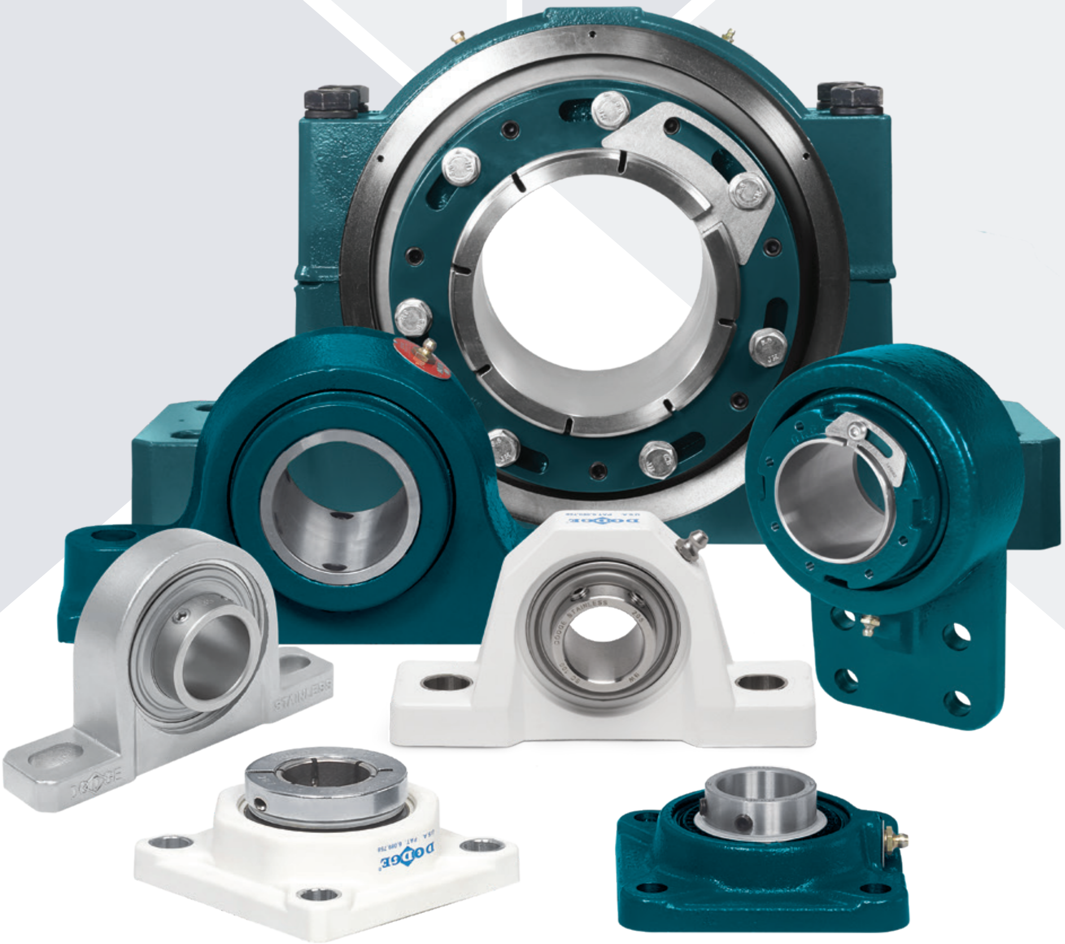
MOUNTED BEARINGS

Solutions Guide



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Introduction

Friction is the force that resists relative motion between two bodies in contact. Bearings were created to allow low-friction motion between two surfaces in contact. One of the first bearings involved tree trunks place below a body, such as a large stone, in order to move it across the ground. The first bearing that most resembles today's bearings were constructed of wood.

Bearings are needed to allow free rotation and to support the weight of related machine components that are required to rotate. At the same time, maintaining machine component locations relative to other machine components. The forces acting on a bearing can usually be defined as a specific load. A load from a rotating machine can be either radial, axial (thrust) or a combination of the two. Radial loads are the forces acting on a bearing at right angles to the centerline of the shaft. Thrust loads are forces applied parallel to, or in line with, the bearing shaft. In many cases, a bearing will be required to support both radial and thrust loads (see Figure 1).

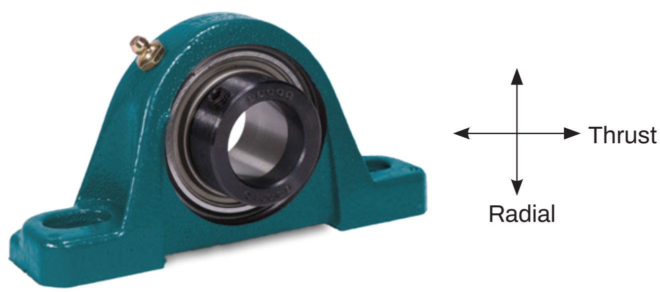


Figure 1 - How radial and thrust loads apply force

Bearings may be described as either pure thrust bearings, pure radial bearings, or a combination of the two. Modern machine design dictates that a multitude of factors be considered for effective use of bearings. This, in turn, has given rise to numerous bearing designs.

This manual details the different bearing types, their uses, and the various materials used. It will also cover bearing loading, predicted life, selection, handling and installation, lubrication, maintenance, failure analysis, and competitive interchanges.

Types and materials

Parts and components

Two basic types of bearings are used for rotating shaft applications: plain and rolling element. Each type has inherent features that determine its suitability for a specific application.

Plain bearings

The most basic type of bearing is called a bushing, plain, or sleeve bearing. This type of bearing is one in which stationary and rotating surfaces are in direct contact. The load-carrying element of a plain bearing is the portion of a bearing that is in direct contact with both the moving and stationary parts of a machine. This type of bearing is designed to allow movement by use of low friction materials, or by use of a fluid layer interface between surfaces that provides some amount of separation between surfaces to reduce friction. Typically, low-friction materials are used for the actual contact surfaces of the bearing. When used as a support bearing for a rotating shaft, sleeve bearings often use a machined portion of the rotating shaft itself for one of the contact surfaces. This portion of the shaft is termed the bearing journal. The earliest form of this type of bearing was a simple sleeve surrounding the rotating shaft to provide support and lower friction. Originally, the bearing material used was wood, which is still used today in low speed shaft bearings for ship propulsion and in some grain elevator applications. Later bearings, following the development of new shapeable materials, were made of metals.

Throughout the evolution of the sleeve bearing, the materials used included various metals, alloys and eventually nylons, Teflon®, and even ceramics. The bearing itself has no moving parts. Reliability of a sleeve bearing is excellent because wear of the bearing material is gradual. This prevents the bearing from failing suddenly. This type of bearing is highly suitable for oscillating shafts and low-speed shafts. With proper material selection, sleeve bearings are adaptable to many extreme environmental conditions. Figure 2 shows a typical sleeve bearing.

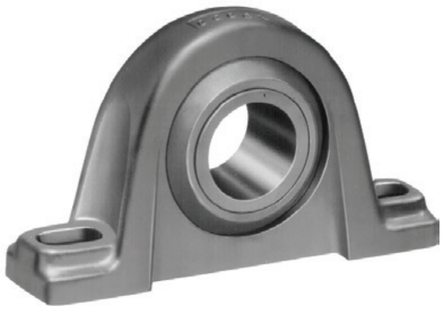


Figure 2 - Sleeve bearings

Roller element bearings

Bearings using rolling elements are considered either “ball” bearings or “roller” bearings. The name reflects the geometry of the rotating element within the bearing. Ball bearing rolling elements are round in shape allowing single point contact with the inner and outer raceway surfaces. Roller bearing rolling elements vary in shape from cylindrical, conical, tapered to barrel and have a larger contact area with the load carrying surfaces (see Figure 3).

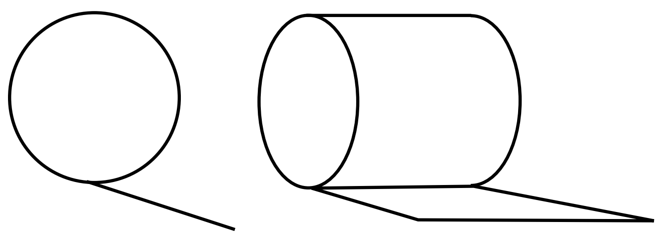


Figure 3 - Ball and roller bearing contact area comparison

The rolling elements of a ball bearing make contact with the raceways at only a small area or point which allows the bearing to move with little effort. For this reason, ball bearings generate less heat, allowing them to operate at high speeds. However, ball bearings cannot carry as heavy a load as a comparably sized roller bearing. Compression stresses occurring at the contact areas of both the balls and races vary on average from 200,000 to 300,000 psi under normal load conditions.

The rolling elements of a bearing are also classified as either full compliment (open) or caged. A bearing without a cage, retainer, or spacer would be considered a full compliment bearing. Other more common bearings include an additional part—the cage, retainer, or spacer. This spacer holds the rolling elements in a fixed spacing. The parts of a rolling contact bearing are shown in Figure 4.

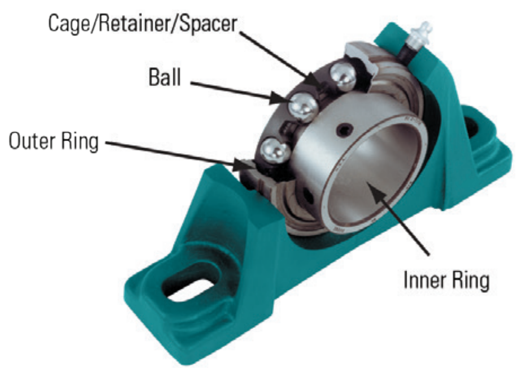


Figure 4 - Bearing parts

Ball bearings are assembled by what is called the Conrad method. The procedure is as follows:

1. Place the outer ring flat on a surface.
2. Place the inner ring inside the outer ring with the rings touching at the top.
3. Put the appropriate number of rolling elements in the gap between the bottom of the inner and outer rings.
4. Pull or snap the inner ring to the center of the outer ring.
5. Evenly space the rolling elements.
6. If a nylon cage is used, simply snap the cage over the rolling elements.
7. If a metallic cage is used, the two halves are placed around the balls then riveted or spot welded together.

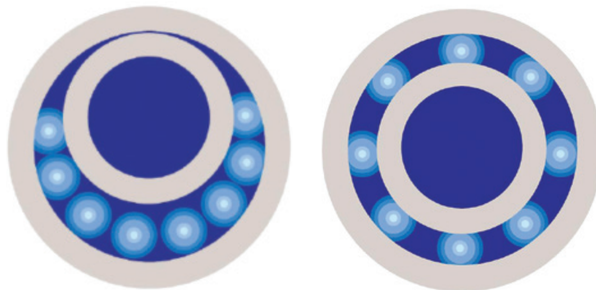


Figure 5 - Bearing assembly procedure

Types

The following bearing types are most commonly found in metric dimensions with a few notable exceptions:

- Deep groove ball bearings are sometimes offered with an inch bore
- Insert ball bearings are offered in both inch and metric bores
- Spherical roller bearings with a tapered bore are matched with an adapter that creates an inch bore
- There is a series of tapered roller bearings that is offered in inch dimensions

Deep groove ball bearing

The rolling elements in this bearing ride in a groove in the inner and outer rings. They can handle radial, thrust, and combinations loads. They are the most widely recognized bearing both inside and outside the industry. The cage is typically made of two pieces of pressed or stamped steel that are either welded or riveted together. They can also be provided with nylon, machined steel, and brass cages.

Numerous seal options are available and typically vary by manufacturer. Other features include a snap ring groove, snap ring in the outer ring, expansion-compensating rings or o-rings in the outer ring, and a flange on one edge of the outer ring.

Deep groove ball bearings are also offered as an insert style. These come with a shaft attachment mechanism and are designed to fit into a housing supplied by the bearing manufacturer. The internal design is usually the same as the standard deep groove ball bearings except the outer ring is spherical, not cylindrical.

The inner ring is manufactured with a locking mechanism (i.e. set screw, eccentric collar, concentric collar or adapter). The seal options are often different since there is more room on the wider inner ring to accommodate different seal designs. These bearings are discussed in more detail in the components section.

Angular contact ball bearing

The name for this bearing style comes from the angle at which the balls contact the raceways. Typically contact angles offered are 15, 30, 45, and 60 degrees.

The 15 degree angle style is used for a high speed, low thrust load application such as machine tools. As the contact angle increases, the thrust load capabilities increase and the speed capabilities decrease.

The 60 degree angle style is typically found in ball screws. This type of application usually has high thrust loads and low speed. These bearings are designed to handle light to moderate loads and can support radial, axial (thrust), and combination loads.

A thrust load in the wrong direction on a single bearing can cause the bearing to come apart; therefore, these bearings are typically sold in pairs. They can also be sold in sets, typically ranging from three to six bearings.

The pairs are offered in three arrangements:

- Back-to-back is used when the shaft must be held straight and radial run-out cannot be tolerated
- Face-to-face is used when radial run-out is not a great concern
- Tandem is used to support more thrust load

A third bearing (sometimes a deep groove ball bearing) is required on the shaft to ensure angular contact bearings do not disassemble should the thrust load be applied in the opposite direction. Using two bearings in tandem does not double the thrust load capabilities. Typically, adding a second bearing in tandem only increases the thrust capability by 50 percent.

The cage is typically made of nylon or a phenolic material so as not to decrease the speed capabilities, although some are offered with a brass cage.

The rolling elements are most often provided in steel, however, ceramic is also an option. Ceramic increases the speed capabilities of the bearing and is typically not offered with seals. Certain manufacturers will provide them with seals, but they are usually considered a special order.

Four point contact ball bearing

The inner ring on four point contact ball bearings is supplied in two pieces. The outer ring raceway is machined differently in order to create four points of contact instead of the standard two points of contact, allowing for the support of thrust loads in both directions using a single bearing.

Self-aligning ball bearing

The self-aligning ball bearing contains two rows of balls instead of one, allowing for misalignment much like spherical roller bearings.

Cylindrical roller bearing

Cylindrical roller bearings incorporate rolling elements shaped like cylinders—designed for higher loads and lower speeds. The inner and outer rings are offered in different styles which incorporate shoulder(s). The shoulders are added to capture the rollers and provide thrust load capabilities.

The two most common cylindrical styles are NU and N. The NU has shoulders on both sides of the outer ring and a separable inner ring. The N style has shoulders on both sides of the inner ring and a separable outer ring. The separable rings in each of these styles allows for thermal expansion of the shaft without inducing a thrust on the bearing. Neither of these designs can accommodate a thrust load. If a thrust load is applied, the separable ring will separate from the rest of the bearing causing the shaft to no longer be supported. Other styles (NJ and NUP) have one ring with two ribs/shoulders and the other ring with a single rib/shoulder. This allows the bearing to support a small amount of thrust load in a single direction. A collar (HJ) can be added to the assembly to allow for support of thrust loads in both directions. These bearings are not offered with seals. The cages are made of steel, nylon, or brass. Cylindrical roller bearings can be supplied without a cage—this is called full complement.

Cylindrical roller bearings have a minimum load requirement. If the bearing does not have enough radial load, the rollers will skid instead of roll. A high pitch squealing sound is emitted from the bearing when this occurs. Typically, a minimum load requirement would be two percent of the dynamic load rating.

Spherical roller bearing

Spherical roller bearings are designed for moderate to heavy loading. They can accommodate thrust loads, but the radial load applied must exceed the thrust load. They also typically have a minimum load requirement of 0.08 percent of dynamic load rating. This may vary between manufacturers.

Cage material is most commonly steel, with larger sizes using machined steel. Occasionally cages will be made of nylon or brass. Availability and standard material may vary by manufacturer. Internal designs for spherical roller bearings differ across manufacturers and may vary for specialized applications such as shaker screens.

Spherical roller bearings are offered with straight and tapered bores. The tapered bores are for adapter mounting and are more common than straight bores. Spherical bearings are available as both single and double-row bearings, with double-row being most common.

Spherical roller bearings are also available in a split style. The housing, seals, bearing, and cage are split. This allows for replacement of the bearing without removing the other components (i.e. gearbox, drive) from the shaft.

Tapered roller bearings

Tapered roller bearings are used to accommodate both thrust and radial loads. They can handle pure thrust loads and do not have a minimum load requirement. They can only handle thrust in one direction for a single-row bearing.

Much like the angular contact ball bearings, they are sold in pairs or sets and are offered in different styles such as the inch, metric and J series. The J series has metric outer dimensions with inch inner dimensions. These bearing are not typically offered with seals, though there are some suppliers that can provide this bearing with a seal on one side.

Common applications for tapered roller bearings include machine tools and automotive wheels.

Needle roller bearings

Needle roller bearings are used when space is limited. Some have inner and outer rings, some have either the inner or outer ring, and others contain only the cage and rolling elements. Needle roller bearings can be supplied without a cage—this is called full complement. If you choose this style, keep in mind that the shaft and housing surfaces where the rollers will ride have stringent diameter, roundness, and surface finish requirements.

Common applications for needle roller bearings include automotive motors and transmissions.

Thrust bearings

Thrust bearings are offered in all of the styles previously covered. These bearings are designed for pure thrust loads and cannot support radial loads. When supplied with only two rings and a set of rollers and cage, the thrust load can only be supported in one direction. A third ring and second set of rolling elements and cage are added to accommodate thrust from both directions.

Other bearings

There are many other types of bearings in the world, typically for specialized applications. A combination bearing incorporates both a ball and needle roller bearing in a single package.

The maximum capacity or filling notch bearing has a notch on one side in both the inner and outer ring. When these notches are lined up, this allows for more balls to be inserted into the bearing, increasing its load capacity.

Two angular contact ball bearings are packaged in a single inner and outer ring called a double-row angular contact. Cam followers are typically needle roller bearings with the shaft already installed and the end of the shaft is often threaded for installation.

Angular contact ball bearing

Four point contact ball bearing

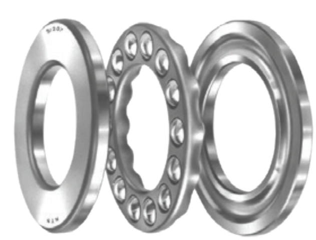
Self-aligning ball bearing

Cylindrical roller bearing

Spherical roller bearing

Tapered roller bearing

Needle roller bearing



Thrust bearing

Enclosures/housings

A bearing must be located in an enclosure or housing in order to give it support, protect the internal components from damage, and to transmit the thrust and radial load it carries to or from the associated machine or structure. Additionally, some bearing housings are designed to dissipate heat, provide locations for lubricant addition or storage, and allow for bearing shaft alignment.

An unmounted bearing is typically supplied without a housing and is pressed onto the shaft. This style relies on the design features of the associated machine to provide an enclosure. Unmounted bearings can be found in many common machines such as a motor or gearbox.

Only bearings that are manufactured with a housing, locking mechanism, and seals are considered mounted bearings. Mounted bearings allow the machine designer to simplify the overall design with self-contained bearing assemblies. These will be discussed in more detail in the next section.

Nomenclature

While there is not a standard for bearing part numbers, many manufacturers follow the same basic numbering systems. Most use a base number that details the bearing style and size. Prefixes and suffixes are typically added to detail the features specific to a particular manufacturer.

The first digit(s) in the base number details the style of bearing:

5 = Self-aligning ball bearing

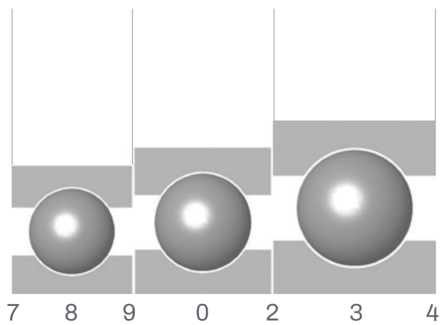
6 = Deep groove ball bearing

7 = Angular contact ball bearing

22 = Spherical roller bearing

NU = Cylindrical roller bearing

The next digit details the cross section size:



The last two digits detail the bearing bore in millimeters when multiplied by 5:

10 = 50 mm

22 = 110 mm

Prefixes often detail changes to materials in the bearing. Suffixes include references to contact angle, cages, seals, clearance, precision, grease, etc. Many manufacturers only include suffixes to call out features that are different from standard offerings. Since the standard features are not referenced in the part number, they are often detailed in the manufacturer's catalog.

Materials

A bearing must be able to reduce friction while supporting the rotating part of a machine under the conditions imposed by the associated machine and the physical environment where the bearing is located. This makes the selection of materials for the specific design of a bearing critical to the serviceability of a bearing.

Sleeve bearing materials

Sleeve bearings utilize various materials for the load-carrying portion of the bearing. Some of the most common materials are carbon-graphite, bronze, babbitt and polymer. Each has a specific performance characteristic that lends itself to a specific application. Further details on sleeve bearing materials are discussed in later chapters. A typical mounted babbitt sleeve bearing is shown in Figure 5.

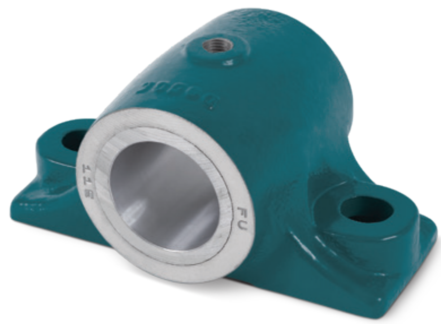


Figure 5 - Babbitt sleeve bearing

Rolling contact bearing materials

Due to complexity of the parts and the concentration of load forces in a rolling contact bearing, the materials used in these bearings are very specific and are manufactured to extremely accurate tolerances and finishes.

Bearing rings and rolling elements

Most bearing rolling elements are constructed of heat-treated 52100 alloy steel. In addition, they are manufactured to very precise standards, both in purity of steel composition and in the actual manufacturing process where they are ground to a perfect sphere within one/25-millionth of an inch (.000025).

Bearing rings are also normally machined from 52100 alloy steel or another through hardenable bearing-grade steel. They can also be made from case-hardened material such as 8629 or 4140 or other similar carbon steel. There are two different types of hardened steel used in bearings.The first is through-hardened in which the bearing steel is the same hardness throughout, typically between 58—65 on the Rockwell C scale. The second is case-carburized, where the steel is harder towards the outer edges and softer at the core. The harder outer section provides the strength needed for long life and the softer core absorbs shock loads. This is often used in tapered roller bearings for automotive applications, specifically wheel bearings, due to the frequent shock loads seen in normal driving. The basic bearing consists of two concentric rings, an inner and outer ring, with rolling elements placed between them. The rolling elements separate the two rings and allow rotation.

A retainer, sometimes called a cage or separator, is placed around the rolling elements to provide even spacing. The retainer is typically a one-piece reinforced polymer or a two-piece riveted metallic material. Other cage materials include machined steel, brass, bronze, stainless steel, and phenolic.

Seals

Sealed bearings, particularly as applied to mounted bearings, are bearings with contact or labyrinth seals (or some variation) that minimize the escape of lubricant or entry of foreign material. Rubber, steel, felt, viton, or Teflon® are only a few of the materials used to construct a seal for a bearing.

A shield (sometimes known as a flinger) are washer-like discs that are used to protect a bearing and the primary seals from contaminants. They are typically stamped steel or stainless steel, but the material may vary depending on the application. Other cage materials include machined steel, brass bronze, and stainless-steel phenolic.

Housing materials

Bearing housings are normally made of either cast or forged machined parts using materials suitable to withstand the stresses and environmental conditions for a given bearing design. Typically, mounted bearing housings are made of cast iron, but cast steel, ductile iron, polymer, and stainless steel are also used for specific applications.

Bearing fasteners

Bearing mountings, housing assemblies, and the method of locking the bearing races in position frequently involves the use of threaded fasteners. Fasteners used in bearings must be carefully selected for material suitability and correctly installed to ensure the bearing assembly will perform as designed and will operate properly throughout the design service life.

A defining component of correct fastener installation is the relative force exerted between the fastener and components clamped by the fastener. The amount of force exerted by a fastener is directly related to the torque required to turn the fastener. This allows fastener torque to be used as a measurement criterion for fastener tightness.

Different fastener materials, sizes, and specific designs have limits to the amount of torque that can be applied. These limits are one of many considerations involved when selecting fasteners for a given application. Additional factors to be considered are:

- Need for a specified holding force relative to the expected force likely to be encountered that tends to separate the parts clamped by the fastener
- Elasticity/plasticity characteristics of the parts being clamped
- Environmental conditions that the bearing or assembly is designed to withstand
- Materials used in the parts clamped by the fastener and the chemical, environmental, or contact reactivity characteristics of that material and the fastener material

Mounted bearing components

Due to their specialized applications, mounted bearings often have specific parts that differentiate them from unmounted bearings. The following sections describe the components of mounted bearings in detail.

Grease fittings

The grease fitting, shown in Figure 6, is a simple threaded fitting for injecting a lubricant into the bearing. There is usually a spring-loaded ball check valve in the grease port of the fitting to prevent contaminants from passing through when the fitting is not being used. Grease caps may also be used for extra protection from the elements. The fitting must be aligned with a path that leads through the housing and into the bearing.

Figure 6 - Grease fitting

Rolling elements

The type of rolling element used in a mounted bearing is dependent on the type of bearing under examination. Ball bearing assemblies utilize rolling elements that are completely spherical in shape. They contact the bearing inner and outer race at a single circular point. A tapered roller bearing assembly utilizes a rolling element that is conical in shape. Tapered rolling elements make contact with the inner and outer race along a line and have larger contact area. They also roll with a true rolling motion due to their tapered design. The rolling elements in a spherical roller bearing assembly are barrel-shaped and produce an oval contact area on the raceways. A sleeve bearing does not have rolling elements but the contact area of the shaft in the bore is rectangular.

Seals

Multitudes of sealing arrangements are available for mounted units, with the seal selection being based on the bearing application. Seals can be made from a variety of materials and, in many cases, specialty seals can be incorporated if a standard seal is insufficient for the application. Seals supplied with grease-lubricated mounted bearings are sometimes designed to allow excess grease to purge out of the bearing. This enables relubrication to occur safely under normal bearing maintenance. Not all bearing manufacturers use this type of seal.

Contact seal

Contact seals typically incorporate a resilient, flexible component that completely closes any path for contaminants to pass through to the bearing. The flexible element will always make direct contact and have relative movement with another component of the bearing. The flexible element tends to return to its original shape if deformed. Contact seals are typically arranged in single or multiple combinations and are best suited for wet or dry environments under slow-to-moderate speeds.

Labyrinth seal

In contrast to a contact seal, a labyrinth seal protects a bearing without completely closing off the path to it. The seal is provided through a complex maze sometimes filled with grease. This maze blocks easy passage while simultaneously reducing bearing operating temperature due to the absence of rubbing components. The lower operating temperature allows for high-speed operation without overheating the bearing. In addition, labyrinth seals are usually made from all metallic components and are suited for high-temperature environments.

Combination seal

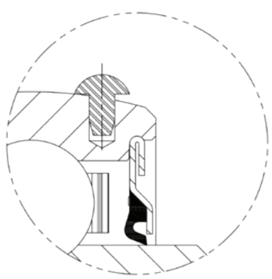
As the name implies, combination seals blend elements or features of the above seal types. Combination seals use contact seals toward the interior of the bearing and labyrinth seals at the outside of the bearing.

Clearance seal

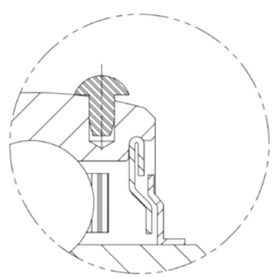
A basic clearance seal consists of multiple stationary, thin rings or washers of rigid material. This seal does not make contact with the rotating surface of the bearing, but is very close to it. The absence of rubbing components allows for reduced operating temperature and, therefore, high running speeds. It effectively blocks medium and large size contaminants. Clearance seals are usually entirely metallic and operate with the same benefits as a labyrinth seal—suitable for high-temperature or high-speed applications. Clearance seals are often preferred in high-temperature environments.

Shields or flingers

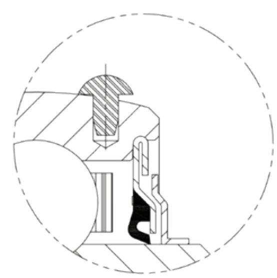
A flinger is a shield that is pressed over the inner ring or shaft and is used as a deflector as it rotates with the inner ring to “fling” material away from the bearing. Flingers are installed to take advantage of centrifugal force imparted by the shaft rotation to deflect foreign material and/or shield the primary seal from direct water sprays or larger particles.



Contact seal



Labyrinth seal



Combination seal

Locking methods

Mounted ball and roller bearings are slip-fitted over a shaft and must be secured to the shaft to prevent rotation within the bearing bore. There are many methods of securing a mounted bearing to a shaft; each one is designed to carry out the same principal task.

Set screw locking

A basic set screw lock (see Figure 7) is a very simple method that incorporates set screws directly threaded into the inner ring. An alternate version uses a separate ring or lock collar (see Figure 9) around the extension of the inner race. This ring or lock collar has tapped set screw holes which match clearance holes in the inner ring extension. This prevents stresses and resulting distortion caused by the torque and pressure of the set screws from deforming the inner race of the bearing. In either case, when tightened, the set screws will embed themselves into the shaft and force the shaft against one side of the inner ring.

Set screw locking bearings are easy to install and are relatively inexpensive. However, they impose limitations on high-speed bearing operation due to the non-centered shaft and rely on strict shaft tolerances for ideal performance.

When the set screws are tightened correctly, the clamp load causes the set screws to dig into the shaft. This clamp load provides better holding power in axial (thrust) load applications when compared to other locking methods. The deformation of the shaft that occurs from the clamp load can make it more difficult to remove the bearing from the shaft.

Concentric collar locking

A concentric lock (see Figure 9) uses a split collar with one or more clamping screws. This clamping collar fits over the extended inner ring, which has radial slots to allow compression of the inner ring extension. When the bearing is in the proper location on the shaft, the lock collar cap screws are tightened to close the collar, compress the inner ring, and affix the bearing to the shaft.

It locks the shaft in a 360-degree contact pattern, centers the shaft in the bore, and does not mar the shaft. A concentric collar lock is limited in axial (thrust) holding power.

Eccentric collar locking

The eccentric locking mechanism (see Figure 8) uses a cam design to create a wedge effect and secure the inner race to the shaft. The cam action is created by the eccentricity of the inside diameter of the locking collar in relation to the engaging extension of the inner ring of the bearing. A single set screw in the lock collar assures the retention of the collar's position by threading through the collar into the shaft. An eccentric collar locking mechanism has the same advantages and disadvantages as set screw locking bearings, but is limited to non-reversing applications.

Tapered adapter sleeve locking

A tapered adapter is designed to wedge a sleeve between an inner ring bore and a shaft. This wedging action is produced and retained by a lock collar that is used to draw the tapered sleeve into the bore of the bearing, or drive the bearing onto the outer diameter of the sleeve. This locking method excels at centering the shaft in the bearing bore, providing 360-degree locking and reducing fretting corrosion between the bearing and shaft.

The shaft tolerance requirements are broadened, allowing use of commercial shafting. However, they are usually more complicated and time consuming to install compared to the previously discussed locking methods. Once experience is gained with the installation process, it can take the same amount of time to install as the other locking methods. Dismounting the bearing can be faster and easier.

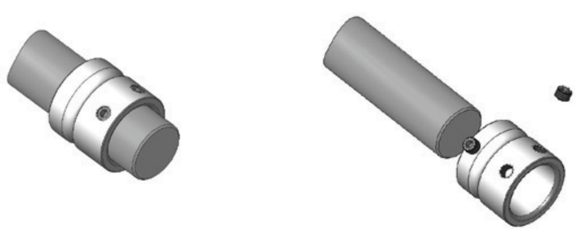


Figure 7 - Set screw lock

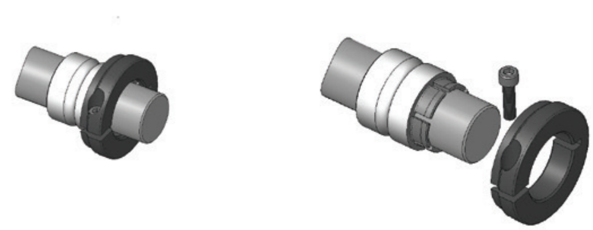


Figure 9 - Concentric collar

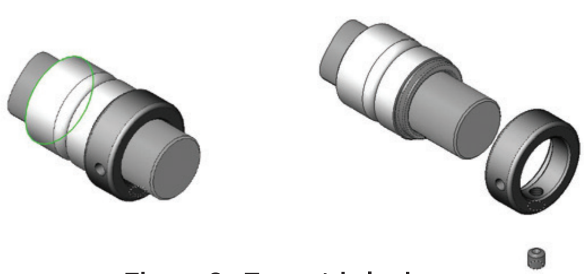


Figure 8 - Eccentric lock

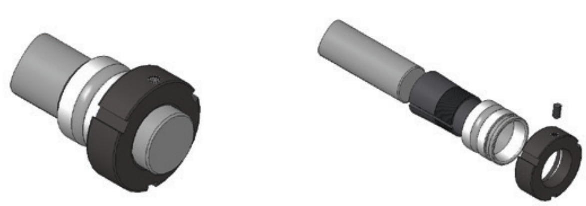


Figure 10 - Tapered adapter sleeve lock

Interference fit

Despite the number of slip-fit locking methods available, some applications require a bearing to be pressed onto a shaft for installation. This type of installation calls for an interference (or press) fit between the bearing and the shaft. The amount of interference is dependent on the type of bearing and the application.

The press fit can be achieved by forcing the bearing onto an oversized shaft or by heating and expanding the bore until it can be easily installed. After cooling, the bearing will shrink around the shaft and a press fit will be achieved.

One advantage of a press fit is a concentric 360-degree lock. In addition to a difficult installation process, the main disadvantage of a press fit is that it requires precision-machined shafting along with additional shaft collars or shaft shoulders to retain the axial location of the bearing.

There are other methods and variations of those discussed above, some of which are patented systems from various manufacturers. There are advantages and disadvantages to using one locking system over another. The locking device selected for use is often determined by installation location, application, or customer preference.

Housing materials

Bearing housings are offered in a wide variety of styles (see Figure 11) and materials.

Figure 11 - Examples of bearing housings

The housing styles are designed for different mounting purposes. In all styles, the flatness of the mounting surface is important. If the mounting surface flatness is outside of industry standards, the stress on the housing could exceed the limit and cause cracking or fractures.

Pillow blocks are offered in one- and two-piece styles. Ball bearings are only offered in one-piece housings. Spherical, taper, and sleeve bearings are offered in both. The two-piece housing is beneficial during installation of larger housings. The housings can get heavy and difficult to handle at the larger sizes.

Flanges are most often supplied as a one-piece housing. In spherical and tapered roller bearings, the four-bolt flanges might be offered as a two-piece housing. Some flanges are equipped with a pilot which is an extension of the housing material that sticks out the back side. This is used to position the housing properly on the mounting surface and can help support radial loads. Pilots are mostly available in four-bolt flanges.

Cast iron is the most common material. Other materials include ductile iron, steel, stainless steel, and polymer. The stainless-steel and polymer housings are typically used in applications where corrosion of the cast iron occurs easily. The food industry is a good example of this due to the constant exposure to water during wash-down procedures.

Some manufacturers supply two-bolt flanges with pilots.

Housings are one of the most diversified parts of mounted bearings. There are numerous styles and configurations, which usually fall into one of several common types. The dimensions change but the principle is the same.

In addition to housing configurations, there are a wide variety of housing materials. The most commonly used are cast iron, ductile iron, cast steel, and steel.

Cast iron – A general purpose housing most commonly used for a variety of applications. This is the lowest-cost housing and is easily machined and adapted. This housing can handle a wide temperature range and light-to-moderate loads. The most common grades have a 20,000—30,000 psi ultimate tensile strength.

Cast steel and ductile iron – Ideal for rugged heavy-duty applications and accepts shock and heavy loads. They dissipate heat well, but are usually more costly than cast iron and not as readily available from stock. The most common grades have a 65,000—100,000 psi ultimate tensile strength.

Although cast iron, cast steel, and ductile iron are the most common materials available for use, there are many other materials available for bearing housings (stainless steel, polymer, etc.) depending on the specific application requirements. Specific requirements may range from corrosion resistance to electrical resistance and are commonly available from various suppliers.

Housings are designed as solid units or in two pieces. They are cast to shape and machined to size to accept a certain size bearing. The two-piece housings are cast and machined to ensure a proper mate between the two halves. An alignment dowel pin and hole can be used to help locate the two halves, ensuring a unified fit to accept the housing halves. Because they are machined together, housing halves cannot be mixed.

Housing types

Pillow block – The most common housing type used. It encompasses the largest range of bore sizes and is easily adapted to most applications. Two- and four-bolt hole patterns are most common and as with the other mounted types, a variety of housing materials, shapes, and sizes are available.

Tapped base – A compact version of a pillow block when space constraints limit the size of the housing. The housing has bolt holes tapped into the base for securing the assembly to a mounting structure.

Flange bearings – Mounts flush against a mounting structure and allows for assembly of mounting bolts in the same direction as the shaft. They are available in two-bolt through six-bolt designs depending on bore size.

Piloted flange – Uses a pilot on the back of the housing to mount into a frame or hole for added stability or precision locating.

Take-up bearings – Available in numerous shapes and are always used where shaft positioning is required. This could be to add tension to a conveyor belt or move a bearing to increase ease of maintenance within an application.

Hanger bearings – Used in applications where the support is an overhang position, on a threaded connecting rod, or for eccentric or concentric drives.

Cartridge bearings – Designed with cylindrical (straight) outer housing to fit into a piece of equipment or customer-supplied housing.

Expansion mounted bearings

Mounted bearings are often used in locations where a shaft is subjected to heating and cooling as the operating conditions change. This causes the shaft to expand or contract lengthwise.

If the mounted bearings on the shaft were rigidly fixed in position on both the shaft and the machine foundation, the changing length of the shaft could damage or even destroy the bearings.

When calculating the thermal growth of a shaft, the thermal growth of the mounting structure can be taken into consideration when determining if allowances for shaft expansion are needed (see Figure 12).

If needed, most bearings can be obtained with features that accommodate linear expansion of the shaft. An assembly that can allow for shaft expansion is termed a float or expansion bearing. The housing and bearing assembly design allows the bearing to move axially in the housing while supporting the radial load. This mount design is normally paired with a non-expansion, or fixed mount bearing, to allow for thermal elongation of the supported shaft in one direction but still retain the shaft in place.

Ball, spherical, and tapered roller bearings are available in floating designs but each utilizes a unique method of performing the expansion function.

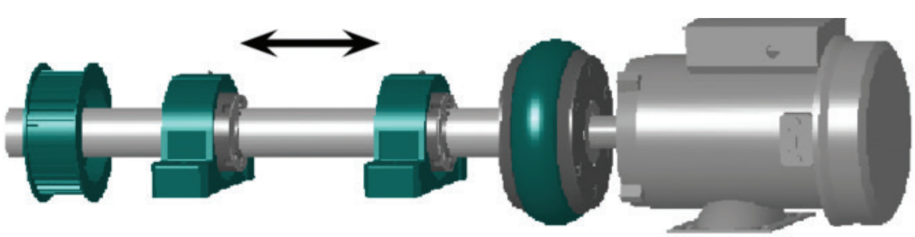


Figure 12 - Fixed and expansion mounts

Anti-friction mounted rolling element bearings

Mounted anti-friction bearings can usually be classified into three groups:

1. Ball bearings
2. Tapered roller bearings
3. Spherical roller bearings

Types of mounted ball bearings

The following paragraphs contain brief descriptions of two types of ball bearings used in mounted bearing applications.

Single-row ball bearing

One of the most common anti-friction bearings is a ball bearing. Ball bearings are capable of handling pure radial load, pure thrust load, or a combination of both. They are suitable for low- or high-speed applications and are typically the least expensive type of mounted anti-friction bearing.

Although there are many ball bearing manufacturers, the basic mounted bearing design is the same. This design is referred to as the Conrad bearing, named after its inventor Robert Conrad.

A Conrad bearing features a single-row of precision ground balls that travel in two ball paths. One path exists in both the inner and outer rings. The rolling elements are separated with a retainer to maintain the spacing of the rolling elements. Almost all mounted ball bearings are the Conrad design.

Mounted ball bearings are generally supplied “shaft-ready” with a locking device, lubricant (usually grease), seals, and housing. Each component is discussed in previous sections and varies in design from supplier to supplier. In addition to their shaft-ready features, almost all single-row mounted ball bearings are designed to be statically self-aligning.

Alignment of a single-row mounted ball bearing is accomplished by special design of the outer ring and the housing. The outer ring is spherically machined to match a spherically machined housing bore. This allows the bearing to swivel with respect to the housing and accommodates misalignment between the shaft/bearing assembly and the housing.

The amount of torque required to misalign a bearing in its housing is factory-set to a low value and is controlled by installing the bearing into the housing with a loose fit. However, this loose fit may allow the bearing’s outer race to creep in the housing and could cause damage to the bearing. This movement can be controlled by installing an anti-rotation pin in the outer ring.

Double-row ball bearing

Another ball bearing design found in mounted bearing applications is the double-row ball bearing. A double-row ball bearing uses two rows of rolling elements to increase the radial load capacity of the assembly over a single-row ball bearing.

Like the single-row Conrad ball bearing, the rolling elements on the double-row ball are evenly spaced with a retainer and travel around the inner ring within a ball path. However, unlike the single-row ball bearing, the outer race does not have a ball path for the rolling elements. It is machined with only a single spherical surface for both sets of rolling elements.

Double-row ball bearings are self-aligning bearings, but misalign differently than the single-row bearing. The inner race and rolling elements (along with the attached shaft) are allowed to swivel within the outer race. Therefore, a double-row ball bearing can statically and dynamically misalign. However, the luxury of dynamic misalignment is provided at a cost. The absence of axial support for the roller on the outer race surface limits the ability of the bearing to handle thrust load.

Types of mounted roller bearings

Mounted roller bearings have many characteristics in common with mounted ball bearings. The primary advantage to this group of bearings is a greater load carrying capacity when compared to a similarly sized mounted ball bearing. However, the gain in load capacity comes with a sacrifice in the maximum allowable speed.

Tapered roller bearing

Tapered roller bearings consist of four basic components: inner ring (cone), outer ring (cup), rolling elements (cone-shaped rollers), and retainer (cage).

The inner ring has a shoulder, or rib, which makes contact with the end of the roller. Tapered roller bearings are designed so the contact surface and roller surfaces converge at a common apex on the shaft axis (see Figure 13). This, combined with the tapered cone shape of the rolling elements, allows the rolling elements to rotate with a true rolling motion. This is an important feature of tapered roller bearings because it allows for smooth, low-temperature operation.

Tapered roller bearings are suitable for relatively high loads and low-to-moderate speeds. The loads can be pure thrust, pure radial, or a combination of both. Most mounted tapered roller bearing and housing assemblies are designed to operate with grease lubrication.

Mounted tapered roller bearings are typically found in pairs within a single housing. This allows for thrust load in either direction and produces a high radial load carrying capacity. The inner ring on a mounted tapered roller bearing is usually a single cone that contains both sets of rollers. The outer diameter on a tapered roller bearing cup is usually machined cylindrically (straight). There are some manufacturers that make the cups with spherical ODs. This is in contrast to a ball bearing with spherical outer diameter. The cup's cylindrical outer surface does not allow the bearing assembly to swivel or misalign freely.

In order to produce a mounted tapered roller bearing with a self-aligning feature, an intermediate cartridge must be used. This cartridge is machined with a cylindrical bore to hold the bearing components.The spherical outer surface mates with a spherical housing bore and, like the ball bearing, these two spherical surfaces allow the bearing to self-align with a factory-set swivel torque.

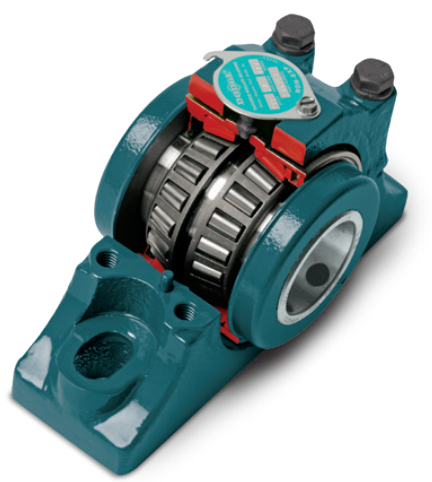


Figure 13 - Mounted tapered roller bearing

Spherical roller bearing

The basic design of a spherical roller bearing, like anti-friction mounted bearings, consists of an outer ring, an inner ring, a double-row of barrel-shaped rolling elements, and a retainer (see Figure 14).

Spherical roller bearings are suitable for applications that require high radial loads and moderate thrust loads, but are not well-suited for pure thrust applications. They are designed for use in low-to-moderate speed applications with grease as the standard lubricant (occasionally oil).

The inner ring for a double-row spherical roller bearing contains two individual roller paths (raceways) for each set of rolling elements. However, the outer ring has a single spherical shaped surface to support both sets of rollers. This concept was previously seen in the discussion of the double-row ball bearing. The design allows for static and dynamic internal misalignment of the bearing but sacrifices thrust load capacity.

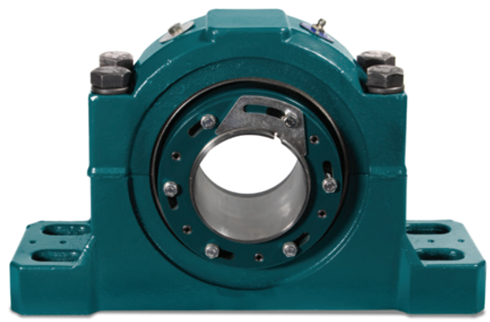


Figure 14 - Mounted spherical roller bearing

Rod end bearings

Rod end bearings are plain bushing bearing units designed to handle a transfer of motion with angular misalignment, full rotation, and reciprocating oscillation. This transfer of motion is normally associated with various types of linkage control applications. The design and makeup of a rod end is fairly simple—consisting of a housing, a wearing race, and a ball.

The housings are available in a variety of shapes and sizes with a wide range of materials. The body supports the ball and raceway and attaches to an arm of some type. These bodies are available in male or female—the female style contains internal threads into which the application arm screws, while the male style contains an external thread which screws into a corresponding threaded part.

The raceway is usually made from an aluminum bronze, low carbon steel, plated steel, or brass.

Not all rod ends contain a race or sleeve—some are pressed into the body without a wearing raceway. The type of material used in the race depends on the application in which the bearing is being used.

The ball is the part of the bearing that presses or fits onto the shaft. It is usually made of hardened steel and plated for wear and corrosion resistance. A rod end is available in two-, three- or four-piece constuction.

Some of the many uses for rod ends include: hanger support applciations, steering, linkages, eccentric arm linkages for printing press application or drive wheels, and connecting linkages for gates, doors, and valves.

Types of mounted sleeve bearings

A sleeve bearing is a simple device for providing support and radial positioning while permitting rotation of a shaft. It is the oldest bearing device known to man.

The broad category of sleeve bearings includes a great variety of materials, shapes, and sizes. Materials used include an untold number of bronze metallic alloys, sintered powdered metals, nylon, Teflon®, wood, rubber, ceramic, and composites. Types range from a simple hole in a cast iron machine frame to some exceedingly complex, gas-lubricated, high-speed rotor bearings.

With proper selection, installation, and lubrication, sleeve bearings usually do not fail suddenly. Wear is gradual and replacement of worm bearings can be scheduled when equipment is normally idle. These bearings are uniquely suited to conditions involving oscillating movement of the shaft. Excessive moisture, submersion in liquids, and extreme temperatures can often be accommodated with the proper selection of materials.

Application and selection of sleeve bearings

Ideally, the application and selection of sleeve bearings—like rolling element bearings—is based on a review of the conditions of operation. These conditions include: load, speed, temperature, environment, and service requirements.

For load, one should know the variations in loading, peak loads, shock loads, vibration, load direction, etc. Speed involves starting, stopping, frequency, acceleration, deceleration, and variations while running.

The consideration of temperature must include maximum and minimum expected temperatures, as well as operating temperatures and expected variations.

The external environment may be gas or liquid with solid contamination, corrosive or abrasive, explosive, ultra clean, etc. The quality of maintenance and service expectations, in terms of life and reliability, can also influence bearing selection.

Assuming that a sleeve bearing (rather than a rolling element bearing) best serves a particular application, the correct type must be selected.

The analysis of operating conditions will generally point to a particular material as the most suitable for an application. If the material selection is a clear-cut decision because of temperature or environmental requirements, the selection procedure then establishes the bearing size to satisfy the load and speed conditions.

Along with size determination, the style of housing and installation arrangements should also be considered. For example, a cap-load condition (load through the top of the housing) may require special consideration for the housing material or alternative mounting orientation may be required. This, in turn, could complicate any gravity feed arrangements for lubrication or other aspect of the design. Consult the bearing manufacturer to resolve atypical bearing problems and establish the best solution.

The service life of a sleeve bearing is generally not predictable with a high degree of precision. With all conditions of selection, installation, lubrication, and maintenance in accordance with theory, bearing failure will develop only as gradual wear conditions exceed allowable amounts. In practice, the wear rate cannot be precisely predicted except by history of performance on a particular application.

Babbitt metal bearings

The actual bearing operation temperature for babbitt metal bearings must not exceed 130 °F. Babbitt is used for applications involving light-to-moderate loading.

Babbitt metal bearings are universally accepted as providing reasonable capacity and dependable service under adverse conditions. It is a relatively soft bearing material, allowing abrasive particles to embed themselves in the material and minimizing the danger of scoring or damaging shafts or journals.

Leaded and tin bronze bearings

Bronze bearings are more suitable for heavier loads than babbitt, with capacities ranging from 75 to 200 percent higher depending on the specific range of loads and speeds. A bronze sleeve bearing can withstand a higher shock load than a babbitt sleeve bearing, permits slightly higher speed operation, and can be used up to 300 °F ambient temperature. However, bronze is a harder material than babbitt and has a greater tendency to score or damage journals when abrasive contaminants are present or in the event of malfunction. Some bronze bearings can be repaired in the field with replacement of the bushing liner.

Carbon-graphite bearings

A carbon-graphite bearing material is utilized for applications at temperatures up to 1000 °F where the use of conventional bearings and lubricants is nearly impossible.

This design is entirely self-lubricating. Upon startup, a small amount of bushing material will be transferred to the shaft or journal which acts as a lubricant. While in service, the bushing is gradually consumed with the shaft/bushing clearance gradually increasing. These bearings have been particularly useful in applications such as ovens, dryers, and furnaces where loads are relatively low.

They are often used in alien environments because of the basic inertness of the carbon-graphite material. Occasionally, this type of bearing will develop a high-frequency vibration in resonance with the operating system to produce a high-pitched squeal or noise condition. Correction usually requires damping or modification of the shaft resonant frequency.

Sleeve bearing mounts

Mounted sleeve bearings have several housing configurations—the two most common being a pillow block or a flanged mount. Misalignment of sleeve bearing (similar to a ball bearing) depends on the housing bore and the outer diameter of the sleeve. A spherical housing bore with a matching spherical OD-shaped sleeve bearing will allow for static misalignment.

After a thorough analysis of a bearing's end use, the type of bearing to be used in a specific application is often the first decision to be made. Understanding the advantages and disadvantages of each bearing type is essential. Always keep in mind that the manufacturer's literature is extensive and should be consulted in making final decisions. The following sections provide additional insight.

Special bearing materials

In some situations, special bearing materials are required for an application. When feasible, custom designs can be provided. Full application information is necessary for evaluation, custom deliveries, development, and prototype testing as required. A minor modification of the equipment design is often a more desirable approach, whereby standard bearings can be used and replacements can be easily obtained.

Load and life

Loading

Bearing load determines the amount of stress on the bearing and is directly related to its life. Load can take many forms including radial loads, thrust loads, peak loads, shock loads, and vibration. A complete analysis of the direction and magnitude of the load is necessary in order to make an accurate bearing selection. The majority of the time you will be working specifically with radial and thrust loads or a combination of both.

Radial load – Loads that apply forces perpendicular to the shaft

Thrust load – Loads that apply forces parallel to the shaft

Radial or thrust loads are primarily caused by the weight of the rotating component, however, they are also imposed by the magnitude and direction. For example, Figure 15 shows a horizontal fan application used to force air through air conditioning ducts. Radial loads can be easily determined by calculating belt pull and measuring the weight of the shaft, sheave, and fan. The thrust load acting on the bearings will be determined by airflow direction and fan static pressure.

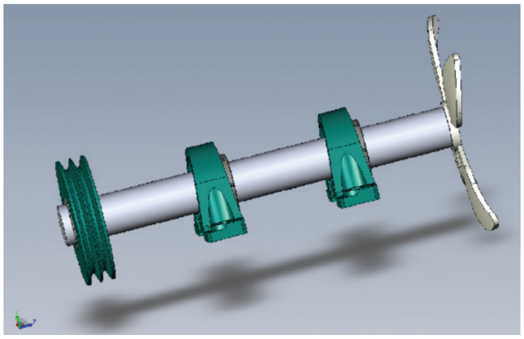


Figure 15 - Fan assembly

Another important aspect is speed. Speed is generally measured in revolutions per minute (rpm).

It is also important to take temperature into account. This includes both maximum and minimum temperature. Keep in mind that indirect sunlight will act on bearing and shaft assemblies as though the temperature is higher than the ambient temperature. The external environmental conditions will consider a gas or liquid environment, solid or liquid contaminant, corrosive, abrasive, flammable, explosive, or even ultra-clean conditions of bearing location. The quality of maintenance and service expectations in terms of life and reliability can influence bearing selection. The initial design considerations often have unknowns in the various conditions mentioned above. Assumptions and decisions can be made based on best judgments; however, the risks of making such decisions must also be evaluated on a worst-case scenario basis.

A given bearing might be satisfactory for continuous operation at a particular speed but prove unsuitable in the start-up condition. Because of the complexity of operating conditions in many applications, it is not feasible to reduce the bearing selection technique to a precise engineering formula. Engineering judgment is a prime requisite. The most accurate method of determining a specific bearing for an application involves calculating the expected service life of a bearing based on the known operating conditions. For this calculation, the known conditions are:

- Radial load
- Thrust load
- Revolutions per minute of the rotating ring

Equivalent radial load

The initial calculation is for determining the equivalent radial load on a bearing. When a bearing has no thrust loading, the actual radial load is used for the equivalent radial load. If the bearing has both radial and thrust loads, they both must be converted into an equivalent radial load.

The calculation for equivalent radial load is as follows:

$$P = XF_R + YF_A$$

Where:

P = Equivalent radial
F_R = Radial load
F_A = Thrust load
X = Radial load factor
Y = Thrust load factor

The radial load and thrust load factors used in the above formula are available from bearing manufacturer catalogs and vary for the size and type of bearing. Table 1 is an example of a tapered roller bearing chart in a manufacturer catalog.

Example:

Calculating:

P = Equivalent radial load = $XF_R + YF_A$

Given:

Fan application consisting of:

- Radial load = 1,500 lbs
- Thrust load = 400 lbs
- Rpm= 1,500
- Bearing = 2-15/16” tapered roller bearing

Equivalent radial load calculation: $P = XF_R + YF_A$

First determine the proper radial (X) and thrust (Y) load factors:

$F_A/F_R = 400/1500 = 0.26$

e = .46 (from Table 1)

Therefore, $F_A/F_R = 0.26$ is < 0.46 which gives you:

- X= 0.87
- Y= 1.87

Proceeding to work the equation:

P = 0.87 (1500) + 1.87 (400)
P = 2,053 lbs

Table 1 - Radial and thrust load factors

Shaft size (in)	e	$F_A/F_R<e$		$F_A/F_R>e$		Dynamic capacity (lbs)	Static capacity (lbs)
		X	Y	X	Y	C90	C0
1-3/16 1-1/4	0.49	0.87	1.77	0.70	2.14	2,980	15,760
1-3/8 1-7/16	0.46	0.87	1.89	0.70	2.28	4,760	26,000
1-1/2 1-5/8 1-11/16	0.44	0.87	1.96	0.70	2.37	6,140	33,000
1-3/4 1-7/8 1-15/16 2	0.33	0.87	2.64	0.70	3.18	8,070	43,000
2-3/16	0.36	0.87	2.38	0.70	2.87	8,550	48,200
2-1/4 2-7/16 2-1/2	0.40	0.87	2.17	0.70	2.63	9,090	54,000
2-11/16 2-3/4 2-15/16 3	0.46	0.87	1.87	0.70	2.26	9,600	61,200
3-3/16 3-1/4 3-7/16 3-1/2	0.50	0.87	1.71	0.70	2.07	15,300	108,600
3-15/16 4	0.49	0.87	1.77	0.70	2.14	21,000	154,000
4-7/16 4-1/2	0.53	0.87	1.63	0.70	1.97	25,800	188,400
4-15/16 5	0.47	0.87	1.83	0.70	2.21	35,500	266,000
5-7/16 5-15/16 6	0.49	0.87	1.76	0.70	2.12	40,700	354,000
6-7/16 6-1/2 6-15/16	0.54	0.87	1.61	0.70	1.95	69,200	574,000

Bearing load reactions

Bearing life (L_{10})

The second calculation is to determine the expected service life of a bearing in hours, referred to as the bearing L_{10} life. L_{10} is the life attained by 90 percent of a statistically similar group of bearings operating under similar load and speed conditions. This can also be described as the point in time when 10 percent of a group of like bearings under normal conditions has failed. L_{10} life in hours is used as a design point for selecting a specific bearing for a known application.

For the installer and maintainer of the bearings, the L_{10} life is useful in determining the amount of time a bearing can be expected to last under ideal conditions. The failure mode expected at the calculated life is due to material fatigue resulting in spalling on the raceways. When selecting a bearing from a particular manufacturer's catalog, the installer needs to first determine the equivalent radial load (as shown in the previous example), the rpm of the machine, and the dynamic capacity of the bearing. The dynamic capacity is based on the bearing bore diameter and can be found in the manufacturer's catalog. The definition of dynamic capacity for spherical, ball, and tapered roller bearings can be found below. Note that the dynamic capacity is denoted as C_r for spherical roller bearings and ball bearings and as C_{90} for tapered roller bearings. The difference in notation is because the dynamic capacity C_r (spherical/ball) and C_{90} (tapered) are not to the same base. To compare basic dynamic capacities of spherical and tapered roller bearings, multiply C_r x 0.259 and compare to C_{90}.

Basic dynamic capacity definitions

Spherical and ball bearings, C_r – The load at which 90 percent of a given group of bearings can meet or exceed 1,000,000 revolutions.

Tapered bearings, C_{90} – The load at which 90 percent of a given group of bearings can meet or exceed 90,000,000 revolutions.

When consulting with a manufacturer, providing the equivalent radial load, rpm and diameter of the shaft will return a list of suitable bearings with varying expected service lives (see manufacturer's catalog for formula). An installer or maintenance supervisor must consider that this L_{10} value is based on bearings in an ideal environment, correctly maintained.

A prudent estimate of the actual expected life of a bearing would be somewhat lower. In most cases, the customer will specify the desired L_{10} life. In cases where the customer does not specify a desired L_{10}, then 10,000 hours is considered a proper design life for heavy industrial applications. When L_{10} is greater than 100,000 hours, the fatigue life of the bearing is considered non-existent. The formula for calculating the L_{10} value is shown below.

Where:

Ball bearing	Spherical roller bearing	Tapered roller bearing
$\left(\frac{C_r}{P}\right)^3 \times \frac{16667}{rpm}$	$\left(\frac{C_r}{P}\right)^{10/3} \times \frac{16667}{rpm}$	$\left(\frac{C_{90}}{P}\right)^{10/3} \times \frac{1,500,000}{rpm}$

C_r = Dynamic capacity for ball or spherical bearings
C_{90} = Dynamic capacity for tapered roller bearings
P = Equivalent radial load
Rpm = Speed of the rotating ring

Example 1:

2-15/16" tapered roller bearing:

Dynamic capacity = 9,600 lbs
(determined from manufacturer's catalog)

Rpm = 1,500
Load = 1,500 lbs radial, 400 lbs thrust
P = 2,053 lbs

For tapered roller bearings:

$$\left(\frac{C_{90}}{P}\right)^{10/3} \times \frac{1,500,000}{rpm} \rightrightarrows \left(\frac{9600}{2053}\right)^{10/3} \times \frac{1,500,000}{1,500} \rightrightarrows 9,498 \text{ hours}$$

Example 2:

1-15/16" set screw ball bearing:

Dynamic capacity = 7,891 lbs
(determined from manufacturer's catalog)

Rpm = 1,800
Load = 500 lbs radial, 0 lbs thrust
P = 500 lbs

For ball bearings:

$$\left(\frac{C_r}{P}\right)^{3} \times \frac{16,667}{rpm} \rightrightarrows \left(\frac{7891}{500}\right)^{3} \times \frac{16,667}{1,800} \rightrightarrows 181,980 \text{ hours}$$

Selection

After a thorough analysis of a bearing's end use, the type of bearing to be used in a specific application is often the first decision to be made.

Understanding the advantages and disadvantages of each bearing type is essential. Always keep in mind that the manufacturer's literature is extensive and should be consulted in making final decisions. The following sections provide additional insight.

Starting friction

Starting friction generally comes into play if a customer is looking for a low starting torque due to their drive constraints. When trying to decrease the starting friction of a bearing there are two parts that play major roles in dictating the degree of starting friction:

- Type and fill amount of lubrication

  To decrease starting friction, a lubricant should be chosen with a low NLGI number. NLGI values of 2 or 3 offer ideal consistencies. The amount of lubricant in the bearing also affects the starting torque of the bearing. To decrease starting torque, use only enough grease to properly lubricate the bearing.
- Type of seal incorporated

  To decrease seal drag and, consequently, decrease starting torque, a clearance or labyrinth seal should be used. Contact seals such as rubber lip seals, while more effective in decreasing the incursion of contaminates, tend to increase the starting torque of the bearing.

Expansion capability

When selecting the proper bearing, a determination must be made as to whether the application requires the use of expansion bearings.

The benefit of expansion bearings is most clearly seen in applications likely to experience shaft growth due to heat. When excessive shaft growth is apparent, one expansion bearing should be incorporated into the system. As the shaft starts to grow, the expansion bearing will move with the shaft in order to eliminate additional bearing loads.

Adapter-mounted bearings require expansion to allow for axial movement when tightening the unit to the shaft.

Note: Under no circumstance should all bearings on the shaft be expansion type bearings.

Space requirement/limitation

When space is limited, the bearing manufacturer's catalog should be used to determine whether a bearing is dimensionally suitable for the application.

If dimensions are critical, it is best practice to consult the manufacturer's engineering department.

Maintenance

Bearing maintenance primarily involves relubrication issues. To decrease maintenance performed on bearings, sealed-for-life/no-lube bearings are available. This type of bearing is lubricated at the factory and sealed in such a way that the bearing cannot be re-lubricated.

Note: If using this bearing type, remember that the life of the bearing is directly related to the life of the lubricant chosen.

Type of locking device

Many types of locking devices are available—each with its own advantages and disadvantages. The most common types are: set screw, concentric (using a tapered adapter sleeve or clamp collar), and eccentric (using a cam-like collar and equivalent machined inner ring). See corresponding section for a detailed review of each type.

Cost

When using cost as a determining factor in choosing the appropriate bearing(s), make sure to consider the following costs:

- Total bearing
- Installation time
- Downtime

Once the above factors are placed into the equation, the cost of the bearing generally does not play a significant role. In most cases, the load and speed requirements will dictate the appropriate bearing selection, effectively removing cost from the equation.

Environmental operating conditions

Environmental conditions can play a role in selecting the appropriate bearing type (tapered, spherical, or ball), but often play a more significant role in selecting bearing options. For example:

- Seal type and configuration
- Grease type and fill
- Special bearing and housing coatings
- Special bearing hardware, i.e, stainless or other corrosion-resistant

Accessibility

The accessibility of the bearing must be considered before a certain bearing is chosen. Factors such as installation, maintenance, and bearing removal play a major role in the selection of the proper bearing and its options, from lubricant type to locking device and overall dimensions.

Housing style

There are multiple styles of housings available from pillow blocks to flanges and take-ups. Each style has its place in the industry and corresponding advantages and disadvantages.

Criteria that must be considered when selecting the proper housing style are as follows:

- Housing strength
- Housing material
- Accessibility
- Environment
- Application

The proper bearing selection is key to obtaining the rated life of the bearing. Considerable time and care should be taken when making this critical decision. Decisions will have to be made for each application as to which selection criteria are most important.

Availability

With the multitude of bearing styles, housings, and various features available, no manufacturer can have every bearing readily available. The most common bearings are kept in stock in large quantities. The less common bearings can often be made to order. It may be necessary to sacrifice a special feature if availability is critical. If certain features are critical, you may be required to keep spares on hand.

Handling and installation

As with precision-machine components, mounted bearings are sensitive to improper storage and handling. All bearings should be stored in a cool, dry area. Manufacturers often supply a bearing in packaging designed to protect unused bearings from the effects of humidity, handling, and exposure to contamination. Keep the bearings in their original packaging until ready for use.

Mounted bearings usually come with factory-packed lubrication, oil, or rust preventative that also will protect the bearing. If the bearing does not have any factory lubricant, covering the bearing with an additional light coating of a rust preventative may extend the storage life of the bearing.

Storage guidelines

When a bearing remains in storage for an extended period of time, precautions should be taken to extend shelf life. For long-term anti-friction bearing storage, be sure to use the following procedures.

Note: Refer to instruction manual provided with your bearing for specific handling, installation, and maintenance information.

- Coat the bearing and housing bore assembly with a corrosion inhibitor, lubricating oil, or grease
- Apply a bead of #3 or #4 grease at the junctures of the seal, housing, and shaft
- Seal all vents and other openings to the pillow block
- Rotate the shaft a minimum of 10 to 20 revolutions every 2 to 6 months; this will re-coat the bearing surfaces and reduce corrosion
- Bearings should be packaged within plastic sheeting, but should not be completely sealed as this can trap humidity
- Store the mounted bearings in a temperature-controlled and dry area—temperatures should not exceed a minimum of -20 °F and maximum of 120 °F; relative humidity should not exceed 60 percent
- Inspect the stored bearings at regular intervals—check for oxidized or hardened grease, brittle seals, and corrosion both in and around the bearing

The standard shelf life for long-term bearing storage is approximately three to five years due to the limited shelf life of factory-lubricated bearings and nonmetallic component of the bearings (i.e., rubber contact seal).

Handling and initial startup

Before use, refer to instruction manual for proper lubrication for your application. After startup, monitor the bearing operating temperature, noise, and/or vibration to determine the initial condition of the bearing.

For most rolling contact bearings, the initial startup is critical to the life expectancy of the bearing. Before installation, closely inspect all components for obvious damage or corrosion. After installation, cautiously rotate the bearing at low speed to purge excess lubricant. If needed, add lubricant as recommended by the manufacturer.

During the first several hours of operation, inspect newly installed bearings for overheating, noise, and vibration—all of which could indicate problems. If possible, re-check the bearing locking mechanism (set screws, lock collar, tapered adapter sleeve) to confirm proper installation.

It is normal for a bearing to operate at a higher than normal temperature when first installed or relubricated. The temperature should return to normal within a few minutes to a few hours, depending on bearing size and lubricant used. Below is a list of key temperatures:

- Normal operating temperature: 18—72 ˚F (10—40 ˚C) above ambient
- Pain threshold (when touched by hand): 130 ˚F (54 ˚C)
- Water evaporation: 220 ˚F (105 ˚C)

Alignment

Bearing alignment has a dramatic effect on bearing performance and service life. Misalignment can lead to premature bearing failure due to excessive loading, high bearing temperatures, and vibration. Misalignment, normally measured in degrees, can originate from any one of several causes, but is usually attributed to improper installation.

Most mounted bearings are provided with allowances for misalignment and are termed "self-aligning." The manufacturer's literature will identify self-aligning bearings and their degree of acceptable misalignment.

The various forms of misalignment are identified below and are illustrated in Figures 16 and 17.

- Static misalignment conditions (bearing and shaft axis not co-linear before operation)
    - Bearing supports not on same plane
    - Vertical axis
    - Horizontal axis
    - Deflection misalignment (shaft bending in a fixed direction due to load)
- Dynamic misalignment
    - Bent shaft
    - Unbalanced rotating load (eccentric load)

Most mounted bearings are designed with the ability to statically misalign. However, only spherical roller bearings can dynamically misalign. Spherical roller bearings misalign internally to the bearing, while most ball and tapered roller bearings (and some plain bearings) misalign externally.

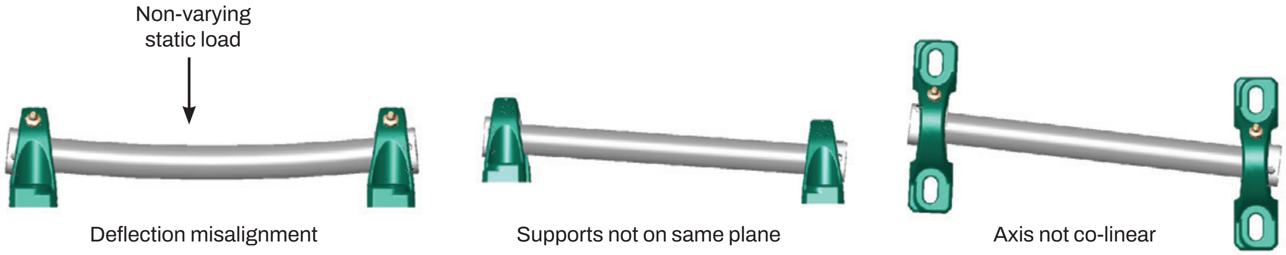


Figure 16 - Static misalignment

Figure 17 - Dynamic misalignment

Foundations

Bearing housings require a firm and fixed mounting location, or foundation. The bearing housing must be secure or the bearing alignment may not be maintained. This can cause premature bearing failures.

In many instances, mounting structures are made from thin sheet metal. Therefore, bearing misalignment swivel torque (force required to rotate insert in the housing) is critical. Allowing the bearing to misalign and keeping surrounding framework from buckling is important in obtaining long bearing service life.

Under heavy loads, proper housing bolt tightening torque is essential. In addition, housing shear bars may be used to keep the housing from shifting on the mounting surface and applying a shear load on the mounting bolts.

Housing foundations must also be flat and smooth. If a mounting surface is not true, the housing may be forced into an out-of-round condition that can "pinch" a bearing insert or cause housing fracture during installation or later during bearing operation. A pinched bearing insert may cause the bearing rings to become elliptical (out of round) and may result in accelerated bearing wear, overheating, noise, and ultimately, bearing failure.

Shaft tolerance

Most mounted bearings are slip-fitted over a shaft and secured with a locking device. This slip fit is necessary for easy installation of the bearing onto the shaft. However, an excessively undersized shaft may result in increased bearing vibration, temperature, and reduced locking reliability.

If a bearing is not secured to a shaft or loses lock to the shaft, the shaft will usually rotate in the bearing bore, damaging the bearing and shaft. Typical shaft tolerance recommendations are listed below. Refer to bearing instruction manuals for specific recommendations for your application.

Recommended shaft dimensions

When selecting a bearing shaft diameter, it is best to use increments of 15/16 inches and 7/16 inches for shaft sizes below 6 inches. For sizes 6 inches and above, increments should be 1/2 inches. Bearings in these sizes will have the best availability from bearing manufacturers and local power transmission component distributors.

Table 2 shows the size tolerances of standard shafting and the finish normally provided.

Tapered adapter mount ball bearings can be mounted on standard commercial tolerance shafting due to the method of locking the bearing on the shaft. The figures below illustrate the contact of the inner ring and/or locking mechanism on the shaft. Note that the tapered adapter mount features the most contact between the locking mechanism and the shaft.

Shaft expansion

One of the prime considerations in bearing installation or replacement is the effect of thermal shaft expansion on a bearing. As described in previous sections, one of the ways to accommodate this expansion is to install a bearing that will allow for thermal growth or shrinkage of the overall shaft length.

The following formula will determine the change in length of a shaft due to thermal factors:

$$\Delta L = \alpha * L * \Delta T$$

Where:

ΔL = The change in length of the shaft (inches)

α = The coefficient of linear expansion of the shaft material

L = The length between bearings (inches)

ΔT = The change in temperature (˚F)

Some shaft material coefficients of expansion are:

Carbon steel: 0.0000063 in/in/˚F

Stainless steel: 0.0000083 in/in/˚F

Aluminum: 0.0000123 in/in/˚F

Most mounted bearings are manufactured with a factory-set clearance (radial and axial) and can tolerate some change in length of the shaft. A change in shaft length that exceeds the axial clearance will result in an induced thrust load within the bearing.

Table 2 - Steel shaft diameter tolerances

Diameter tolerance (inch) – steel shafting			
Shaft size	**Recommended set screw, eccentric, and concentric mounted bearing turned ground and polished**	**Recommend tapered adapter sleeve mounted bearing, turned ground and polished or cold roller**	**Typical use cold roller shafting**
Up to 1-1/2	0.0000—0.0005	0.0000—0.002	0.0000—0.002
Over 1-1/2 to 2-1/2	0.0000—0.0010	0.0000—0.003	0.0000—0.003
Over 2-1/2 to 4	0.0000—0.0010	0.0000—0.004	0.0000—0.004
Over 4 to 6	0.0000—0.0015	0.0000—0.005	0.0000—0.005
Over 6 to 8	0.0000—0.0020	0.0000—0.006	0.0000—0.006

Setting bearing clearance

Most mounted bearings are shipped with a factory-set internal radial clearance. However, a few bearing types require measurement and reduction of the internal radial clearance to properly install the bearing to the shaft. Check the instruction manual to determine if the internal clearance will need to be adjusted.

Cleanliness

As is true with all of the components of mechanical power transmission systems, keeping the machine components clean of foreign materials, debris and contamination will contribute to the expected service life of a mounted bearing.

Fastener maintenance

The process of inspection, maintenance, and assembly of mounted bearings will invariably involve the use of threaded fasteners. Many of the fasteners used are specialized as to type, design, and material. A manufacturer's fastener selection is based largely on the application, with some consideration for cost or availability.

Fastener torque

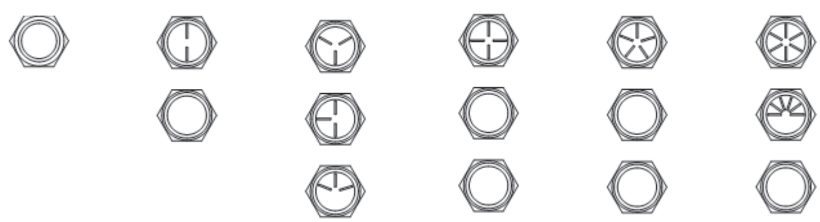
The various manuals and maintenance procedures for specific equipment will often contain cautions and notes specifying the degree of fastener tightening to be maintained on assembly of certain components. These should be specified by the manufacturer as necessary for the specific application.

In all cases where a manufacturer has specified a specific torque value, it is important that the personnel assembling the component adhere to that torque requirement. The tightening torque is directly related to the resultant fastener clamping force and is limited by the strength of the fastener and the mounted bearing housing.

Table 3 shows standard torque values and also illustrates some of the bolt head grade markings that may be encountered during maintenance.

Table 3 - Steel fastener torque values

SAE bolt torque specifications



Bolt size (inch)	Threads per inch, coarse thread	Grade 0-1-2 74,000 psi low carbon steel	Grade 3 100,000 psi med carbon steel	Grade 5 120,000 psi med carbon steel	Grade 6 133,000 psi med carbon steel	Grade 7 133,000 psi med carbon steel	Grade 8 150,000 psi med carbon steel
		Standard dry torque (ft-lbs)					
1/4	20	6	9	10	12.5	13	14
5/16	18	12	17	19	24	25	29
3/8	16	20	30	33	43	44	47
7/16	14	32	47	54	69	71	78
1/2	13	47	69	78	106	110	119
9/16	12	69	103	114	150	154	169
5/8	11	96	145	154	209	215	230

Torque values for lubricated threads

A common maintenance practice that aids future disassembly of components is to coat the fasteners with a never-sieze compound or a thread sealant before reinstallation. Although this can prevent corrosion and ease installation and removal of fasteners, the addition of a lubricant will change the torque required to achieve a specific bolt loading as described above.

The torque values provided by a manufacturer, or in Table 3, are normally for non-lubricated or “dry” fasteners. This is often specified as dry torque. To determine the equivalent torque value for a lubricated fastener, the specific lubricant type must be known. For each type of lubricant, the dry torque value must be reduced by a percentage to find the wet torque equivalent. The percentage of that reduction for several common thread lubricants is shown in the table below.

Lubricant	Percent of dry torque
SAE 20 oil	36
SAE 40 oil	41
White grease	45

Lubrication

Lubrication is one of the most important aspects of a bearing’s performance and service life expectancy. Since bearings are not frictionless and do not always operate in perfectly clean surroundings, lubrication along with sealing helps the performance and extends the service life of bearings.

Purpose and definitions

The primary function of lubrication is to reduce friction between contact areas within a bearing. Even though much care is taken to use low friction materials in bearings and contacting surfaces are highly polished, microscopic irregularities on each of the contacting surfaces will tend to resist the force applied to move one surface relative to the other. The addition of a lubricant allows the contacting surface irregularities to be separated by a microscopic oil film.

A second function of lubrication is to reduce wear of the two moving surfaces. As the irregularities of the moving surface are forced against those of the stationary surface, the inherent cohesive strength of the irregularities on one of the two materials will overcome the cohesive strength of the other material. The peak irregularity of the weaker material will tend to shear away as a free particle. This produces two conditions that tend to limit the service life of the bearing surfaces.

The first is a loss of the total mass of the softer of the two materials. The second is the introduction of a debris contaminant between the bearing surfaces. When a lubricant is used to provide a separation layer between surface irregularities, this activity is reduced.

A third function of a lubrication is to carry away heat generated by the friction and wear activity that occurs as the surfaces move. When the two surfaces move relative to each other, energy is expended to produce that movement. This energy is equal to the force required to overcome the friction resistance of the two materials.

Energy expenditure is converted to heat as the movement continues. A lubricant fluid between the two materials provides a medium for conducting this heat away from the bearing materials to an area where the heat can be dissipated. This allows the use of bearing materials that would otherwise be altered in form by the build-up of heat within the bearing.

Finally, a lubricant protects bearing components from contamination. Many bearings are required to operate in areas that have ambient conditions detrimental to the service life of the materials or material finishes of the bearing. These ambient conditions can include contaminants such as dirt and debris, moisture, chemical corrosive agents, or even the very oxygen in the air surrounding a bearing.

A lubricant between the contact surfaces of a bearing can act as a barrier or collecting agent for contaminants to prevent them from coming into physical contact with the bearing surface material. Used in this way, periodically replacing the lubricant will allow the trapped contaminants to be removed from the bearing.

The oil film provided by the lubricant serves to prevent metal-to-metal contact of the rolling elements. To accomplish this, the lubricant should have sufficient film strength. When the oil film breaks down or has insufficient strength to support the load, the result is a lubrication failure. When lubrication failure occurs, it creates spalling of the metal surface (see Figure 18).

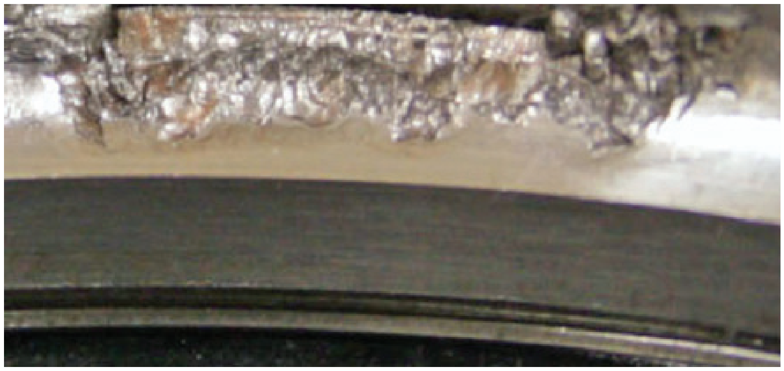


Figure 18 - Bearing lubrication failure

Lubrication types and classifications

For the most part, bearing lubrication is accomplished by the use of fluids, although some bearings use dry lubrication methods. Of the fluids commonly used, the majority are oil or grease.

Although dry lubrication methods and materials are not commonly used in mounted bearing applications, the dry lubricants are often used as additives in both oils and greases. The most common dry film lubricants are graphite and molybdenum disulfite. Molybdenum disulfite as a lubricant comes in powder, paste, oil, or grease carriers. It is normally used where conventional oils or greases cannot be used because of extreme pressures, very high or low temperatures, and slow speeds. Other dry lubricants used are: Teflon®, lead, babbitt, and silver or metallic oxides.

Oils fall into three categories: mineral, synthetic, and animal/vegetable. Most bearing lubricating oil is obtained from refined crude petroleum—this type of oil often contains additives that resist oxidation, reduce foaming, and improve lubricity.

Synthetic oils are special application oils formulated to overcome temperature extremes or environmental conditions that preclude the use of a refined petroleum product. They have a useful life up to four times the life of mineral oils.

Animal/vegetable oils are rarely encountered in bearing lubrication applications due to their low resistance to chemical contamination, oxidation, or emulsification with water.

Greases used in bearing lubrication are a combination of mineral and/or synthetic oils with a thickener plus additives. Typically, this is approximately 80 percent oil with 20 percent thickener and additives. In nearly all greases, the thickener is a metallic soap. The soap base keeps the oil in suspension and releases the oil as a film between the bearing surfaces. Grease additives are anti-oxidants, rust inhibitors, oil film enhancing compounds, and stabilizers.

Greases can be divided into several types:

- Petroleum oil grease
- Synthetic oil grease
- Food-grade grease

Advantages and disadvantages

Oil lubrication

Advantages:

- Can be used in applications with higher temperatures (the oil is circulated to remove heat from the bearing assembly)
- The amount of lubricant is more easily regulated
- Lends itself more readily to the lubrication of all parts of the machine (e.g., a speed reducer)
- Easier to drain and refill
- Can flush out foreign matter

Disadvantages:

- Susceptible to leakage through seals
- Higher initial cost than grease lubrication
- Limited number of bearing housings accept oil lubrication

Grease lubrication

Advantages:

- Assists the seals in keeping dirt and moisture out of the bearing
- Leakage is less likely to occur when using grease
- More easily confined to the bearing
- Tends to perform better at higher temperatures than static oil lubrication

Disadvantages:

- Difficult to clean when replacing grease types
- Susceptible to contamination during maintenance

Methods

Methods vary for applying a lubricant to the bearing contact surface area. The chosen method depends primarily on the type of lubricant used, but is also determined by the type and end use of the bearing, its environment, and its physical location. The following describes lubrication methods commonly in use based on lubricant type.

Oil lubrication

Oil lubrication methods for mounted bearings include oil bath, oil circulation, oil mist, and oil jet. The method selected is often dictated by the number of bearings, accessibility, type of oil used, etc.

Oil bath lubrication - For moderate and high speed applications, oil bath lubrication should be used whenever possible. Since this system is non-circulating, the static oil level should never be higher than the center of the lowest ball or roller in the bearing being lubricated. Excess oil levels can cause churning which produces heat—leading to high operating temperatures—and increases the opportunities for leakage through the seals.

Circulating oil lubrication - This type of system utilizes a circulating pump to assure a positive supply of lubricant to the bearings and is generally used in low-to-high speed, heavy-duty bearing applications. The flow path of the oil in this system is important because a bearing churning a captive volume 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 plugs are necessary to prevent damage to the bearings. In general, oil is pumped into the top of the bearing housing and drained from the bottom. Maximum oil flow rates are supplied in the manufacturers' catalogs.

Oil mist lubrication - Oil mist is used in high-speed, continuous operation applications. Normally, the oil is mixed with compressed air and misted onto the bearing. The continuous passage of pressurized air and oil through the labyrinth seals used in the system prevents atmospheric contaminants from entering the system. Oil mist systems should be turned on well before the machinery is started. No more than a continuous thin film of oil is required to lubricate a bearing.

Oil jet lubrication - This type of lubrication to similar to oil mist lubrication, but the oil is sprayed into bearing at a higher pressure.

Oil lubrication change frequency:

How often the oil has to be changed depends upon the operating conditions and the quality of the oil. With oil bath lubrication, it is generally sufficient to change the oil once a year if the bearing temperature does not exceed 122 °F (50 °C). At higher temperatures or with heavy contamination, the oil must be changed more often.

For example, with operating temperatures of 212 °F (100 °C), the oil should be changed once every quarter. With oil circulation, the oil must be inspected periodically for oxidation and the presence of abrasive particles. In this way, history and experience can be gained on the oil change period.

As a rule of thumb, the service life of a petroleum oil is specified as 30 years at 85 °F (30 °C) and 15 years at 104 °F (40 °C). Its life is halved for each temperature increase of about 18 °F (10 °C), resulting in a service life of approximately three months at 212 °F (100 °C).

Oil lubrication notes:

- In mounted bearings, the correct static oil level is at the center of the lowest rolling element at rest
- The higher the oil temperature, the faster the oil breaks down

Grease lubrication

Anti-friction bearings are usually lubricated with grease because it is much easier to retain grease than oil in the housing over a long period, and because grease acts, to some extent, as a seal against dirt and other contaminants entering the bearings.

Rolling element bearings are often provided with an initial grease charge that allows installation with little or no addition of grease before operation. The typical installation of grease-lubricated mounted bearings includes a grease fitting (see Figure 6). After a period of running, the operator may find it necessary to add grease using a hand grease gun or other pressurized grease injecting system.

Lubrication of unmounted bearings in storage will involve hand-packing the bearing. Before renewing the grease in a hand-packed bearing, the bearing assembly should be washed in clean kerosene, degreasing fluid or other solvents. As soon as the bearing is clean, it should be washed immediately in a clean, light, rust-inhibiting mineral oil. The bearing should not be spun before or while it is being oiled.

When replacing the grease, use your fingers to force the grease between the balls or rollers. The available space inside the bearing should be filled completely and the bearing should then be spun by hand. Wipe off any grease thrown out.

As a general rule, it is not necessary to grease-fill the free space in a ball or roller bearing greater than one-third of the void available. This is because, under normal operation, a bearing will expel or purge all grease in excess of about one-third of the volume available. The one-third rule, therefore, is essential for bearings with two shields or seals since the excess grease cannot escape during normal operation. The result would be damage to the grease and seals as well as the bearing because the churning of excess grease in the bearing during operation would create considerable heat.

The exception to the one-third rule is bearings that turn very slowly. The definition of a slow-turning bearing is one that rotates at 20 percent or less of the maximum rated catalog speed. Bearings of this type are usually filled from 80 percent to 100 percent with grease.

Some manufacturers make bearings with seals that are capable of purging excess grease without causing damage to the seal or the bearing. Bearings that have no seals or shields or only one seal or shield can be filled more than one-third full if desired since the excess grease will be purged out of the bearing void space (during operation) and into the free housing space outside of the bearing. This purged grease will often help protect the interior of the bearing from dust and dirt.

Determining which grease to use

For most applications, a NLGI #2 lithium soap-based grease blended with an oil from 250 to 600 Saybolt Universal Seconds (SUS) at 100 °F (38 °C) is suitable. This is a very general determination and maintenance planners often desire to make a more detailed examination of the applicability of the various greases to a particular bearing based on the conditions affecting the use of a bearing. The following sections will provide that guidance.

Compatibility and properties of different greases

Since some greases are incompatible with other greases, it is recommended that you completely clean out old grease from a bearing before fresh grease is inserted. If the same grease as the original grease is used, the bearing does not have to be flushed. However, grease going into a bearing must be free of dirt, contamination, and moisture.

The compatibility characteristics and properties of some common types of greases are shown in Table 4 and Table 5.

Table 4 - Properties of grease soap bases

Grease type	Temperature range (˚F)	Water resistance	Corrosion resistance	Load carrying capacity	Price relationship	Remarks
AL complex	-20—320	Very good	Very good	Moderate	2.5—4	Multipurpose grease
Barium complex	-20—285	Good	Very good	Good	4—5	Multipurpose grease; good in vacuum environment
Calcium	-20—120	Very good	Good	Moderate	1	Good sealing action against water
Calcium complex	-20—285	Good	Good	Good	1—1.2	Multipurpose grease; may harden
Lithium	-30—265	Very good	Good	Good	1	Multipurpose grease; emulsifies with water
Lithium complex	-30—300	Good	Moderate	Good	2	Multipurpose grease; emulsifies with water
Polyurea	-15—320	Very good	Moderate	Good	3	For higher temp. at medium speeds
Sodium	-20—210	Poor	Very good	Good	1	Emulsifies with water; may solidify

Table 5 - Grease consistency and NLGI numbers

NGLI #	Worked penetration	Un-worked comparison	Stiffness
00	400—430	Paint	Very soft
0	355—385	Brown mustard	
1	310—340	Tomato paste	
2	265—295	Peanut butter	
3	220—250	Vegetable shortening	
4	175—205	Plaster	Hard

During the selection process of a suitable grease, the following areas need to be considered:

- Grease consistency
- Oil viscosity in the grease
- Soap base (Lithium, Barium, Polyurea, etc.)
- Load-carrying properties
- Operating conditions

Grease consistency

Grease consistency is identified by a NLGI number as shown in Table 5.

Selecting grease by speed

Typically, grease with a lower viscosity and a higher NLGI number are chosen when operating at high speeds. When dealing with a bearing operating at low speeds, a grease with a high viscosity and lower NLGI number would be chosen.

Selecting a grease or oil by viscosity

Oils and the oils used in specific greases are rated by viscosity. Viscosity is a measurement of the volume of oil that will flow through a given-sized orifice in a specified period of time at a specific temperature. Effectively, this is a measurement of oil thickness.

When an oil temperature increases, it becomes “thinner.” Therefore, at higher temperatures the oil can be considered to have a lower operating viscosity. The operating viscosity of an oil is critical to the life of the oil and the effectiveness of the oil as a lubricant. During operation, a bearing will have an increase in temperature due to internal friction and from outside influences. As this occurs, the oil or grease (containing oil) that is used to lubricate the bearing also increases in temperature. The increase in oil temperature in a bearing will lower the lubricating ability of the oil and will shorten the life of the oil. Additionally, the specific bearing size and speed will determine the required oil viscosity of the lubricant.

For these reasons, the oil used in a bearing must be based on the rated viscosity and the operating viscosity. The ratio of the two is called the Kappa value. Different bearing types have different recommended Kappa values, as shown in the following sections.

1. To determine the viscosity value for an oil or grease for use in a particular bearing, you must know the following:
   - Bearing type
   - The mean bearing diameter in mm
   - Operating speed (rpm)
   - Operating temperature in degrees C
   - The required Kappa value
2. To determine the mean bearing diameter, add the OD of the outer bearing ring to the ID of the inner bearing ring. Divide that sum by two for the bearing mean diameter: (outer ring OD + inner ring ID) / 2.
3. To determine the rated oil viscosity for a bearing, find the mean bearing diameter on the bottom of Figure 19 and draw a line straight up to intersect the corresponding bearing rpm line. Follow the chart to the left to find the rated viscosity for that bearing.

Next, determine the Kappa value (K) of the bearing from the list. Different bearing types have different recommended Kappa values:

- K = 1 for ball bearings
- K = 2 for roller bearings
- K = 2.5 for slow turning applications

To find the required viscosity of a lubricant, you must first solve for the operating viscosity by using the following equation. Once the operating viscosity has been determined, it can be used in Figure 19 to determine the required viscosity of the lubricant.

Kappa value (K) = operating viscosity (v) / rated viscosity (v1)

Draw a vertical line originating from the determined operating viscosity until it intersects the horizontal operating temperature line.

Finally, compare that intersection point to the diagonal required viscosity.

Example of selecting a grease based on viscosity

The following example illustrates how to determine the correct viscosity of a grease for a specific bearing.

Given:

Fan application
22220 spherical roller bearing
Rpm = 2000
Operating temperature = 90 °C

1. Identify bearing type:
   - 22220 spherical roller bearing
2. Calculate the mean bearing diameter:
   - dm = (D+d)/2
   - where D = O.D. of bearing in mm
   - dm = (180+100)/2
   - d = I.D of bearing in mm
   - dm = 140 mm
3. Determine operating rpm and temperature:
   - Given: operating rpm(n) = 2000
   - Temperature = 90 °C
4. Determine the kappa value (K):
   - Given: spherical roller bearing
   - Therefore, k = 2

We now have all the information needed.

1. Using Figure 20, draw a vertical line from the 140 mm mean diameter axis until it intersects the 2000 diagonal rpm(n) line.
2. From this intersection draw a horizontal line until it intersect with the rated viscosity (v1) axis. Record this value, rated viscosity (v1) = 8 mm 2/s, because it will be for the next step.

3. Now solve for the operating viscosity (v) by taking the rated viscosity (v1), determined from the previous diagram, and plugging it into the following equation:

   Kappa (K) = Operating Viscosity (v) / Rated Viscosity (v1)
   2 = Operating Viscosity (v) / 8 mm 2/s
   Operating Viscosity (v) = 16 mm 2/s

4. Now find 16 mm 2/s on the operating viscosity(v) axis in Figure 19 and draw a vertical line until it intersects the operating temperature of 90 °C. Compare this intersection point to the diagonal required viscosity lines. The intersection point falls between the 100 and 150 diagonal required viscosity lines.

Scaling the diagram shows that the minimum required viscosity is 125 mm 2/s. Therefore, when selecting a lubricant for this application, choose one with a minimum viscosity of 125 mm 2/s.

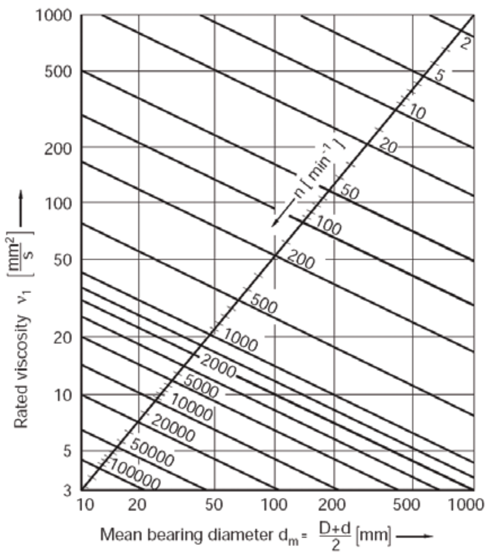


Figure 19 - Rated viscosity table

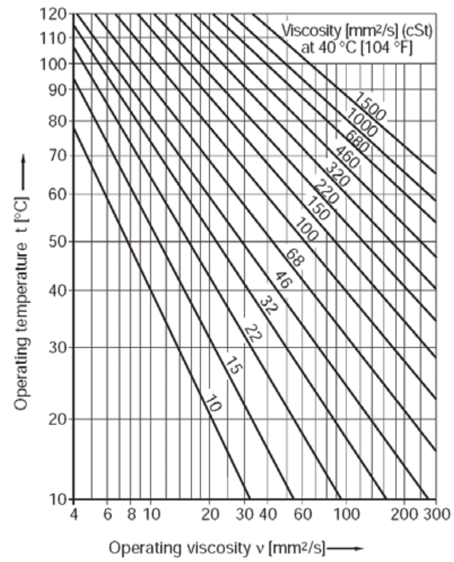


Figure 20 - Operating viscosity table

Grease relubrication

Re-greasing of a bearing depends on the type, size, revolution speed, operating temperatures, environment, sealing arrangements, and types of grease. Establishing relubrication intervals are discussed in Maintenance and Failure of this guide. In all cases, refer to the manufacturer's recommendations for when to relubrication.

Grease lubrication notes

1. Sodium-based greases are not water resistant, and decompose when subjected to high quantities of water. However, they can absorb small quantities of moisture and offer some protection against corrosion.
2. Calcium-based greases are insoluble in water.
3. Lithium-based greases are normally stable with respect to water up to +195 °F (90 °C).
4. The type and amount of thickening agent used (organic, inorganic, metal, soap) and the base oil type (mineral or synthetic) and its viscosity determine the upper and lower operating temperature limits of lubricating grease. As a rule of thumb, mineral oil-based lubricating greases are suitable for the following temperature ranges:
   - Calcium-base grease -22° to 140 °F (-30° to 60 °C)
   - Sodium-base grease -22° to 265 °F (-30° to 130 °C)
   - Lithium-base grease -22º to 265 ºF (-30º to 130 °C)
   - Gel- and complex-base grease -22° to 300 °F (-30° to 150 °C)
5. Synthetic greases can satisfy higher (+350 °F/177 °C) and/or lower temperatures (-100 °F/-73 °C).
6. For heavily loaded bearings—such as mill bearings—greases containing EP, additives are used.
7. The correct amount of grease for a bearing is one-third to one-half full depending on the available space within the bearing.

Maintenance and failure analysis

The key to extending the service life of mechanical devices and system is a maintenance program that is based on determination of probable component failures, accurate analysis of failure indicators, and timely corrective action to prevent the occurrence of failures. Using failure analysis techniques, we can produce a cost-effective maintenance program that focuses on the known ways in which a particular mechanical device will fail.

Failures

Maintenance personnel often report bearing problems in relation to the resulting condition of the failure. Here is a sample list of the most commonly reported conditions:

- Bearing running hot
- Bearing running noisily
- Excessive vibration
- Bearing damaging shaft (spinning)
- Shaft difficult to turn
- Lubrication leakage
- Bearing life is too short

It is an established fact that roughly 80 percent of all bearings failures are lubrication-related. The following list shows the most frequently encountered lubrication failure modes, plus other common causes of bearing failure:

- Wrong type of lubricant
- Insufficient amount of lubricant
- Excessive amount of lubricant
- Contamination of lubricant
- Misalignment
- Inadequate bearing clearance
- Undersize shafting
- Imbalance in the system
- Improper bearing selection for application
- Mounting/handling

Since the vast majority of bearing failures are related to lubrication issues, it is imperative that proper lubrication techniques be incorporated into a preventative maintenance program. In order to do this, you need to determine the following:

1. Type of lubricant
   a. Soap base (discussed in lubrication section)
   b. Required viscosity (discussed in lubrication section)
3. Lubrication schedule
4. Lubrication amount

The following two sections will cover how to properly determine the correct lubrication schedule/interval and the amount of lubrication that should be added at each interval.

Establishing a lubrication schedule

The correct relubrication interval is essential in achieving the maximum life of a bearing. An incorrect relubrication interval can decrease the life of the bearing in several ways:

- Infrequent relubrication interval
  - Bearing can fail due to lubrication breakdown, causing premature metal-to-metal contact between the rollers and raceways
  - Grease acts as a barrier/seal and aids in decreasing the incursion of contaminates into the bearing. When sufficient lubricant is not present the sealing ability of the bearing is decreased and contaminants can more easily enter the bearing.
- Excessive relubrication interval
  - In a high speed application, the bearing could overheat due to the amount of grease being pumped into the bearing (all Dodge bearings have seals that will purge excess lubrication, but this purging is spread out over time)
  - If the amount of grease pumped into the bearing is greater than the amount that can be purged from the bearing it will begin to fill. At this point, the bearing will begin to generate excess heat. If this relubrication interval continues to be followed, the bearing will continue to fill with grease even will eventually overheat and fail.

To properly determine the correct relubrication interval, the following information is needed:

- Identify bearing type (ball, tapered, or spherical)
- Determine the bearing factor (kf)
    - Ball bearings: kf = 0.9—1.1
    - Tapered roller bearings: kf = 4
    - Spherical roller bearings: kf = 7—9
- Calculate the mean bearing diameter: dm = (D+d)/2
- Determine the operating rpm
- Determine the grease service life (gl)

Once the above information is known, the grease service life (gl) of a lubricant can be determined. See the example below.

Example:

Given:

Fan application
22220 spherical roller bearing
Rpm = 1000
Operating temperature 140 ºF

1. Identify the type of bearing:
    - 22220 Spherical roller bearing
2. Determine the bearing factor (kf)
    - Given: spherical roller bearing
    - Therefore, kf = 7—9 (we will choose a nominal value of 8)
3. Calculate the mean bearing diameter
    - dm = (D+d)/2
    - where D = O.D. of bearing in mm
    - d = I.D. of bearing in mm
    - dm = (180+100)/2
    - dm = 140 mm
4. Determine opertating rpm
    - Given: operating rpm(n) = 100
5. Determine the grease service life (gl)
    - To complete step 5, we must first calculate the bearing and speed factor. This calculated value will be used to determine the grease service life (gl).
    - Bearing and speed factor = kf x n x dm = 8 x 1000 rpm x 140 mm
    - Bearing and speed factor = 1,120,000 rpm-mm

We now have all the information needed to determine the grease service life (gl) using Figure 21.

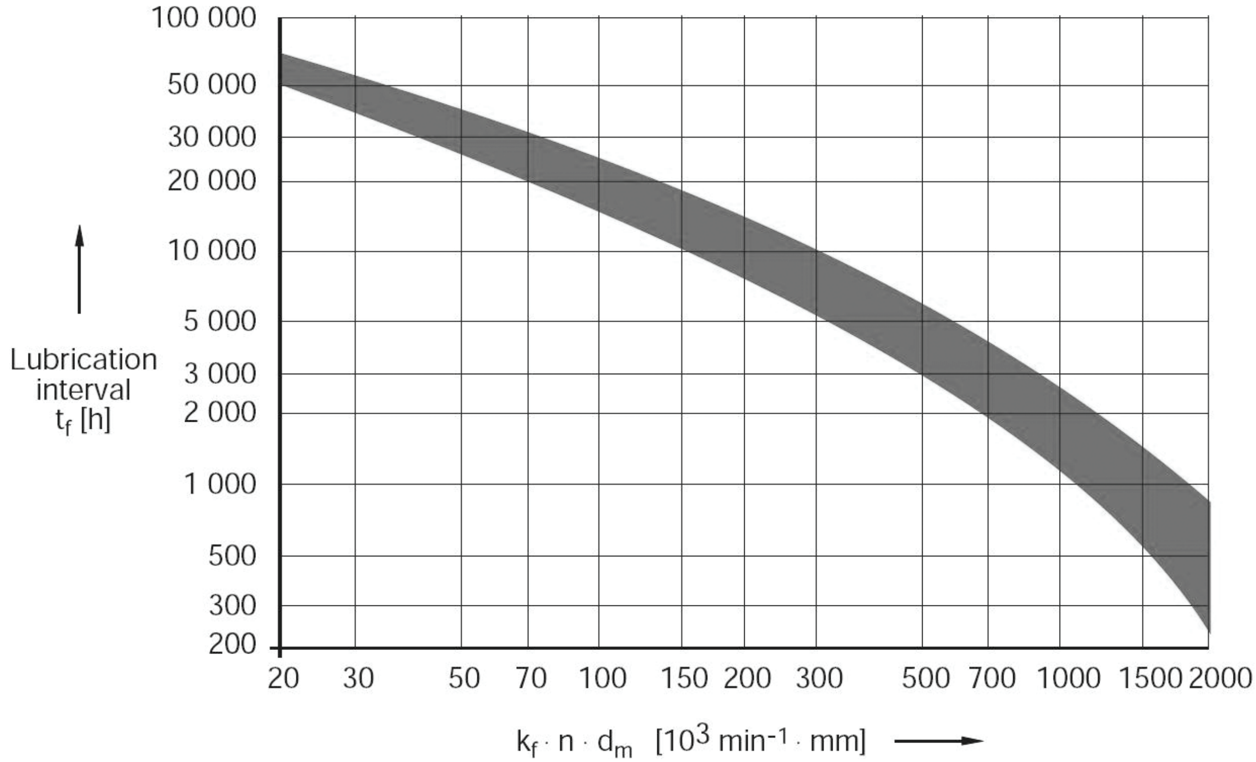


Figure 21 - Grease service life (gl)

1. First, draw a vertical line from the 1,120,000 rpm-mm bearing and speed factor axis until it intersects the grease service life curve.
2. From this intersection, draw a horizontal line until it intersects with the grease service life (gl) axis.
3. Record this value (grease service life or gl = 1,500 hours) because it will be required to determine the correct relubrication interval.

Depending on the operating conditions, there are two ways to calculate the relubrication Interval. If the operating and environmental conditions are favorable, use the equation in case 1. If operating and environmental conditions are poor, then reduction factors (f1, f2, f3, and f4) must be included and the equation in case 2 must be used.

The example will be calculated using both cases with chosen values for the reduction factors.

Case 1

Under favorable conditions

Re-lube interval = grease service life (gl) = 1500 hours

This equates to a relubrication interval of roughly every 17 weeks, assuming the bearing is operating 12 hours per day, 7 days per week.

Case 2

Under poor operating and environmental conditions

This is far more common and should be incorporated in most applications.

Re-lube interval = f1 x f2 x f3 x f4 x gl

f1: Effect of dust and moisture
f1= 0.7— 0.9 Moderate
f1 = 0.4— 0.7 Strong
f1 = 0.1—0.4 Very strong

f2: Effect of shock load and vibration
f2 = 0.7—0.9 Moderate
f2 = 0.4—0.7 Strong
f2 = 0.1—0.4 Very strong

f3: Effect of temperature
f3 = 0.7—0.9 Up to 170 °F
f3 = .04—0.07 170 to 185 °F
f3 = 0.1—0.4 0.07 185 to 240 °F

f4: Effect of high loads
f4 = 0.7—1 When P/C = 0.1 to 0.15
f4 = 0.4—0.7 When P/C = 0.15 to 0.25
f4 = 0.1—0.4 When P/C = 0.25 to 0.35

For the purpose of this example use:

- f1 = 0.7
- f2 = 0.9
- f3 = 0.9
- f4 = 1
- Grease service life (gl) = 1,500 hours

Therefore:

- Re-lube interval = f1 x f2 x f3 x f4 x gl
- Re-lube interval = 0.7 x 0.9 x 0.9 x 1 x 1500 = 850 hours

This equates to a relubrication interval of roughly every 10 weeks, assuming the bearing is operating 12 hours per day, 7 days per week.

Note: These calculations are based on a lithium-based grease. If a synthetic grease is being used, a good rule of thumb is to multiply the relubrication interval by four.

Establishing lubrication amount

To manually determine the correct relubrication quantity, we must first obtain the following information:

- D = bearing outer diameter (mm)
- B = bearing width (mm)
- Q = relubrication interval factor
  - Use Q = 0.002 for weekly re-lube interval
  - Use Q = 0.003 for monthly re-lube interval
  - Use Q = 0.004 annual re-lube interval
- Relubrication quantity equations: grease quantity (grams) = D x B x Q
- Grease quantity (oz) = (D x B x Q) / 28.35

Once the above information is known, the grease quantity can be determined.

Example 1

1-15/16" SC ball bearing relubrication
Interval = Weekly

1. Determine: D = bearing outer diameter (mm)
   Given: D = 90 mm
2. Determine: B = bearing width (mm)
   Given: B = 22 mm
3. Determine: Q = Relubrication interval factor
   Given: Q = 0.002 (weekly)

Plug this information into the following equations to determine the correct grease quantity:

- Re-lube quantity (grams) = D x B x Q
- Re-lube quantity (grams) = 90 mm x 22 mm x 0.002 = 3.96 grams
- Re-lube quantity (oz) = (D x B x Q)/28.35
- Re-lube quantity (oz) = (90 mm x 22 mm x 0.002)/28.35 = 0.14 oz

Example 2

2-7/16" Safety Mount mounted spherical roller bearing
Relubrication interval = monthly

1. Determine: D = bearing outer diameter (mm)
   Given: D = 120 mm
2. Determine: B = bearing width (mm)
   Given: B = 32.3 mm
3. Determine: Q = relubrication interval factor
   Given: Q = 0.003 (monthly)

Plug this information into the following equations to determine the correct grease quantity:

- Re-lube quantity (grams) = D x B x Q
- Re-lube quantity (grams) = 120 mm x 32.3 mm x 0.003 = 11.6 grams
- Re-lube quantity (oz) = (D x B x Q)/28.35
- Re-lube quantity (oz) = (120 mm x 32.3 mm x 0.003)/28.35 = 0.41 oz

Note: If for any reason you cannot calculate the correct relubrication quantity and the bearings have seals that will purge grease, then the following rule applies: while the bearing is operating, if safe to do so, continue to add grease until fresh grease can be seen purging past the seals.

Failure analysis

With all failure analysis, the initial step is to identify the machine component parts in which a failure of that part will prevent the parent machine from operating. Those parts, identified as meeting this criterion, are the critical components.

If we consider a typical rolling contact mounted bearing as the parent machine, the following would be considered critical components:

- Inner race
- Outer race
- Balls or rollers
- Retainer or cage
- Seals
- Shaft locking devices
- Locking device fasteners
- Bearing housing
- Housing fasteners
- Bearing lubrication system
- Grease fitting
- Grease/oil reservoir
- Oil feed system

For each of these critical components, the first step in failure analysis is to determine the manner in which that component will fail.

Note: This is not a determination of what the part failed to do—we know that it failed to operate as designed. What we are looking for is the exact condition of the part that produced the failure. This is the failure mode.

For each failure mode, it is necessary to identify the causes of that particular failure. Once the causes are known, the next step is to place the causes in parent-child sequence. This step allows the identification of the root cause of the failure.

The last step is the determination of the condition that existed to produce the root cause of a failure. Once the failure mode and the root cause of the failure has been determined, the next step is to develop a maintenance schedule that will eliminate the root cause in order to prevent the next failure.

Preventive maintenance

Preventive maintenance actions are maintenance activities designed to correct the causes of failures that are expected to occur based on the failure history of like-machinery components. These maintenance actions are typically time-based on machine operating periodicity.

Most of these actions are repetitive and scheduled at regular intervals. This type of maintenance has the advantage of simple planning of maintenance resource allocation.

A preventive maintenance program alone has the disadvantage of not accommodating changes to operational variables. These include periods of no load, idle operational periods, changes to environment, or less than ideal installation/maintenance of individual machine components. A typical preventive maintenance program will include maintenance activities scheduled by calendar periodicity and/or operating time periodicity.

A common example of preventive maintenance scheduling is getting your automotive oil changed after every 3,000 miles of operation. It is easily scheduled, resources can be allocated to accomplish the task, and the maintenance history is traceable. Notice that this maintenance alone will not keep the engine oil system operating as designed. If the previous oil change was performed incorrectly, if engine use happened during abnormal conditions, or if maintenance to a related component was incorrect, the strict adherence to periodicity would not prevent component failure.

Preventive bearings maintenance addresses the following specific maintenance actions on a time or operating period-based schedule:

- Bearing cleanliness
- Bearing relubrication
- Bearing corrosion prevention
- Checking shaft attachment devices

Predictive maintenance

Predictive maintenance actions are those actions taken to correct causes of failures that are expected to occur based on the history of machine performance degradation. This is most often determined by installed instrumentation, operator inspection, recorded machinery operating history, and a comparison of this information to failure modes and root-cause analysis data.

Condition-based monitoring

Condition-based monitoring (CbM) is a tool that predicts maintenance needs by tracking specified operating parameters and comparing them to a standard set of parameters. This comparison determines when a machine's operating performance has degraded to the point at which maintenance is required to restore performance to an acceptable level. This monitoring requires a method of performance data collection, in addition to follow-up comparison and analysis of that data.

In its most basic form, CbM is accomplished by simple inspection of a machine by an experienced operator/technician who "reads" the performance indicators and, based on personal knowledge, decides that a specific maintenance activity must be performed to restore the machine to a level of performance that allows continued operation.

For more complex machines and systems, modern technology has replaced individual inspection with data collection instruments or sensors that can record and transmit collected data to a centralized data collection point where it is entered into a computerized database that compares the data received to a performance standard. This comparison normally uses a set of algorithms that sort the data sets using a condition inequality to trigger the need for maintenance. Often this CbM program is incorporated into a Computerized Maintenance Management System (CMMS) that allows collection of performance history, maintenance history, performance trend analysis, automated condition reporting, tracking, and scheduling of maintenance resources, generation of maintenance action orders, and even maintenance cost analysis and accounting.

Some basic data elements required to make an effective condition-based monitoring program for mounted bearings are:

- Bearing temperature
- Bearing speed
- Bearing vibration

As you can see, an effective mounted bearing maintenance program may include preventive maintenance and condition-based maintenance elements. The actual maintenance program used by a particular facility will be determined by the most cost-effective method based on the number of bearings, the type of bearings, and their value relative to other facility components, in addition to the cost of the maintenance resources needed to keep the mounted bearings operating as designed.

Troubleshooting guide

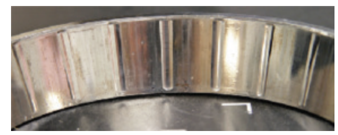
This section provides some guidance for the most commonly reported problems with mounted bearings. Most complaints can be placed in one or more of the following categories:

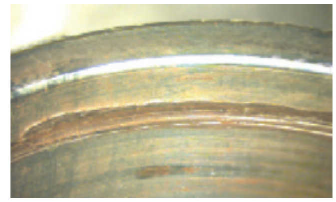
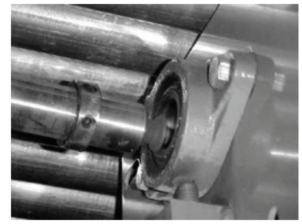
- Bearing running hot
- Bearing running noisily
- Bearing replacement too frequent
- Excessive vibration
- Bearing damaging shaft (spinning)
- Shaft difficult to turn
- Lubrication leakage

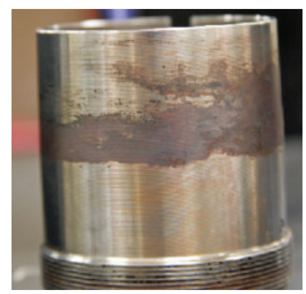
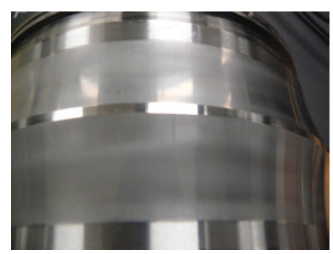
For each of the above complaints, the effect can be produced by any of several bearing conditions. These conditions are evaluated in the table on the following pages.

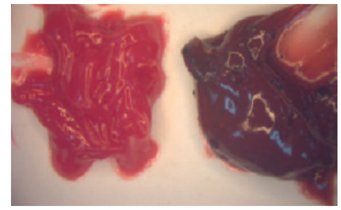
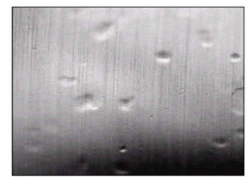
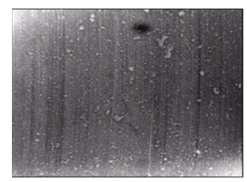
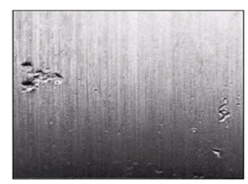
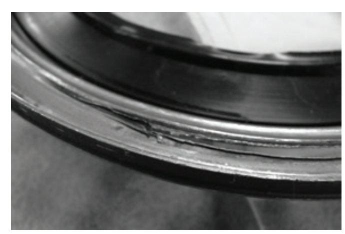
Examples of bearing failures

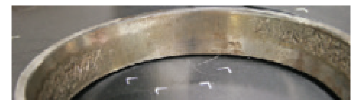
The following illustrations show various examples of common bearing failures.

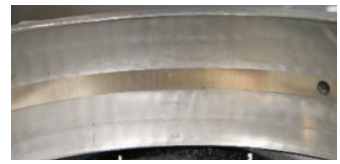
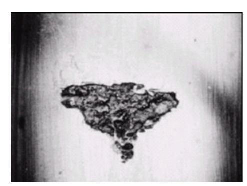
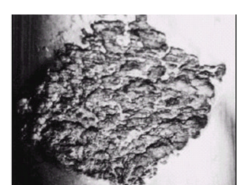
Observation	Explanation	Failure mode	Recommendation	Figures
Anti-rotation pin missing/sheared	When the anti-rotation pin is sheared or missing, an imbalanced load is usually present. The outer ring will begin to rotate or swivel within the housing, which causes the anti-rotation pin to 'bottom out' in the lube slot and shear.	Static misalignment, dynamic misalignment	Align bearings/shaft assembly. Inspect mounting surfaces for imperfections. Verify shaft deflection does not exceed bearing misalignment capability. Check shaft concentricity and straightness. Evaluate eccentric loading within the system.	
Brinelling	Brinelling is a type of failure that leaves small indentations or dents in the races or rolling elements of a bearing. These dents are often so small it is hard to see without a microscope. The dents, even the smallest ones, cause the bearing to vibrate excessively during operation. Brinelling occurs when a bearing is at rest, not when it is in operation and failure usually starts when the bearing is installed. If installation force is incorrectly applied, the balls or rollers are forced up against the races, and both the rolling elements and the races get 'dented'. Brinelling is permanent deformation of the material due to loading beyond the material strength.	Improper handling, excessive shock loading	Contact application engineering to review your application to find a more suitable bearing.	
Cakey/hard/ oxidized lubricant	When a lubricant becomes 'cakey' or hard it loses all lubricating properties. It is generally caused by improper lubrication intervals or mixing two or more incompatible greases.	Ineffective lubrication, insufficient lubrication, aged lubrication	Immediately increase lubrication frequency. An increased lubrication frequency will prevent contaminants from entering the sealing cavity and at the same time will drive out any contaminants that have penetrated the sealing cavity. The best protection against the ingress of contamination and moisture is to keep grease at the seal area. Increase the amount of lubricant being pumped into the bearing at each relubrication interval. Fresh grease should be seen purging from the bearing seal area at each relubrication interval. Decrease relubrication interval in order to keep fresh grease in the bearing and decrease the incursion of contaminates. Fresh grease should be seen purging from the seal area at each relubrication interval.	
Cap bolts fractured	Not using a torque wrench; over-torqueing	Improper selection, excessive shock loading	Contact application engineering to review your application to find a more suitable bearing.	Picture not available

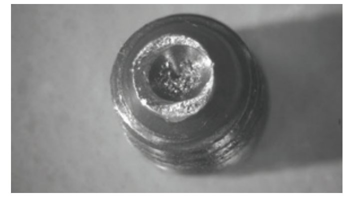
Observation	Explanation	Failure mode	Recommendation	Figures
Centrifugal wear on adapter bore	Centrifugal wear on adapter or bore inside diameter is caused by under tightening of the adapter locknut and/or failure to remove the load from the bearing during the tightening process. It can also be caused by improper set screw torque.	Improper mounting, undersized shafting	Refer to corresponding instruction manual for proper mounting instructions. Verify shafting is within recommended tolerances.	
Centrifugal wear on bearing inner ring inside diameter	Centrifugal wear on adapter or bore inside diameter is caused by under tightening of the adapter locknut and/or failure to remove the load from the bearing during the tightening process. It can also be caused by improper set screw torque.	Improper mounting, undersized shafting	Refer to corresponding instruction manual for proper mounting instructions. Verify shafting is within recommended tolerances.	
Damaged threads on adapter sleeve	Adapter thread damage is a common issue if care is not taken during the installation process. Installation hammer blows which are misguided will deform threads, restricting proper locknut rotation.	Improper mounting	Refer to corresponding instruction manual for proper mounting instructions	
Edge wear on rollers	Roller edge wear is caused by misalignment. The roller edges will show increased wear and possible chipping due to the abnormal operation.	Static misalignment, dynamic misalignment, improper selection, excessive thrust loading	Align bearings/shaft assembly. Inspect mounting surfaces for imperfections. Verify shaft deflection does not exceed bearing misalignment capability. Check shaft concentricity and straightness. Evaluate eccentric loading within the system. Evaluate capacity for expansion within the application. If applying an expansion bearing, insure the bearing is installed with full capacity for axial growth. Additionally, evaluate bearing suitability for application.	Picture not available
Fractured cage	A fractured cage is generally a lubrication and or temperature related failure. The cage, which is usually the thinnest wall component in the bearing, will tend to fracture after a prolonged period without sufficient lubrication. Depending on the cage material, excessive temperature could cause a cage to melt or fracture.	Ineffective lubrication, insufficient lubrication	Immediately increase lubrication frequency. An increased lubrication frequency will prevent contaminants from entering the sealing cavity and at the same time will drive out any contaminants that have penetrated the sealing cavity. The best protection against the ingress of contamination and moisture is to keep grease at the seal area. Increase the amount of lubricant being pumped into the bearing at each relubrication interval. Fresh grease should be seen purging from the bearing seal area at each relubrication interval.	

Observation	Explanation	Failure mode	Recommendation	Figures
Fractured housing cap	A fractured housing cap is caused by excessive load applied in through the housing cap.	Improper handling, improper selection, excessive shock loading	Contact application engineering to review your application to find a more suitable bearing.	
Fractured housing feet	A fractured housing foot is caused by excessive load applied in an upward direction and/or an excessive shock load in the axial direction.	Improper mounting, improper handling, improper selection, excessive shock loading	Refer to corresponding instruction manual for proper mounting instructions.	
Fractured ring	Due to the nature of through-hardened material, cracks developed in the raceway will propagate through, fracturing the ring.	Improper mounting, improper selection, excessive shock loading	Refer to corresponding instruction manual for proper mounting instructions.	
Fretting corrosion	Fretting corrosion, often confused with rust due to its similar visual characteristics, is a minor film of corrosion that forms with minor vibration between two similar metallic surfaces. Excessive levels of fretting indicate undersized shafting and/or improper installation.	Undersized shafting, improper mounting, undersized shafting	Verify shafting is within recommended tolerances. Refer to corresponding instruction manual for proper mounting instructions.	
Frosty raceway	Evidence of a frosty metallic surface is one of the initial signs of lubrication breakdown and metal to metal contact between rollers and raceways. Frosty raceways are also indicative of contamination with dull tracks representing course abrasive matter and shiny tracks representing fine abrasive matter.	Ineffective lubrication, soft-particle lubrication contamination	Immediately increase lubrication frequency. An increased lubrication frequency will prevent contaminants from entering the sealing cavity, drive out any contaminants that have penetrated the sealing cavity as well as re-establishing the oil film thickness. The best protection against the ingress of contamination and moisture is to keep grease at the seal area. Decrease relubrication interval in order to keep fresh grease in the bearing and decrease the incursion of contaminates. Fresh grease should be seen purging from the bearing seal area at each relubrication interval.	

Observation	Explanation	Failure mode	Recommendation	Figures
Gritty lubricant	Gritty lubricant is a sign of lubrication contamination.	Ineffective lubrication, hard-particle lubrication contamination, insufficient lubrication	Immediately increase lubrication frequency. An increased lubrication frequency will prevent contaminants from entering the sealing cavity and at the same time will drive out any contaminants that have penetrated the sealing cavity. The best protection against the ingress of contamination and moisture is to keep grease at the seal area. Decrease relubrication interval in order to keep fresh grease in the bearing and decrease the incursion of contaminates. Fresh grease should be seen purging from the seal area at each relubrication interval. Increase the amount of lubricant being pumped into the bearing at each relubrication interval. Fresh grease should be seen purging from the bearing seal area at each relubrication interval.	
Hard particle contamination – identations	Hard particle contamination can be caused by the incursion of outside contaminates into the sealing cavity or from the internal components of the bearing. When lubrication breaks down metal to metal contact will take place within the bearing. Once this happens miniscule particles of metal are pulled from the roller and raceway surfaces which contaminate the lubricant even further.	Ineffective lubrication, hard-particle lubrication contamination	Immediately increase lubrication frequency. An increased lubrication frequency will prevent contaminants from entering the sealing cavity and at the same time will drive out any contaminants that have penetrated the sealing cavity. The best protection against the ingress of contamination and moisture is to keep grease at the seal area. Decrease relubrication interval in order to keep fresh grease in the bearing and decrease the incursion of contaminates. Fresh grease should be seen purging from the seal area at each relubrication interval	  
Internal wear on seal carrier	Excessive misalignment on spherical roller bearing will cause the rollers to rub against the seal.	Static misalignment, dynamic misalignment	Align bearings/shaft assembly. Inspect mounting surfaces for imperfections. Verify shaft deflection does not exceed bearing misalignment capability. Check shaft concentricity and straightness. Evaluate eccentric loading within the system.	
Lack of set screw hex deformation	Set screw hex deformation will occur when set screws are torqued to recommended installation values. Set screws were not torqued to specifications listed in the corresponding instruction manual	Improper mounting	Refer to corresponding instruction manual for proper mounting instructions.	

Observation	Explanation	Failure mode	Recommendation	Figures
Load zone evidenced on one side of raceway - thrust load	A load zone that is evidenced on only one side of the raceway is normally caused when an axial thrust load is applied to the bearing. Due to the decrease in clearance on the loaded side of the bearing all wear will be visible on that side of the bearing raceway.	Improper selection, excessive thrust loading	Evaluate capacity for expansion within the application. If applying an expansion bearing, insure the bearing is installed with full capacity for axial growth. Additionally, evaluate bearing suitability for application.	
Meandering wear pattern on raceway	Meandering wear patterns on raceways evidence misalignment between the outer and inner rings. This is typically represented by unusual side-to-side wear patterns on one ring raceway and a very wide wear pattern on the opposing ring.	Static misalignment, dynamic misalignment	Align bearings/shaft assembly. Inspect mounting surfaces for imperfections. Verify shaft deflection does not exceed bearing misalignment capability. Check shaft concentricity and straightness. Evaluate eccentric loading within the system.	
Milky grease	'Milky' grease or grease with white discoloration is evidence of water, moisture or other liquid chemical contaminating the lubricant.	Ineffective lubrication, moisture contamination	Immediately increase lubrication frequency. An increased lubrication frequency will prevent contaminants from entering the sealing cavity and at the same time will drive out any contaminants that have penetrated the sealing cavity. The best protection against the ingress of contamination and moisture is to keep grease at the seal area. Decrease relubrication interval in order to keep fresh grease in the bearing and decrease the incursion of contaminates. Fresh grease should be seen purging from the seal area at each relubrication interval and is best to relubricate prior to shut-down.	
Moisture stains	Moisture stains are caused when water or other liquid chemicals contact the internal bearing surfaces for a period of time and actually etch into the bearing surfaces. Moisture stains are dark and can usually be felt by rubbing a finger over the stained surfaces	Ineffective lubrication, insufficient lubrication, moisture contamination	Immediately increase lubrication frequency. An increased lubrication frequency will prevent contaminants from entering the sealing cavity and at the same time will drive out any contaminants that have penetrated the sealing cavity. The best protection against the ingress of contamination and moisture is to keep grease at the seal area. Increase the amount of lubricant being pumped into the bearing at each relubrication interval. Fresh grease should be seen purging from the bearing seal area at each relubrication interval. Decrease relubrication interval in order to keep fresh grease in the bearing and decrease the incursion of contaminates. Fresh grease should be seen purging from the seal area at each relubrication interval and it is best to relubricate prior to shut-down.	

Observation	Explanation	Failure mode	Recommendation	Figures
No lubricant in grease fitting hole	If no grease is present beneath the grease fitting hole then the bearing has either been lubricated through other means or has been absent of fresh grease.	Ineffective lubrication, insufficient lubrication	Immediately increase lubrication frequency. An increased lubrication frequency will prevent contaminants from entering the sealing cavity and at the same time will drive out any contaminants that have penetrated the sealing cavity. The best protection against the ingress of contamination and moisture is to keep grease at the seal area. Increase the amount of lubricant being pumped into the bearing at each relubrication interval. Fresh grease should be seen purging from the bearing seal area at each relubrication interval.	
No (minimal) lubrication in bearing cavity	If minimal lubrication is found within the bearing cavity, the bearing could be operating a very high speed or the amount of lubricant being added is insufficient.	Ineffective lubrication, insufficient lubrication	Immediately increase lubrication frequency. An increased lubrication frequency will prevent contaminants from entering the sealing cavity and at the same time will drive out any contaminants that have penetrated the sealing cavity. The best protection against the ingress of contamination and moisture is to keep grease at the seal area. Increase the amount of lubricant being pumped into the bearing at each relubrication interval. Fresh grease should be seen purging from the bearing seal area at each relubrication interval.	
Outer ring creep / wear on OD	Outer ring creep is caused by an imbalanced load applied to the bearing. The outer ring outside diameter is worn and the housing shows wear marks from the outer ring rotating within the housing. This type of failure will also be accompanied by a 360° load zone in the roller track area of the outer ring.	Improper selection	Contact application engineering to review your application to find a more suitable bearing.	
Pitting	Pitting is an early indication of onsetting fatigue failure. It is usually represented as small craters over the roller paths with increased localization of pits in the higher-stressed areas of the metal.	Ineffective lubrication, insufficient lubrication, soft-particle lubrication contamination, unsuitable lubrication	Immediately increase lubrication frequency. An increased lubricatio frequency will prevent contaminants from entering the sealing cavity and at the same time will drive out any contaminants that have penetrated the sealing cavity. The best protection against the ingress of contamination and moisture is to keep grease at the seal area. Increase the amount of lubricant being pumped into the bearing at each relubrication interval. Fresh grease should be seen purging from the bearing seal area at each relubrication interval. Decrease relubrication interval in order to keep fresh grease in the bearing and decrease the incursion of contaminates. Fresh grease should be seen purging from the bearing seal area at each relubrication interval.	  

Observation	Explanation	Failure mode	Recommendation	Figures
Set screw tips worn	Worn set screw tips is caused when the shaft has spun inside the inner ring of a set screw-mounted product. This is normally caused by under tightening of the set screws and/or undersized shafting.	Improper mounting	Refer to corresponding instruction manual for proper mounting instructions.	
Severe seal damage	Seal damage can be caused by improper mounting or handling or debris build up around seal area.	Improper mounting, improper handling	Refer to corresponding instruction manual for proper mounting instructions.	Picture not available
Spalling	Spalling, also identified as flaking, is an indication of fatigue failure. Spalling will occur in the roller paths with increased localization in the higher-stressed areas of the metal.	Ineffective lubrication, insufficient lubrication, unsuitable lubrication, high loading, misalignment	Immediately increase lubrication frequency. An increased lubrication frequency will prevent contaminants from entering the sealing cavity and at the same time will drive out any contaminants that have penetrated the sealing cavity. The best protection against the ingress of contamination and moisture is to keep grease at the seal area. Increase the amount of lubricant being pumped into the bearing at each relubrication interval. Fresh grease should be seen purging from the bearing seal area at each relubrication interval. Loading causes fatigue failure - check sources of high stress, such as misalignment or overloads.	
Spalling - localized 180-degree apart	Spalling localized 180 degree apart is generally caused by severe static misalignment or a pinched housing	Pinched bearing misalignment	Check mounting surface for flatness. Flatness of mounting structure should be held to under .005 inch. Check bearing alignment.	Picture not available
Various lubrication types (colors) present in bearing cavity	If more than one grease color is present then it is likely that different types of lubrication were used. Not all greases are compatible.	Ineffective lubrication, unsuitable lubrication	Immediately increase lubrication frequency. An increased lubrication frequency will prevent contaminants from entering the sealing cavity and at the same time will drive out any contaminants that have penetrated the sealing cavity. The best protection against the ingress of contamination and moisture is to keep grease at the seal area.	Picture not available

Observation	Explanation	Failure mode	Recommendation	Figures
360-degree load zone	A 360 degree load zone on the outer ring can be caused by two scenarios. The first is called a dead shaft application where the design is such that the shaft does not rotate but instead the bearing rotates around the shaft. In this case, a 360° load zone would be expected and not considered a failure mode. The second scenario would take place if there is an imbalanced load being applied to the bearing. Bent shafts, out of balance equipment, etc. can cause this type of failure. Outer ring creep is also common in this scenario.	Improper selection, excessive thrust loading	Evaluate capacity for expansion within the application. If applying an expansion bearing, insure the bearing is installed with full capacity for axial growth. Additionally, evaluate bearing suitability for application	Picture not available

Interchanges

There may come a time when bearings from one manufacturer must be interchanged with bearings from another manufacturer. Typically this happens when a breakdown occurs and there are no parts available from the current supplier or when a customer is shopping for the best price and availability. The key factors to consider when doing an interchange are:

- Dimensional interchangeability
- Shaft attachment
- Sealing
- Misalignment capability
- Load rating
- Speed rating

Dimensional interchangeability

Often, the most critical factor when changing bearing styles or manufacturers is dimensional interchangeability. The interchange must be able to fit in the application almost the same way as the original bearing. This means different things depending on the bearing type.

Mounted bearings can be split into four primary categories:

- Pillow blocks (2- and 4-bolt)
- Flanges (2- and 4-bolt)
- Piloted flange
- Take-ups

Pillow blocks

Bolt hole center and shaft-to-center height are critical dimensions.

Flanges (square, round)

Bolt spacing is most critical dimension.

Piloted flange

Bolt spacing and pilot diameter are most critical dimensions.

Take-ups

Slot width, slot depth, and width between rails are critical dimensions.

Shaft attachment

The interchange does not necessarily have to attach to the shaft in the same manner as the original, although it is often preferred. At times, an interchange may attach using an adapter mount locking device if the original bearing was set screw mount. In such cases it is imperative that the installer understands the differences between the installation procedures and compensates accordingly. This may require use of additional tools or supporting the weight of the shaft during installation.

Sealing

The harsher the environment, the more it becomes critical that the interchange have the same or better sealing capabilities as the original. For example, a new bearing is going into a mining application and matches the previously installed bearing in all aspects, but features a labyrinth seal instead of the original heavy contact seal, this would not be a good interchange. The labyrinth seal will allow more contaminants into the bearing, which could lead to a quicker failure. In this case, the interchange seal must be the same or better.

Misalignment capability

Bearings are designed with different misalignment capabilities. If it is important in the application, the new bearing must meet or exceed the capabilities of the original bearing.

Load rating and speed rating

It is preferred that the interchange have at least the same radial load, axial load, and speed ratings as the original bearing—this prevents premature fatigue failure. This is especially critical in the case of high-thrust applications. If a tapered roller bearing is used in an application due to high-thrust load, interchanging to a spherical roller bearing will lead to premature failure of the bearing. Various manufacturers have programs that can be run to determine the L_{10} life of a bearing based on the application information. Some these programs will provide a comparison between the resulting bearing types and styles.

Since ball and spherical roller bearing dynamic load ratings are based on 1,000,000 revolutions and tapered roller bearing dynamic load ratings are based on 90,000,000 revolutions, one must be cautious when comparing the different bearing types. To compare C_r and C_{90}, multiply C_r x 0.259, then compare to C_{90}.

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