. One source of heat developed in a bearing results from these stresses and the deformation of the bearing material associated with them.

The life of an anti-friction bearing running under good operating conditions is usually limited by fatigue failure rather than by wear. Under optimum operating conditions, the fatigue life of a bearing is determined by the number of stress reversals and by the cube of the load causing these stresses. As examples, if the load on the bearing is doubled, the theoretical fatigue life is reduced to one-eighth. Also, if speed is doubled, the theoretical fatigue is reduced to one-half.

Friction Torque

The friction torque in an anti-friction bearing consists essentially of two components. One of these is a function of the bearing design and the load imposed on the bearing. The other is a function of the lubricant type, the quantity, and the speed of the bearing.

It has been found that the friction torque in a bearing is lowest with a quantity of the correct viscosity oil just sufficient to form a film over the contacting surfaces. The friction will increase with greater quantity and/or high viscosity of the oil. With more oil than just enough to make a film, the friction torque will also increase with the speed.

Function of The Lubricant

1. To lubricate sliding contact between the cage and other parts of the bearing.
2. To provide a film of oil between rolling contact surfaces (elastohydrodynamic lubrication).
3. To lubricate the sliding contact between the rolls and guiding elements in roller bearings.
4. In some cases, to carry away the heat developed in the bearing.
5. To protect the highly finished surfaces from corrosion.
6. To provide a sealing barrier against foreign matter.

Oil Versus Grease

The ideal lubricant for rolling element bearings is oil. Grease, formed by combining oil with soap or non-soap thickeners, is simply a means of effecting greater utilization of the oil. In a grease, the thickener acts fundamentally as a carrier and not as a lubricant.

Greases are now used for lubricating by far the larger number of rolling bearings. The extensive use of grease has been dictated by the possibilities of simpler housing designs, less maintenance, less difficulty with leakage, and better sealing against dirt. On the other hand, there are limitations which do not permit the use of grease. Where a lubricant must dissipate heat rapidly, grease should not be used. In many cases, associated machine elements that are oil lubricated dictate the use of oil for anti-friction bearings. Listed below are some of the advantages and disadvantages of grease lubrication.

Advantages

1. Simpler housing designs are possible; piping is greatly reduced or eliminated.
2. Maintenance is greatly reduced since oil levels do not have to be maintained.
3. Being a solid when not under shear, grease forms an effective collar at bearing edges to help seal against dirt and water.
4. With grease lubrication, leakage is minimized where contamination of products must be avoided.
5. During start-up periods, the bearing is instantly lubricated whereas with pressure or splash oil systems, there can be a time interval during which the bearing may operate before oil flow reaches the bearing.

Disadvantages

1. Extreme loads at low speed or moderate loads at high speed may create sufficient heat in the bearing to make grease lubrication unsatisfactory.
2. Oil may flush debris out of the bearing. Grease will not.
3. The correct amount of lubricant is not easily controlled as with oil.

Oil Characteristics

The ability of any oil to meet the requirements of specific operating conditions depends upon certain physical and chemical properties.

Viscosity

The single most important property of oil is viscosity. It is the relative resistance to flow. A high viscosity oil will flow less readily than a thinner, low viscosity oil.

Lubrication Viscosity

There are a number of instruments used for determining the viscosity of oil. In the United States the instruments that are usually used are the Viscosimeter or the Viscometer. The Saybolt Universal Viscosimeter measures the time in seconds required for 60cc of oil to drain through a standard hole at some fixed temperature. When this unit is used the viscosities are quoted in terms of Saybolt Universal Seconds (SUS).

When the Kinematic Viscometer is used to measure oil viscosity, the time required for a fixed amount of oil to flow through a calibrated capillary is used as an intermediate value for calculating viscosity. The unit of kinematic viscosity is the stoke or the centistoke (cSt). The common temperatures for reporting viscosity are 104˚F and 212˚F (40˚C and 100˚C).

Generally, for ball bearings and cylindrical roller bearings, it is a good rule to select an oil which will have a viscosity of at least 70 SUS (15 cSt) at operating temperature.

Viscosity Index

All oils are more viscous when cold and become thinner when heated. However, some oils resist this change of viscosity more than others. Such oils are said to have a high viscosity index (V.I.). Viscosity index is most important in an oil where it must be used over a wide range of temperatures. Such an oil should resist excessive changes in viscosity. A high V.I. is usually associated with good oxidation stability and can be used as a rough indication of such quality.

Pour Point

Any oil, when cooled, eventually reaches a temperature below which it will no longer flow. This temperature is said to be the pour point of the oil. At temperatures below its pour point an oil will not feed into the bearing and lubricant starvation may result.

In selecting an oil for anti-friction bearings, the pour point must be considered in relation to the operating temperature.

Flash and Fire Point

As an oil is heated, the lighter fractions tend to volatilize. With any oil, there is some temperature at which enough vapor is liberated to flash into momentary flame when ignition is applied. This temperature is called the flash point of the oil. At a somewhat higher temperature enough vapors are liberated to support continuous combustion. This is called the fire point of the oil. The flash and fire points are significant indications of the tendency of an oil to volatilize at high operating temperatures. High V.I. base oils generally have higher flash and fire points than lower V.I. base oils of the same viscosity.

Oxidation Resistance

All petroleum oils are subject to oxidation by chemical reaction with oxygen of air. This reaction results in the formation of acids, gum, sludge, and varnish residues which can reduce bearing clearances, plug oil lines and cause corrosion.

Some lubricating fluids are more resistant to this action than others. Oxidation resistance depends upon the fluid type, the methods and degree of refining used, and whether oxidation inhibitors are used.

There are many factors which contribute to the oxidation of oils and practically all of these are present in lubricating systems. These include temperature, agitation, and the effects of metals and various contaminants which increase the rate of oxidation.

Temperature is a primary accelerator of oxidation. It is well known that rates of chemical reaction double for every 18˚F (10˚C) increase in temperature. Below 140˚F (60˚C), the rate of oxidation of oil is rather slow. Above this temperature, however, the rate of oxidation increases to such an extent that it becomes an important factor in the life of the oil. It is for this reason that it is desirable that oil systems operate at as low an over-all temperature as is practical.

The oxidation rate of oil is accelerated by metals such as copper and copper-containing alloys and to a much lesser extent by steel. Contaminants such as water and dust also act as catalysts to promote oxidation of the oil.

Emulsification

Generally, water and straight oils do not mix. However, when an oil becomes dirty, the contaminating particles act as agents to promote emulsification. In anti-friction bearing lubricating systems, emulsification is undesirable and the oil should separate readily from any water present. The oil should have good demulsibility characteristics.

Rust Prevention

Although straight petroleum oils have some rust protective properties, they can not be depended upon to do an unfailing job of protecting rust-susceptible metallic surfaces. In many instances, water can displace the oil from the surfaces and cause rusting. Rust is particularly undesirable in an anti-friction bearing because it can seriously abrade the bearing elements and areas that are pitted by rust will cause rough operation or failure of the bearing.

Additives

High grade lubricating fluids are formulated to contain small amounts of special chemical materials called additives. Additives are used to increase the viscosity index, fortify oxidation resistance, improve rust protection, provide detergent properties, increase film strength, provide extreme pressure properties, or lower the pour point.

Application of Lubrication Fluids

The amount of oil needed to maintain a satisfactory lubricant film in an anti-friction bearing is extremely small. The minimum quantity required is a film averaging only a few microinches in thickness. Once this small amount has been supplied, make-up is required only to replace that lost by vaporization, atomization, and creepage from the bearing surfaces. Some idea of the small quantity of oil required can be realized when it is known that 1/1000 of a drop of oil, having a viscosity of 300 SUS at 100˚F (38˚C) per hour can lubricate a 50 mm bore bearing running at 3,600 RPM. Although this small amount of oil can adequately lubricate a bearing, much more oil is needed to dissipate heat generated in high speed, heavily loaded bearings.

Oil may be supplied to anti-friction bearings in a number of ways. These include bath oiling, oil mist from an external supply, wick feed, drip feed, circulating system, oil jet, and splash or spray from a slinger or nearby machine parts.

One of the simplest methods of oil lubrication is to provide a bath of oil through which the rolling element will pass during a portion of each revolution. Where cooling is required in high speed and heavily loaded bearings, oil jets and circulating systems should be considered. If necessary, the oil can be passed through a heat exchanger before returning to the bearing.

Selection of Oil

The most important property of lubricating oil is the viscosity. Figures 1 and 2 should be used to assure that the viscosity is adequate in an application. Figure 1 yields the minimum required viscosity as a function of bearing size and rotational speed.

The viscosity of a lubricating oil, however, varies with temperature. It decreases with increasing temperature. Therefore, the viscosity at the operating temperature must be used, rather than the viscosity grade (VG) which is based on the viscosity at the internationally standardized reference temperature of 40˚C (104˚F). Figure 2 can be used to determine the actual viscosity at the operating temperature, which, however, varies with bearing design. For instance tapered and spherical roller bearings usually have a higher operating temperature than ball bearings or cylindrical roller bearings under comparable operating conditions.

Example:

A bearing having a bore diameter of 45 mm and an outside diameter of 85 mm is required to operate at a speed of 2000 rpm. The pitch diameter dm = 0.5 (d + D) = 0.5 (45 + 85) = 65 mm. As shown in Figure 1, the intersection of d_m = 65 mm with the oblique line representing 2000 rpm yields a minimum viscosity required of 13 mm^2 /s. Now let us assume that the operating temperature is 80˚C (176˚F). In Figure 2, the intersection between temperature 80˚C and required viscosity 13 mm^2 /s is between the oblique lines for VG46 and VG68. Therefore, a lubricant with the viscosity grade of at least VG46 should be used, i.e. a lubricant of at least 46 mm^2 /s viscosity at the standard reference temperature of 40˚C.

When determining the operating temperature, it should be kept in mind that the temperature of the oil is usually 3˚ to 11˚C (5˚ to 20˚F) higher than that of the bearing housing. For example, assuming that the temperature of the bearing housing is 77˚C (170˚F), the temperature of the oil will usually be 80˚ to 88˚C (176˚ to 190˚F).

If a lubricant with higher than required viscosity is selected, an improvement in bearing performance (life) can be expected.

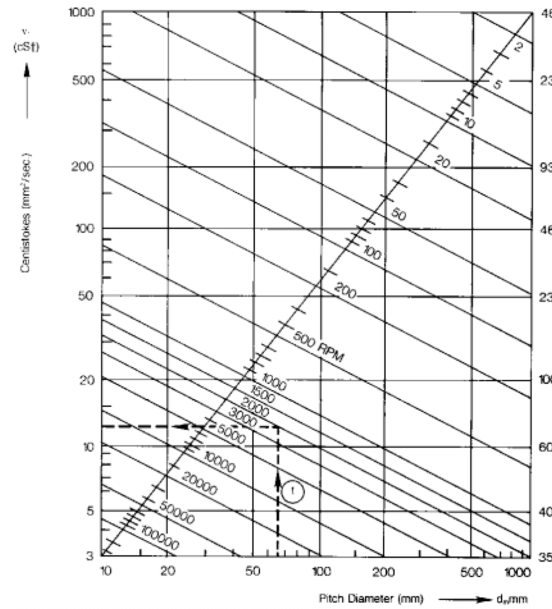


Figure 1
Minimum Required Lubricant Viscosity

d^m = (bearing bore + bearing O.D.)/2

v_1 = required lubricant viscosity for adequate lubrication at the operating temperature

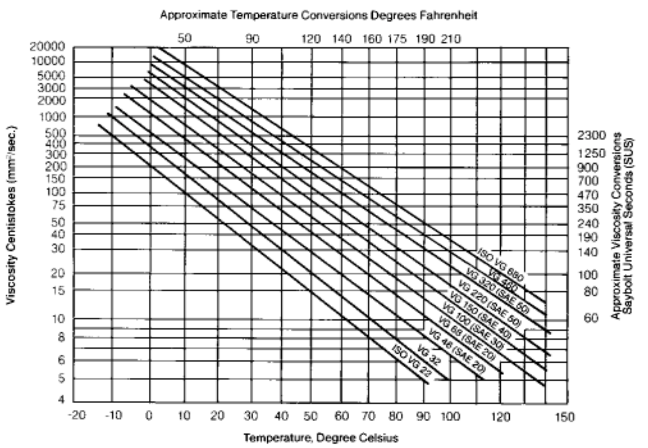


Figure 2 Viscosity-Temperature Chart

NOTE: Viscosity classification numbers are according to International Standard ISO 3448–1975 for oils having a viscosity index of 95. Approximate equivalent SAE viscosity grades are shown in parentheses.

However, since increased viscosity raises the bearing operating temperature, there is frequently a practical limit to the lubrication improvement which can be obtained by this means. Also only solvent refined mineral oil should be used.

For exceptionally low or high speeds, for critical loading conditions or for unusual lubrication conditions, please consult MRC Applications Engineering.

For all calculations, the viscosity should be expressed in mm^2 /s (cSt) rather than in Saybolt Universal Seconds (SUS), as the conversion between these two viscosity units is nonlinear. However, the SUS scale shown on the right of Figures 1 and 2 can be used for approximate conversion of SUS to mm^2 2 /s (cSt).

For comparative viscosity classifications and conversion tables see next page.

Oil Flow Requirement

For high speed and/or high temperature applications, a major function of the lubricant is to remove heat, and circulating oil lubrication is necessary.

Unfortunately, excessive quantity of lubricant within the bearing boundary dimensions, i.e., within the *free volume,* causes increased friction and hence increased heat generation owing to *fluid churning.* Therefore the lubricant flow rate through the bearing should be as little as possible, consistent with good lubricant film formation and heat removal. This minimum acceptable flow rate can be achieved using *air-oil mist* lubrication. Care must be exercised to assure that the lubricant flow rate is sufficient to avoid *lubricant starvation* in high speed applications. In this condition, insufficient lubricant enters the rolling element-raceway contacts to permit formation of lubricant films thick enough to separate the components.

From a heat removal standpoint and as a starting point to determine the required lubricant flow rate in gallons per minute *(W),* the following approximate formula may be used:

In English system units, the flow rate in gallons per minute (W) is:

$$W = \frac{1.9 \times 10^{-4}\,\mu\, P d_m n}{(T_o - T_i)}$$

in which μ is the bearing coefficient of friction, P is imposed load in pounds, d_m is bearing pitch diameter in inches, n is bearing net speed *(shaft speed minus outer ring speed)* in *rpm,* T_o is lubricant outlet temperature in ˚F and T_i is lubricant inlet temperature in ˚F. The table below gives appropriate values of μ.

Coefficient of Friction (μ)

Radial ball bearings	0.0015
Angular-contact ball bearings	0.0020
Split inner ring ball bearings	0.0024
Cylindrical roller bearings	0.0011

Lubricating Grease

Most greases are composed of a soap thickening agent in petroleum oil. Soap is formed by combining a metallic alkali such as the hydroxide of sodium or lithium with a fatty material. The type and quality of soap determines the grease consistency, texture, melting point, and solubility in water. Sometimes a mixture of soaps is used to alter the properties. Additives are used to impart such properties as increase in load carrying capacity, rust prevention, and oxidation stability.

Lithium soap petroleum greases are widely used because of their good water resistance, relatively good high and low temperature characteristics, and good mechanical stability. Sodium soap greases are not water resistant and are readily washed away by large amounts of water. However, they have excellent rust preventive properties due to their ability to absorb minor amounts of water contamination.

Greases containing thickeners other than metallic soaps are being used increasingly because they offer greater resistance to heat. They are a multi-purpose type and have good water resistance. Surface treated clay is an inorganic thickener used in many greases.

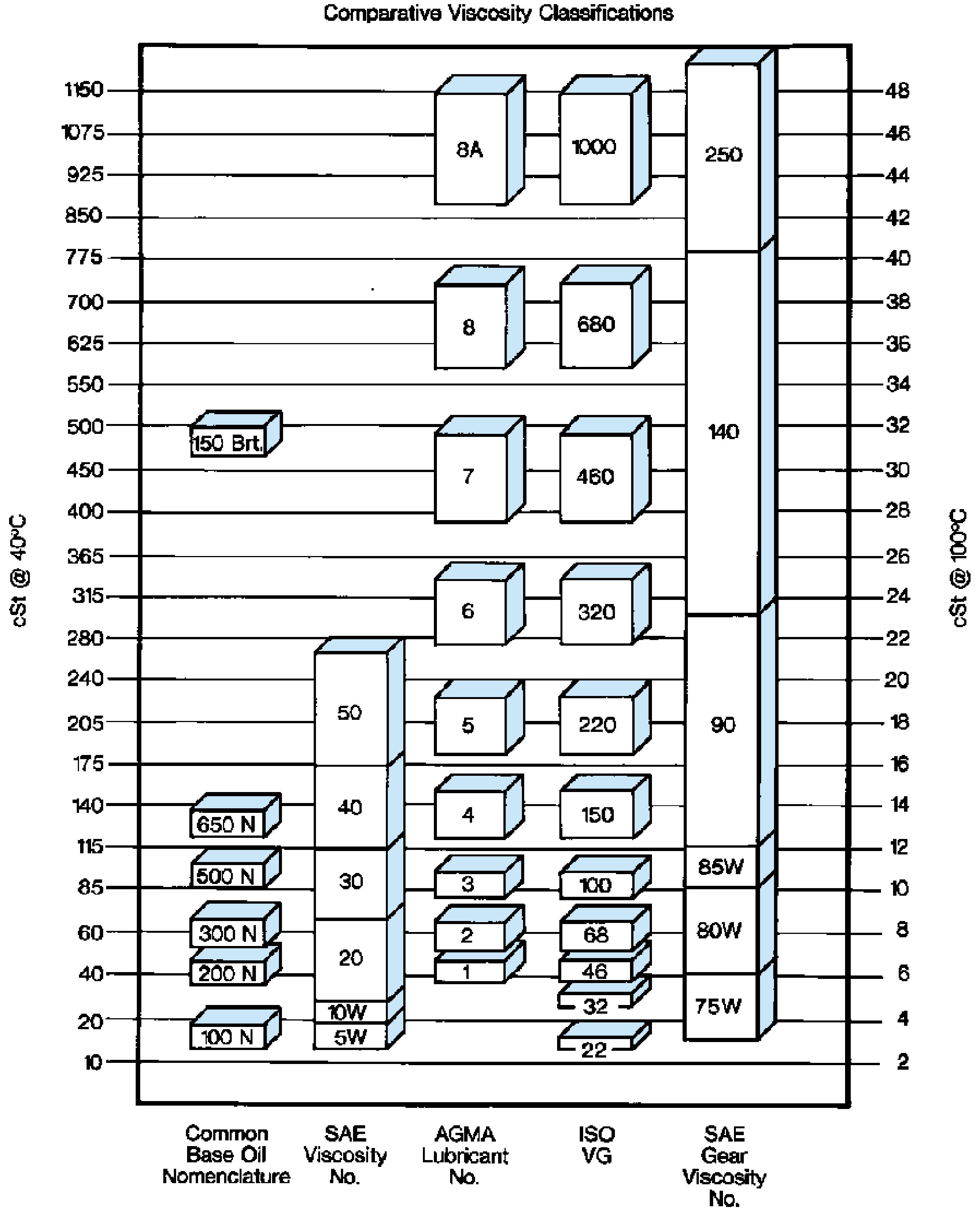
Intensive research in the development of oxidation resistant formulations has resulted in great increases in the life which lubricating greases can provide. Through the use of synthetic oily compounds and non-soap thickeners, grease lubrication can now be achieved over a temperature range of –100˚F to + 500˚F (–73˚C to 260˚C) and higher in some cases.

Synthetic greases are formulated with synthetic fluids such as silicones, esters, perfluoroalkyl ethers, or polyphenyl ethers instead of petroleum oil. The thickener may be soap or non-soap. Synthetic greases are used in extremely high or low temperature applications that are outside the range for petroleum greases. They are relatively expensive and therefore are not usually recommended if petroleum greases will serve the purpose.

In the great majority of applications where the operating conditions are normal, many different greases can be used satisfactorily. However, each grease has certain limitations and properties. In applications where elevated temperature, high speed, heavy loading, high humidity, or other extreme conditions are encountered, consideration must be given to the choice of a grease. In some instances it will be found that no available grease has all the properties to satisfy the requirements and the choice must be a compromise.

It is recommended that the bearing user consult with MRC Technical Services Department to determine the lubricant which will be most suitable for the application.

Comparative Viscosity Classifications



Grease Characteristics

Consistency

Greases vary in consistency from semi-fluids to hard, brick type greases which are cut with a knife. The method for measuring grease consistency (ASTM D-217), established by the American Society for Testing and Materials, uses a penetrometer with which a cone of standard shape and weight is dropped into the grease and the depth of penetration in five seconds at 77˚F (25˚C) is measured in tenths of a mm. The penetration is usually measured on both unworked grease as it comes from its shipping container and also after it has been worked 60 strokes by a perforated disc plunger.

Usually greases become softer when subjected to mechanical working action. These consistency measurements are expressed as unworked and worked. The 60 stroke working is done to minimize the effects of any previous manipulation of the grease in sampling. Also, the worked penetration indicates the relative softening after a limited amount of shear. However, this working cannot be correlated to the much more severe shearing action that occurs in a bearing.

Listed in the table below is a classification of the consistency of grease in terms of worked penetration as developed by the National Lubricating Grease Institute.

NLGI No.	Worked Penetration
000	445 – 475
00	400 – 430
0	355 – 385
1	310 – 340
2	265 – 295
3	220 – 250
4	175 – 205
5	130 – 160
6	85 – 115

Most rolling bearing greases fall into classes 1-4. By far the greater portion of bearing applications use NLGI Grade 2 grease.

Dropping Point

When a grease is heated, it softens. The temperature at which a drop falls from a sample in a standard test (ASTM D-566) is called its dropping point. The dropping point cannot be used to indicate the maximum operating temperature for a grease since some greases oxidize or decompose rapidly at temperatures below the dropping point. Dropping point is of little significance to the grease user but it is of significant value to the grease maker as means of quality control.

Oxidation Stability

Reaction with oxygen in the air, which is accelerated with higher temperatures, is one of the main factors limiting the life of bearing greases. This reaction ultimately results in drying and hardening of the grease with total loss of lubricating properties.

The standard test used to measure the oxidation stability of grease is the Oxygen Bomb Method (ASTM D-942). In this test, the rate of absorption of oxygen by the grease at 210˚F (99˚C) and 110 PSI is recorded. This test is conducted under static conditions and is intended only to be useful in estimating the shelf life of greases. However, it has been found that greases which show low oxygen absorption usually perform reasonably well in service.

Water Resistance

Water resistance varies with the different types of greases. Most sodium soap greases emulsify and thin out when mixed with water. Other types are less affected but their resistance to washout varies with the viscosity of the oil and the amount and type of thickener. No lubricating grease is completely water resistant. Even those classed as water insoluble or water resistant can be washed out of a bearing if exposed to large volumes of water.

The ability of a grease to withstand water washout from a bearing is determined by ASTM Method D-1264. A ball bearing with a specified quantity of the test grease is mounted in a housing with specified clearances to allow entry of water from a jet. After one hour of operation at 600 RPM with the water at a controlled temperature impinging on the housing at a specified rate, the bearing is reweighed and the amount of grease lost is determined.

Shear Stability

(Mechanical Stability)

This is the resistance of a grease to structural breakdown when subjected to the shearing action of being worked.

Two grease working tests are used to measure softening of grease due to working. ASTM Method D-217, described earlier under Consistency, forces the grease through a perforated plate at a rate of 60 times per minute. The Shell Roll Test subjects the grease to the working action of a roll inside a rotating cylinder. Penetration values are determined before and after rolling. The degree of softening that results from working is important from the aspect of leakage from the bearing. However, the results cannot be correlated to bearing performance since greases which have appeared unsatisfactory in these tests have been found to provide very satisfactory bearing performance.

Oil Separation

Most greases show some tendency to allow oil separation in certain circumstances. During storage, depressions in the grease surface or voids collect oil.

This separation increases with higher storage temperatures as the viscosity of the oil phase is lowered. Oil separation, unless excessive, is not reason for rejection of a rolling bearing grease. Five percent is typically permitted. Usually the separated oil can be easily stirred back into the grease body.

The standard test method for determining oil separation from grease during storage is ASTM D-1742. This is a simple test where the sample is placed on a sieve strainer in a pressure cell with inlet air pressure maintained at 0.25 PSI. The test is conducted at 77˚F (25˚C) and after 24 hours the separated oil that has collected on the bottom of the cell is weighed and expressed as a percentage by weight of the original sample. This test is only intended to measure the tendency of a grease to separate oil during storage. It is not intended to predict the stability of grease under dynamic service conditions.

Channeling

Channeling is a term referring to the tendency of a grease to separate and form a channel after the passage of the balls and cage around the ball race. Some greases channel very little and flow back rapidly to fill the voids left by the rotating elements to cause higher torque and higher operating temperatures from the shear stresses within the lubricant. Poor channeling characteristics can make some greases unsatisfactory for high speed operation when a channeling type grease will provide minimum torque and heat rise. Channeling type greases are usually of NLGI No. 3 or No. 4 consistency.

Special Properties

There are many special grease formulations to meet a variety of unusual requirements. Special properties, which have been listed below, are often required in a grease. These special requirements may include:

1. Extra tackiness or adhesiveness to resist leakage or throw-out.
2. Proper structure for sealing to exclude contaminates.
3. Resistance to the action of certain chemicals.
4. Resistance to the action of solvents.
5. Electrical conductivity.
6. Resistance to the effects of nuclear radiation.
7. Resistance to the effects of high vacuum.
8. Non-toxic for use where there may be contact with food.
9. High oil bleed rates ≥ 2.5% for machined land guided cages

Operating Conditions

Low Temperature

Oils and greases tend to thicken and resist flow as temperatures are decreased. For oil lubricated bearings operating at cold temperatures, an oil that has a sufficiently low pour point to remain fluid at the low temperature and the proper viscosity for the operating temperature should be chosen. If the oil is subjected to low temperature start-up but operates at higher temperatures, a high viscosity index is desirable.

Usually the most important consideration in selecting a grease for low temperature operation is start-up torque. Some greases may function satisfactorily during operation but require excessive torque for start-up. Starting torque is not a function of the consistency or the channeling properties of a grease. It appears to be a function of the individual properties of the grease and is difficult to measure. Experience alone will show whether one grease is better than another in this respect. Greases formulated with synthetic oils are available which provide very low starting and running torque at temperatures as low as –100˚F (–73˚C). Generally, a correctly selected grease provides lower torque than an oil.

High Temperature

In oil lubricated bearing applications where ambient temperatures are high, such as in ovens, some means of cooling is usually necessary to avoid excessive bearing temperatures and premature lubricant failure. Some of the commonly used methods for decreasing the oil temperature are cooling coils, water jackets, oil cooling tanks, cooling discs, and fans.

The rate of oxidation of lubricating fluids increases rapidly with temperature rise. As mentioned earlier, the rate of oxidation doubles for each 18˚F (10˚C) temperature rise above 140˚F (60˚C). Above 250˚F (121˚C), petroleum oils tend to oxidize rapidly and sometimes it becomes necessary to use special petroleum oils or synthetic oils to increase the service life of the lubricant.

Where the only heat is that generated by the bearing, temperature rise can usually be held to a reasonable level by the use of a suitable lubricant in proper quantity.

The high temperature limit for greases, i.e. the maximum temperature at which a grease will provide a reasonable life in a non-relubricable bearing, is largely a function of the oxidation stability of the fluid and the thickener. The oxidation process is greatly accelerated with increasing temperature. Another factor is evaporation of the fluid phase. Also, greases thin out at high temperatures. If the grease consistency becomes too soft at operating temperatures there may be leakage from the bearing.

High Speeds

Small size anti-friction bearings are often successfully grease lubricated at high speeds. Larger sizes usually require oil to remove heat as well as to lubricate.

Where extensive cooling is required in high speed and heavily loaded bearings operating with high frictional heat, oil jets and circulating systems should be considered. For small and medium size bearings rotating at high speeds, an oil circulating system, drip feed or oil mist is satisfactory.

With other influences being equal, increasingly lower viscosities are needed with increasing speeds. The quantity of oil needed for successful operation becomes greater with increasing temperature, load, speed, and bearing size.

Extreme Pressures

Various extreme pressure agents are compounded into some greases and oils. These include additives such as sulfur, phosphorus, and chlorine compounds, graphite, and molybdenum disulfide. However, such additives are generally not required in anti-friction bearing lubricants and should be avoided unless their use is dictated by other associated equipment such as gears.

For most applications, higher viscosity oils are required to prevent metal to metal contact if pressures are higher than normal or if shock loading occurs. In cases where heavily loaded bearings operate at high speeds, the selection of oil viscosity must be a compromise between a heavy oil which is desirable for heavy loading and a light oil which is desirable for high speeds.

Wet Conditions

Whenever possible, an anti-friction bearing should be protected from water and moisture to avoid corrosion. Even slight corrosion on the internal surfaces may initiate bearing failure.

Ball and roller bearings are, however, often used successfully where moisture is present. The presence of moisture will affect the choice of a grease with the selection depending upon the quantity of moisture present.

Water soluble sodium base greases will form a non-corrosive emulsion when mixed with a limited quantity of water. However, agitation is necessary to form this emulsion. If water should enter an idle bearing, the bearing may become corroded. There is a limit to the amount of water which a water soluble grease can absorb and still protect the bearing surfaces.

A water resistant grease, such as a lithium base grease that contains an effective rust inhibitor should be used where large amounts of water are present. The term ‘‘water resistant grease’’ is actually a misnomer since no grease will totally resist large amounts of water for extended periods.

Slow moving bearings can be packed full of a cohesive, water resistant grease formulated with a very heavy oil to afford maximum protection against large amounts of water.Where wet conditions are so severe that satisfactory protection cannot be provided by a lubricant, it is sometimes necessary to use bearings fabricated of special corrosion resistant alloys or bearings with corrosion resistant coatings.

Fretting

Anti-friction bearings are sometimes damaged by a wear effect that is variously called fretting corrosion, fretting, friction oxidation and false brinneling. This effect evidences itself by the formation of rust-like wear debris and the formation of wear spots.

Fretting can occur in bearings subjected to vibration, vibratory loads, or oscillation of small amplitudes. It is sometimes seen in the bearings of idle machinery that has been subjected to the vibrations of nearby machines. The wear spots can be recognized as depressions or indentations in the races at the points where they have been in contact with the balls or rolls. If allowed to progress, the wear in these contact areas will become so extensive as to prevent functioning of the bearings.

Fretting can be eliminated or minimized by the selection of a lubricant which has good feed ability. Low viscosity oils minimize fretting to a greater extent than oils of higher viscosities.

With grease lubrication in applications where fretting is a problem, it is good general practice to use a soft grease such as an NLGI 0 or 1 grade or a harder grease which tends to soften considerably upon working.

Dust and Dirt

A high percentage of ball and roller bearing troubles can be attributed to foreign matter entering the bearing after mounting. Because anti-friction bearings are highly sensitive to dust and dirt, elaborate protective devices are necessary in some applications.

Oil lubricated bearings are generally protected from foreign particle contamination by the use of oil filters and the properly designed seals required in oil lubricated systems.

Grease in sealed and shielded bearings can provide an effective barrier against dust and dirt. Where the bearings operate in dusty or dirty atmosphere the grease should be chosen with its sealing properties in mind. Such a product should have good resistance to structural break-down on working. Usually, the stiff consistency of an NLGI Grade 3 grease will provide a good sealing barrier.

Operating Temperature Range

The temperature range over which a grease can be used depends on the type of base oil and thickener used as well as the additives. The lower temperature limit; i.e., the lowest temperature at which the grease will allow the bearing to be started up without difficulty, is determined by the base oil and its viscosity. The upper temperature limit is governed mainly by the type of thickener and indicates the maximum temperature at which the grease will provide lubrication for a bearing. It should be remembered that a grease will *age (deteriorate)* and oxidize with increasing rapidity as the temperature increases and that oxidation products have a detrimental effect on lubrication. The upper temperature limit should not be confused with the grease *dropping point* quoted by lubricant manufacturers as this value only indicates the temperature at which the grease loses its consistency and becomes fluid.

The following table gives the operating temperature ranges for the types of grease normally used for rolling bearing lubrication. The values are based on extensive testing and are valid for commonly available greases having a mineral oil base and no EP *(extreme pressure)* additives.

Operating Temperature Ranges for Mineral Oil-Based Greases

Grease Type (thickener)	Recommended Operating Temperature Range °C			°F		
Lithium base	–30	to	110	–22	to	230
Lithium complex	–20		140	– 4		284
Sodium base	–30		80	–22		176
Sodium complex	–20		140	– 4		284
Calcium base	–10		60	14		140
Calcium complex	–20		130	– 4		266
Barium complex	–20		130	– 4		266
Aluminum complex	–30		110	–22		230
Inorganic thickeners (bentonite, silica gel, etc.)	–30		130	–22		266
Polyurea	–30		140	–22		284

Greases based on synthetic oils; e.g., ester oils, synthetic hydrocarbons or silicone oils, may be used at temperatures above and below the operating temperature range of mineral oil-based greases. If grease-lubricated bearings are to operate at such temperatures, MRC Bearings Applications Engineering should be contacted for advice.

Example
A deep groove ball bearing, the bore diameter (d) of which is 100 mm rotates at 2000 r/min. The operating temperature varies between 60 and 70˚C. What lubricating interval should be expected?

Follow the line from 2000 on the x-axis of the diagram to the curve d =100 mm. Then follow a line at right angles to the first from the point of intersection to the y--axis and across to the value 6500 in the t_{ia} column (radial ball bearings). The lubricating interval is therefore 6500 operating hours.

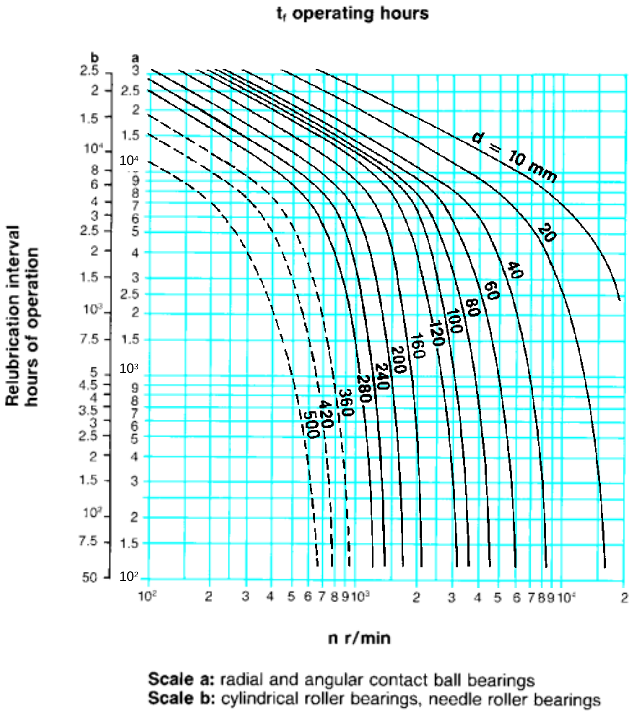


Diagram 1

Relubrication Interval—Grease

The period during which a grease lubricated bearing will function satisfactorily without relubrication is dependent on the bearing type, size, speed, operating temperature and the grease used. The relubrication intervals (hours of operation) obtained from Diagram 1 are valid for bearings in stationary machines where loading conditions are normal. The diagram is based on the use of an age-resistant, average quality grease and is valid for bearing temperatures of + 70˚C measured on the outer ring. The intervals should be halved for every 15˚C increase above + 70˚C, but the maximum permissible operating temperature for the grease should obviously not be exceeded. It should be noted, however, that relubrication intervals may vary significantly even where apparently similar greases are used. For small bearings, particularly deep groove ball bearings, the relubrication interval is often longer than the life of the bearing application. Relubrication is not, therefore, normally required. In such cases, ball bearings fitted with shields or seals and which are ''lubricated-for-life'' may be used.

Where there is a risk of the grease becoming contaminated the relubrication intervals should be reduced. This reduction also applies to applications where the grease is required to seal against moisture, e.g. bearings in papermaking machines, where water runs over the bearing housings, should be relubricated once a week.

Relubrication

The amount of grease needed for relubrication can be obtained from

$$G_p = 0.005\ D\ B$$

where

G_p = grease quantity, g
D = bearing outside diameter, mm
B = total bearing width, mm

When operating conditions are such that relubrication can be carried out at infrequent intervals, it is sufficient if the bearing housing is accessible and can be opened easily. The cap of split housings and the cover of one-piece housings can usually be taken off to expose the bearing. After removing the used grease, fresh grease should first be packed between the rolling elements.

Where more frequent relubrication is required provision should be made for regreasing; preferably a grease nipple should be fitted to the housing. A grease gun (lubricator) can then be used. To ensure that fresh grease actually reaches the bearing and replaces the old grease, the lubrication duct in the housing should either feed the grease adjacent to the outer ring side face, or, better still, into the bearing.

After a number of such relubrications the housing should be opened and the used grease removed before fresh grease is added.

Relubrication Intervals—Oil

The frequency at which the oil must be changed is mainly dependent on the operating conditions and on the quantity of oil used.

Where oil bath lubrication is employed it is normally sufficient to change the oil once a year, provided the bearing temperature does not exceed 50˚C (120˚F) and there is no contamination. Higher temperatures or more arduous running conditions necessitate more frequent changes, e.g. at a temperature of 100˚C (220˚F) the oil should be changed every 3 months.

For circulating oil systems the period between complete oil changes is dependent on how often the oil is circulated over a given period of time and whether it is cooled, etc. The most suitable period can generally only be determined by trial runs and frequent examination of the oil. The same practice also applies to oil jet lubrication.

In oil mist lubrication, most of the oil is lost, as it is conveyed to the bearing only once.

Bearing Cleaning

New bearings should be cleaned only if they have been exposed to dirt after removal from their package or lubricated with an oil or grease that is incompatible with the preservative. (See Compatibility of Lubricants, pg. 298). Bearings which have been in service and require cleaning due to accumulated dirt or deteriorated lubricant may be cleaned as follows: All cleaning operations should be done in a dirt free area and only clean solvents of good quality should be used. Light transformer oils, spindle oils, or automotive flushing oils are suitable for cleaning bearings but oils heavier than SAE 10 motor oils are not recommended. The use of chlorinated solvents of any kind is not recommended in bearing cleaning operations because of the rust hazard involved. The use of compressed air for blowing dirt out of bearings and drying solvents is not recommended unless the air system is filtered to remove moisture and dirt. Bearings should never be spun at high speed by a stream of compressed air during cleaning as this may cause damage to the balls and raceways.

Cleaning Unmounted Used Bearings

Place bearings in a wire or mesh basket and suspend the basket in a suitable container of clean petroleum solvent or kerosene. Allow them to soak, preferably overnight or longer, until all hard deposits have softened. Bearings which contain badly oxidized grease may require soaking in hot, light oil (200˚ to 240˚F) to soften the deposits. The basket should be agitated slowly through the oil from time to time. After deposits have softened, the bearings should be immersed in solvent for cleaning. In extreme cases, boiling in emulsified cleaners (i.e. grinding, cutting, or floor cleaning compounds) may be more effective to soften hard deposits. A stiff brush may be used to dislodge solid particles. If hot emulsion solutions have been used, it is important that all entrapped water be removed from the bearings. This may be accomplished by draining and slowly rotating the individual bearings while hot until the water has been completely evaporated. A more preferable method of removing entrapped water after draining is to spin the bearings in a water displacing type rust preventive oil. After removing the water, the bearings should immediately be immersed in clean petroleum solvent for further cleaning. After the used bearings have been thoroughly cleaned, their condition may be judged by hand. A light hand thrust should be applied against one bearing ring while slowly rotating the other ring. The degree of smoothness felt in rotation will indicate whether the bearing is satisfactory for further service. Bearings which are satisfactory for further service should be immediately rotated in light oil to displace the solvent. Those which will not be installed immediately should be coated with a good rust preventive oil and wrapped in clean oil-proof paper.

Cleaning Mounted Used Bearings

For cleaning bearings without removing them from their mounted assembly, hot, light oil at 180˚F (82˚C) may be flushed through the housing while the shaft or spindle is slowly rotated. In cases of badly oxidized grease and oil, hot water emulsions can be used in place of flushing oil. The solution should be drained thoroughly and the housing flushed with hot, light oil. The shaft should be rotated slowly throughout these operations.

In some cases where deposits are extremely difficult to remove, an intermediate flushing with a mixture of alcohol and light petroleum solvent after the emulsion treatment may be helpful. The flushing oil should be drained completely and oil passages checked to make sure they are not clogged before adding new lubricant.

If the bearing is lubricated with grease, new grease may be forced through the bearing to purge the old grease and contaminates. This may be done, however, only if contamination is not severe and vent openings are provided in the housing for exhausting the old grease. After purging with grease, the bearings should be operated for about ten minutes before the vent plugs are replaced to avoid serious over-heating of the bearing due to churning of excess grease.

Cleaning Sealed or Shielded Used Bearings

Bearings which have non-removable double shields or seals cannot be cleaned. These bearings are normally inspected and reused or rejected on the basis of smoothness and looseness.

Bearings having one seal or one shield may be cleaned satisfactorily by the methods outlined here. Bearings having two shields that are held in place by snap rings can be cleaned and regreased by carefully removing the shields and reinstalling them.

Bearings having two removable rubber seals can be cleaned and regreased if care is exercised in removing and reinstalling the seals. The best procedure for removing the seal is to insert a thin, knife-like blade between the O.D. of the seal and the seal groove in the outer ring, then slowly work around the periphery of the seal, working the seal from the groove. It is important to work around the periphery rather than exert too much pressure at one point which may damage the seal. Usually the seal can be removed without damage.

Things You Should Know About Lubrication

MRC bearings that have seals or shields are generally lubricated for the life of the bearing. Bearings that do not have seals or shields are protected from corrosion by coating the bearing with a preservative. The preservative is compatible with petroleum base oils and lubricants. It is not necessary to remove the preservative from the bearing surfaces when the bearing will be lubricated with either a petroleum base oil or grease.

It is possible that either synthetic oil or greases compounded with synthetic oils, will not be compatible with a petroleum base preservative. It is recommended that the preservative be removed from the bearing surfaces before lubricating with either of these products. Synthetic hydrocarbons are an exception. It is also possible that greases compounded with a polyurea thickener may cause excessive grease softening due to incompatibility with a petroleum base preservative.

Synthetic oils and greases compounded with synthetic oils are classified as special condition lubricants. They are usually not the best choice for operating conditions that fall within the capability of petroleum base lubricants. They are expensive and lack some of the desirable lubricating qualities of petroleum base lubricants. Synthetic hydrocarbon may be an exception.

Because machined phenolic or metal separators occupy a considerable amount of the space between the bore of the outer ring and the OD of the inner ring in a bearing, special care must be exercised when introducing grease into these bearings to ensure that it is uniformly distributed in the bearing. Operation of the bearing will eventually uniformly distribute the grease, but it is possible to initiate a heating-type failure or to cause damage to the active surfaces in the bearing before this occurs. This precaution is especially important when there is a close running clearance between the separator and one of the rings. One method of introducing grease between the rings and the separator is to use a plastic bag. If grease is sealed in a plastic bag and a small opening is cut across one of the corners, the bag can be inserted between the separator and either ring. Grease can then be forced into the bearing by squeezing it from the bag.

In applications where either water or air is used to dissipate heat from the bearing cavity, care must be exercised not to create a significant temperature differential between the bearing inner ring and outer ring. Some cooling methods, i.e. water jacketed housings, very efficiently dissipate heat from the housing and outer ring of the bearing, but have little effect on the shaft and bearing inner ring. Under these conditions, internal clearance in the bearing is removed as the result of thermal expansion of the inner ring and thermal contraction of the outer ring. The loss of internal clearance can result in premature bearing failures due to a significant increase in ball and race stresses, and also due to excessive heat generation. One way to avoid this problem is to circulate and cool the oil.

Compatibility and Storage

It is important when relubricating bearings, not to mix different types of greases or oils. Mixing greases often causes the mixture to become either softer or stiffer. Incompatibility results when the mixture is too soft or too stiff to effectively lubricate the bearing. The mixing of the same type of grease or oil from two different manufacturers can also cause a performance loss unless the manufacturers use the same additives.

There are several environmental considerations when selecting an area for storing bearings. The shelf life of the grease or preservative can be significantly shortened if bearings are stored in an unsatisfactory environment. Because both temperature and humidity accelerate the deterioration of either grease or a preservative, bearings should be stored at a temperature not greater than 80˚F (27˚C) and at a humidity not exceeding 55 percent. It is also desirable to select an area where there is not a great fluctuation in temperature that might produce condensation. Also, in order to reduce the likelihood of bearings being held in storage for excessively long periods of time, bearing stocks should be rotated to make certain that the oldest bearings in stock are used first.

Lubrication Methods

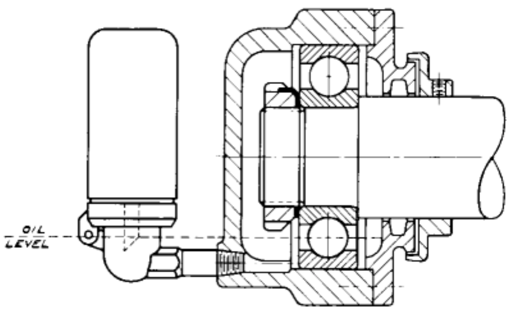


Figure 1

Oil Bath Lubrication

A simple oil bath method is satisfactory for low and moderate speeds. The static oil level should not exceed the center line of the lowermost ball or roller. A greater amount of oil can cause churning which results in abnormally high operating temperatures. Systems of this type generally employ sight gages to facilitate inspection of the oil level.

Figure 1 shows a constant level arrangement for maintaining the correct oil level.

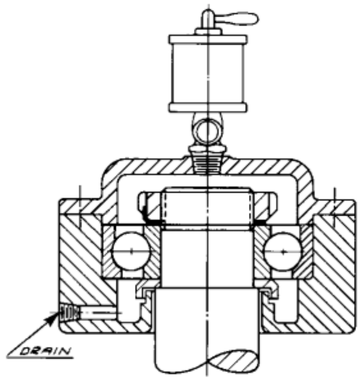


Figure 2

Drip Feed Lubrication

This system is widely used for small and medium ball and roller bearings operating at moderate to high speeds where extensive cooling is not required. The oil, introduced through a filter-type, sight feed oiler, has a controllable flow rate which is determined by the operating temperature of the bearings.

Figure 2 illustrates a typical design and shows the preferred location of the oiler with respect to the bearings.

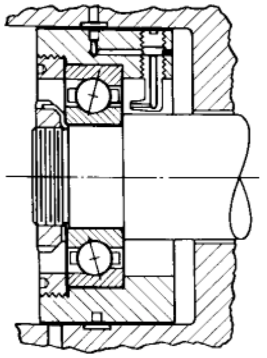


Figure 3

Forced Feed Circulation

This type of system uses a circulating pump and is particularly suitable for low to moderate speed, heavily loaded applications where the oil has a major function as a coolant in addition to lubrication. If necessary, the oil can be passed through a heat exchanger before returning to the bearing. Entry and exit of the oil should be on opposite sides of the bearing. An adequate drainage system must be provided to prevent an excess accumulation of oil. Oil filters and magnetic drain plugs should be used to minimize contamination.

In applications of large, heavily loaded, high speed bearings operating at high temperatures, it may be necessary to use high velocity oil jets. In such cases the use of several jets on both sides of the bearing provides more uniform cooling and minimizes the danger of complete lubrication loss from plugging. The jet stream should be directed at the opening between the cage bore and inner ring O.D., see Figure 3. Adequate scavenging drains must be provided to prevent churning of excess oil after the oil has passed through the bearing. In special cases, scavenging may be required on both sides of the bearing.

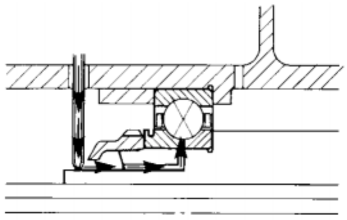


Figure 4

At extremely high speeds, the bearing tends to reject the entry of sufficient oil to provide adequate cooling and lubrication with conventional oil jet and flood systems. Figure 4 shows an under-race lubrication system with a 9000 series bearing having a split inner ring with oil slots. This method insures positive entrance of oil into the bearing to provide lubrication and cooling of the inner ring.

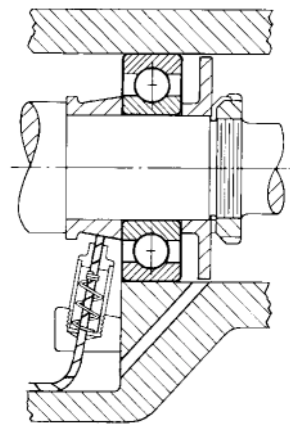


Figure 5

Wick Feed Lubrication

Wick oilers function either by gravity or capillary action to transfer a small quantity of filtered oil from a reservoir to the bearing. Wick feed is satisfactory for high speed operation with no danger of excessive oil churning. Attention must be given to wicks to assure that they are not clogged and they must be replaced occasionally.

Figure 5 shows an arrangement whereby the wick conveys oil by capillary action to a rotating flinger where it is thrown off by centrifugal force and drains back through the bearing.

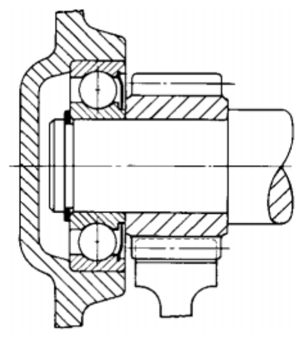


Figure 6

Oil Splash Lubrication

This method of lubrication is used mainly in gear boxes where the gear oil splash is used to lubricate the bearings.

In applications where the oil splash is heavy, shielded bearings are sometimes used to reduce the amount of oil reaching the bearing to prevent heating from excessive churning. See Figure 6.

In applications where normal splash does not provide adequate lubrication, oil feeder trails should be designed into the gear case to direct oil into the bearings.

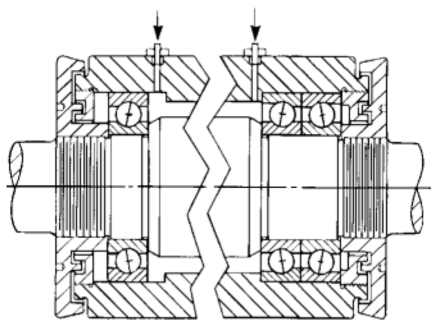


Figure 7

Oil Mist Lubrication

Oil mist systems, see Figure 7, are usually reserved for high speed applications. In mist lubrication systems, the oil is atomized and transported in an airstream through tubing to the bearings. Bearings are constantly fed with an optimum quantity of oil thus minimizing bearing heating due to oil churning. While not as effective as flood lubrication for heat removal, mist lubrication does provide some cooling from the continuous forced circulation of air. A rule of thumb on the use of oil mist is obtained from the formula $K < 10^9$. $K = DNL$. D = bearing bore in mm. N = inner ring speed RPM. L = load in pounds.

Systems can be designed so that a positive pressure is maintained within the housing thereby preventing the entrance of contaminates.

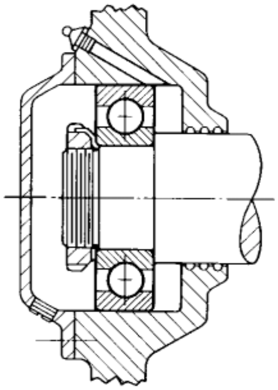


Figure 8

Regreaseable Mounting

Recommended for moderate speeds and loads. Where prelubricated sealed bearings are not suitable for some reason, consideration must be given to use of an open type bearing with provision for relubrication. The grease plug at the bottom should be removed while the grease is being inserted through the fitting at the top. The direction of flow tends to remove the old grease.

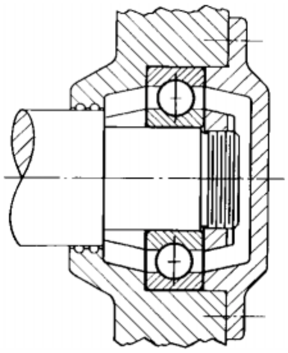


Figure 9

High Temperature Grease Mounting

The life of permanently lubricated installations at high temperatures is a function of the volume of grease present and the design of the mounting. Note that ample grease space has been provided and that the configuration of parts adjacent to the bearing is such as to urge the lubricant into contact with the active bearing parts.

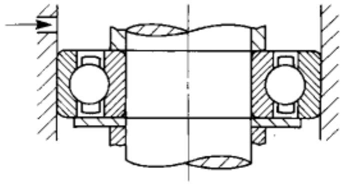


Figure 10

Deep Groove Ball Bearings on Vertical Shaft

In vertical applications where grease is admitted above the bearing, the bearing should be provided with a shield on the lower side, or a separate plate, as shown in figure 10, to retain the grease.

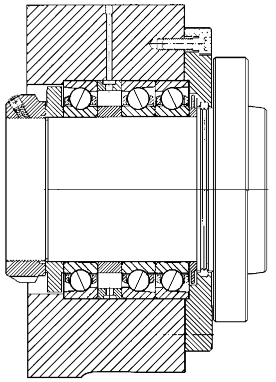


Figure 11

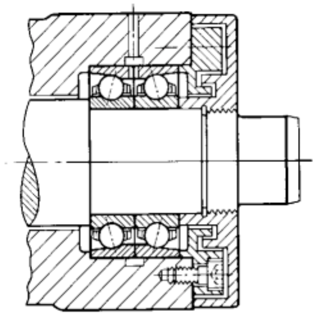


Figure 12

Grease Lubrication For Duplex Arrangements
For duplex mountings it is important that all bearings in the set receive an adequate supply of grease. Typical arrangements to accomplish this are shown above. In Figure 11, the spacer between the outer rings is provided with a circumferential groove and radial holes so that grease applied through the grease fitting and hole in the housing is directed between the bearings. In Figure 12, the bearing outer rings are slotted on the mating faces while the housing has a circumferential groove, grease fitting and hole, thus allowing grease to be applied to both bearings.