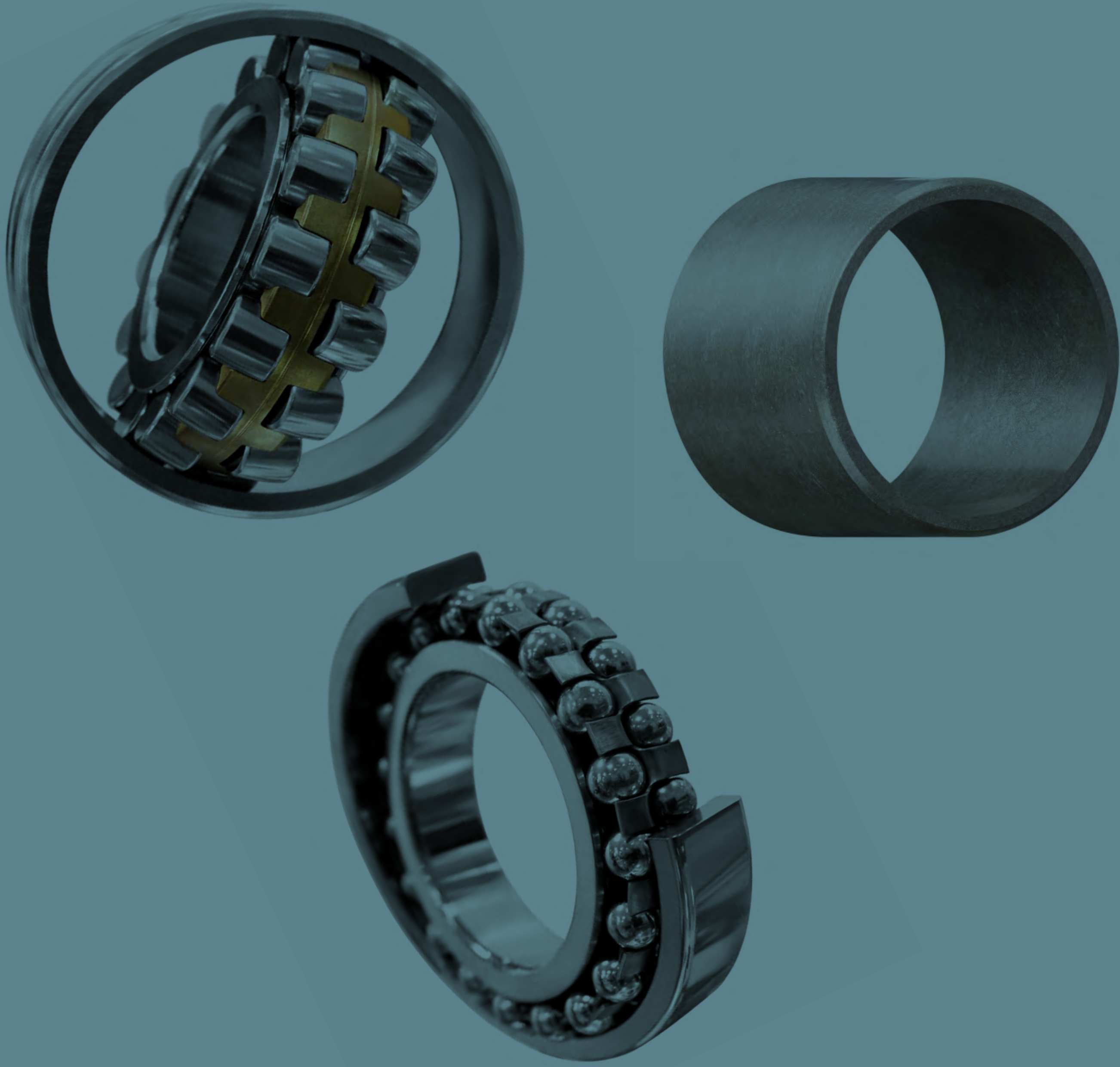
MOTION DESIGN GUIDE

ROTARY BEARINGS: Rolling Element And Plain



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Rotary bearings are mechanical components that bear a load — such as an electric motor's output shaft — while minimizing friction to allow for the free turning of that axis in one (most common) or two planes. In most cases, they're the support interface between rotating and stationary portions of the assembly. Loads borne by rotary bearings are either:

- Radial — loads applied perpendicular to the bearing's rotational axis
- Axial — loads applied parallel to the bearing's rotational axis

As we'll explore, components classified as radial bearings support the first load type; components classified as thrust bearings support the second load type. Many rotary-bearing designs (called combination bearings) simultaneously resolve both load types. Still others even allow concurrent linear and rotary motion. Refer to designworldonline.com/design-guide-library for other Design Guides on linear bearings that allow the free traversal of linear axes … because in fact, linear bearings have quite a lot in common with rotary bearings.

In this Design Guide, we detail rotary bearings that take the form of plain (sleeve) style bearings as well as rolling-element rotary bearings for the support of radial as well as axial loads.

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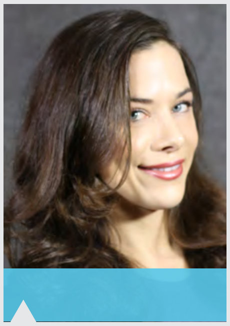

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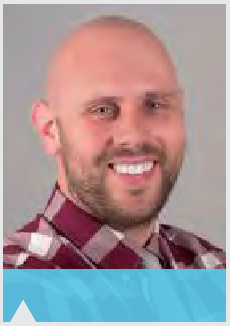

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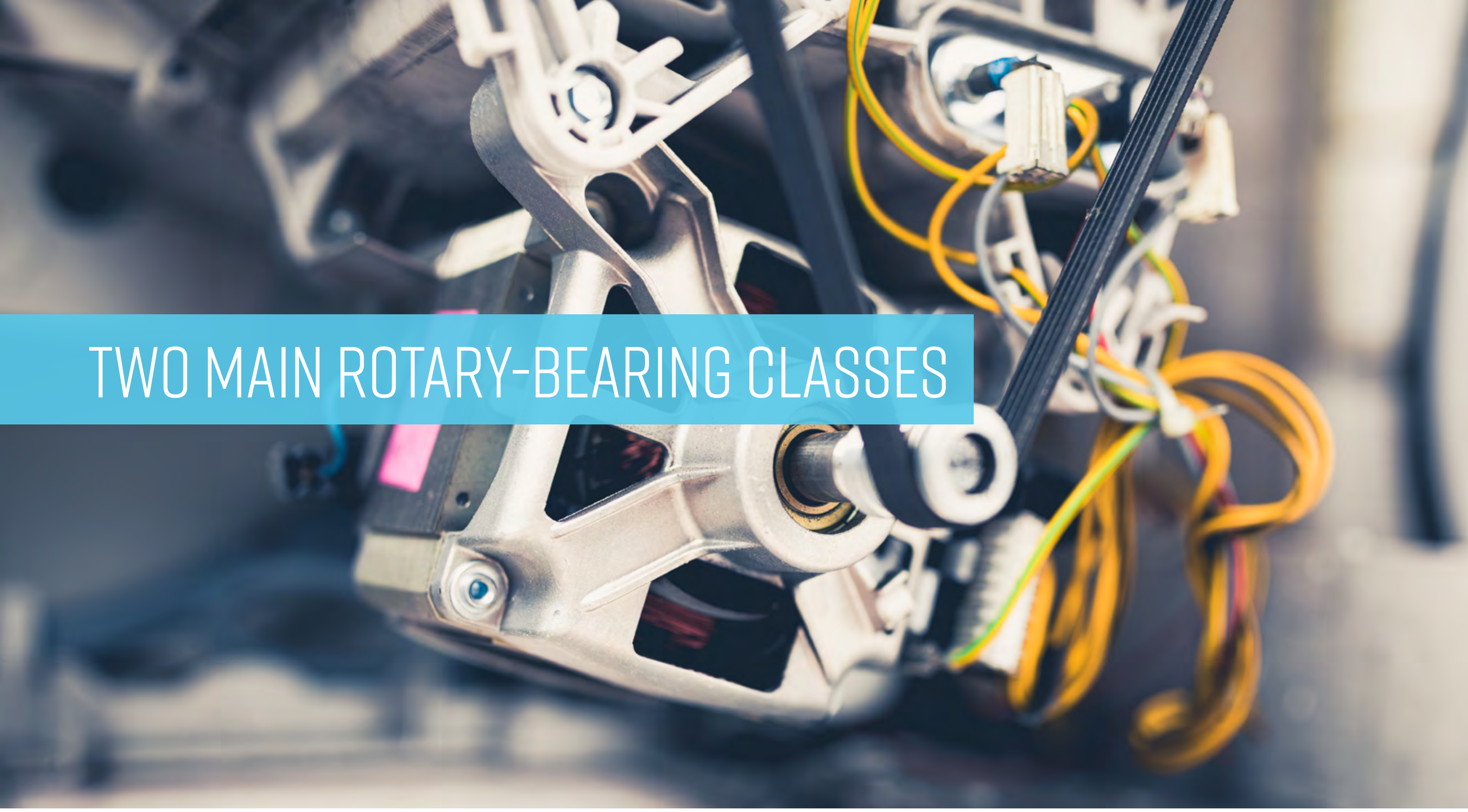


TWO MAIN ROTARY-BEARING CLASSES

Specifying bearings that are appropriate for a given application can boost system throughput and profitability by avoiding unplanned machine downtime.

Rotary bearings are everywhere in motion — in gearboxes, motors, pulleys, and myriad other machine locations involving a rotating shaft that needs low-friction radial and axial load support.

The two major rotary-bearing classifications are rolling-element rotary bearings and plain rotary bearings.

Plain rotary bearings in motion designs have engineered inner surfaces to ride (through sliding) on round shafts with minimal friction while bearing the load at that location on the axis. Usually, their structure only allows support of axial loading. Plain rotary bearings are sometimes called plane bearings (for their single-plane operation) … and "plain bearings" is usually a catchall phrase that also includes related designs called:

- **Journal bearings** from the Old French word for a day's journey or work — in this case, over a hardened shaft journal
- **Bushings** from the Old Dutch word for metal lining … often indicating an engineered plastic or soft metal or cylinder with or without the need of lubricant for load bearing
- **Sleeve bearings** all having their own adaptations and applications.

Key plain-rotary-bearing advantages include simplicity, reliability in wet locations, and cost-effectiveness.

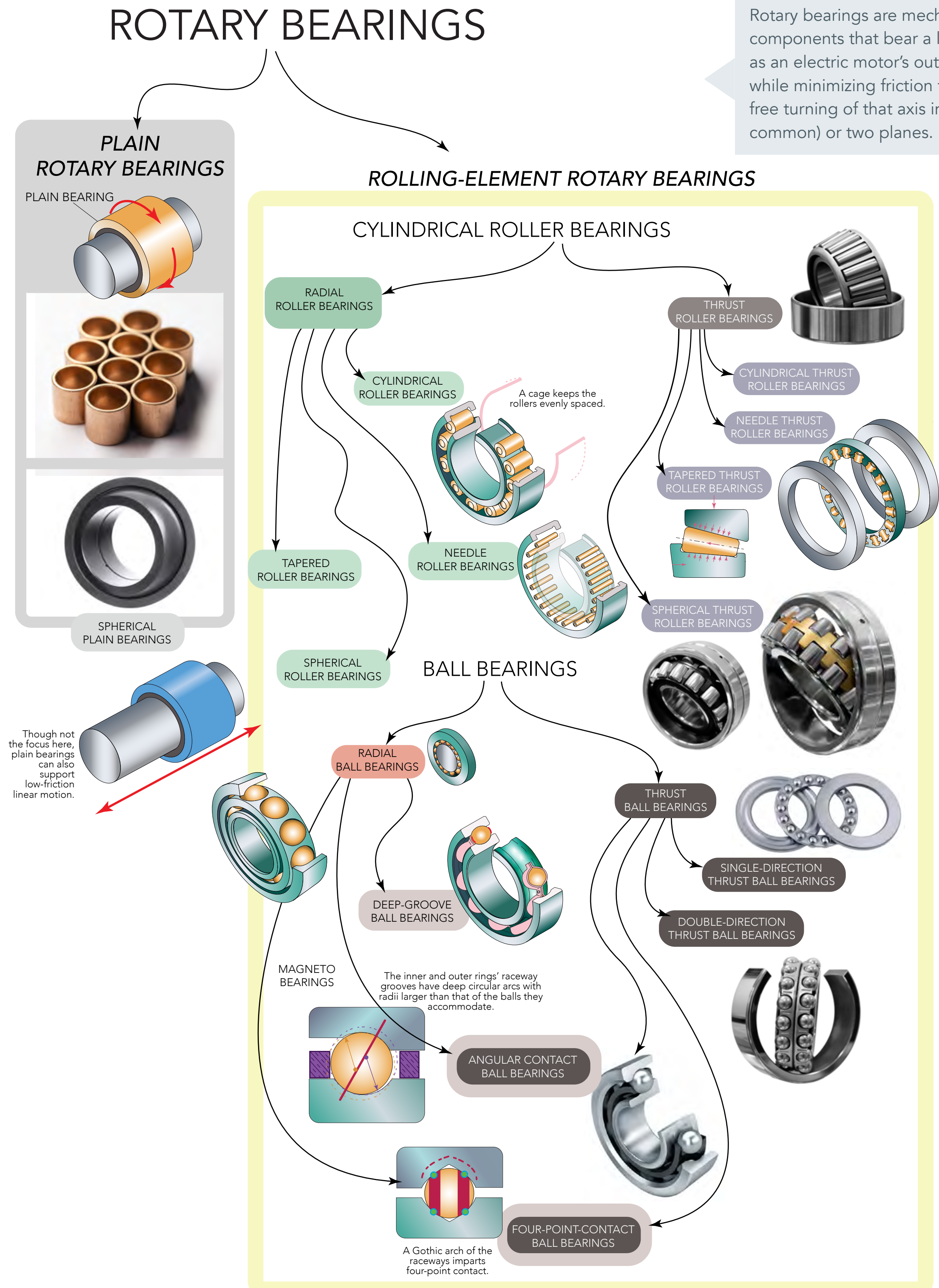
In contrast, most rolling-element rotary bearings include an inner ring with an OD raceway, an outer ring with an ID raceway, and an array of spherical ball rollers (not to be confused with ball-and-socket-style spherical bearings) or cylindrical rollers sandwiched between them. The array of rolling elements ride through rolling on the two bearing-rings' raceways. Their ring structures and roller shape can be designed to allow support of axial, radial, and combination loading.

Key rolling-element rotary-bearing advantages include long service life and the ability to bear heavy loads on exceptionally high-speed axes.

(continued)

TWO MAIN ROTARY-BEARING CLASSES

Rotary bearings are mechanical components that bear a load — such as an electric motor's output shaft — while minimizing friction to allow for the free turning of that axis in one (most common) or two planes.



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INTRODUCTION TO PLAIN ROTARY BEARINGS

Most plain rotary bearings in motion designs are [cylindrical sleeves that bear light to moderate radial loads](). The sleeve — which can be a single piece, a lined piece, or a piece that axially splits in two — works as a support hub that rides a spinning round shaft or *journal* shaft section. Some finely engineered running clearance between sleeve and shaft (with or without oil or grease present) allows rotation based on low-friction sliding upon that round shaft.

Many plain rotary-bearing sleeves that are monolithic or cylindrically layered components incorporate graphite, bearing-grade bronze, or plastic. Combination bronze versions can be cast or sintered to feature graphite lubricant plugs. Combination plastic versions can include PTFE, nylon, and polyacetal. In fact, advancements in material science have in recent years made plastic plain bearings increasingly common — even for particularly dynamic motor-driven motion axes in automated machines.

Lubrication-free deep-groove xiros rotary bearings from igus have races and cages made from high-temperature iglide plastic to withstand chemicals, moisture, and high temperatures … even to a few hundred degrees. Corrosion-free balls are stainless steel, glass or plastic balls for maximum corrosion resistance.

Plain rotary bearings slide radially (and in some versions also axially) over shafts to allow resolution of load vectors associated with machine axis motion. Out of all rotary bearing types, plain bearings are most compact and lightweight — with a high strength-to-weight ratio. In addition, plain bearings have none of the moving subelements that rolling-element bearings have — which reduces the number of potential fail points. That makes them indispensable in certain rugged applications. As alluded to earlier …

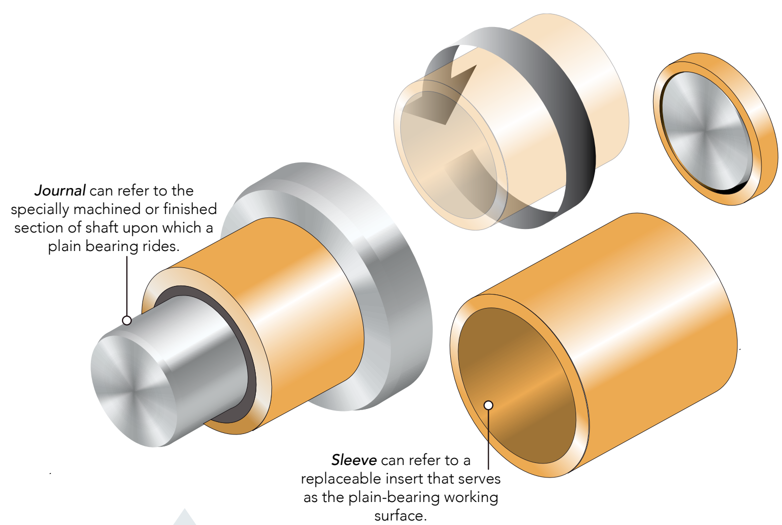
Plain rotary bearings referred to as **journal bearings** often consist of a hardened shaft journal upon which a cylinder rides — via a highly engineered lubrication system.

Plain rotary bearings referred to as **bushings** often consist of an engineered plastic or soft metal cylinder with or without the need of lubricant for load bearing. These can serve as caster-wheel bearings, guidepost bearings, and other simple bearings. Plain rotary bearings referred to as **sleeve bearings** are quite similar — but this term generally implies more sophisticated adaptations for true motor-driven motion applications. What's more, the term sleeve bearing without any additional qualifier often indicates the linear and not the rotary version of this bearing design.

Self-lubricating plain rotary bearings often offer advantages over metal variations. Image courtesy igus

In some instances, the plain rotary-bearing sleeve takes the form of a replaceable insert that presses (with an interference fit) into a machined hole on a carriage or other component. In this form, the plain bearing protects the machined element while allowing low-friction relative motion. If the axis is also expected to take some axial loading, the sleeve bearing end might not be flush with the carriage … but rather include a flange that flares around the press-fit area for a round surface to bear the brunt of abrasion and impact loading. Sometimes called *mounted bearings* (to differentiate them from free-sleeve plain rotary bearings) these must precisely fit the receptacle into which they install for free motion sans assembly slipping.

Plain rotary bearing ratings are based in part on test results and the sleeve's material modulus of elasticity, flexural strength, shore-D hardness, maximum surface pressure and running speed, rotating, and maximum load capacity — with the latter related to the plain bearing's material compressive limit. Recall that the compressive limit is the point at which 0.2% permanent deformation occurs.



Common plain rotary bearing variations are metallic sleeve bearings (which often ride loads on a hydrodynamic or full film of lubrication) and self-lubricating plastic bearings in an array of geometries for bushing, thrust bearing, and integral-slide applications.

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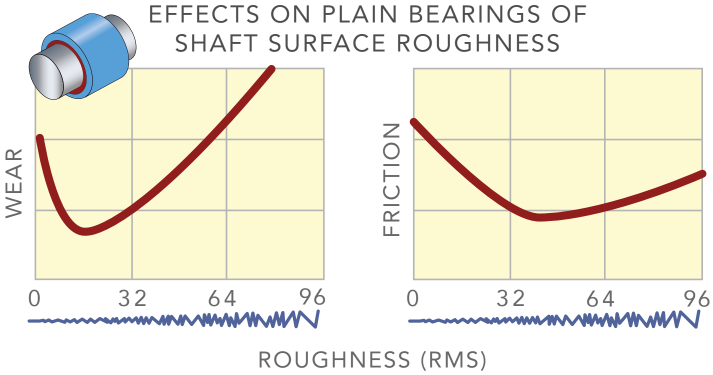
INTRODUCTION TO PLAIN ROTARY BEARINGS



Shaft surfaces for mating with plain bearings shouldn't be too smooth or rough.

In addition, a pressure-speed (PV) value expresses plain-bearing load capacity — for both plain rotary bearings (the focus of this Design Guide) and plain linear bearings (covered in another Design Guide). Usually, PV values are expressed in pounds of pressure per square inch (psi) times shaft rpm. Note though that PV values are only one parameter to help define a plain bearing's overall load capacity … and PV expressions have the potential to mislead engineers into thinking a given plain rotary bearing can bear excessively high loads at very low shaft rpm. The truth is that use of PV values requires concurrent consideration of real-world speed and load limits.

CONSIDERATIONS FOR PLAIN-BEARING MATING SHAFTS

The shafts on which plain rotary bearings ride significantly impact bearing performance and life. One common shaft option is cold-rolled carbon steel. This material makes for a suitable mating surface for plain bearings made of polymers. Ceramic shaft surfaces induce more wear, though are sometimes chosen for their ability to withstand exceptionally harsh environmental conditions. Though aluminum shafts are lightweight and easy to machine, they also induce accelerated plain-bearing wear. Aluminum shaft that's anodized slightly improves assembly performance.

In fact, shaft surfaces for mating with plain bearings shouldn't be too smooth or rough. Overly smooth surfaces cause stick-slip adhesion variations — in turn causing higher friction resistance to bearing movement. More disparity between dynamic and static friction makes for faster bearing wear and jerkier motion. In contrast, overly rough shaft surfaces quickly abrade plain bearings. In fact, the rates of wear induced by shaft-bearing interfaces can vary a hundredfold. Some manufacturers recommend shaft-surface finishes to 64 root mean square (rms) for precision applications needing low friction; a smoother shaft with roughness of 20 rms or so is more suitable where long plain-bearing life is a design objective.

Recall that the rms expression of surface roughness is derived from measurements of a surface's microscopic peaks and valleys. Ra is an alternative measure some in industry use to quantify roughness — in this case, as an average roughness of a surface's peaks and valleys. In other words, the two measures express the same quality … only in different formats. Note that large and outlying peaks or flaws on a shaft surface will affect the RMS value more than its equivalent Ra value.

CAVEATS GALORE WITH PLAIN ROTARY BEARINGS

Following are a few caveats regarding the variations of plain bearings and bearing features we've just described.

Plain bearings can work to bear carriages on linear axes too. Though in this Design Guide section we focus on plain bearings that serve as rotary bearings, plain bearings can also work on linear axes to allow translational movement while bearing loads.

Though they still loom large in some college engineering classes and real-world industries, Babbitt bearings are rare in the motion industry. Many modern versions of these plain rotary bearings rely on a thin solid film of tin, antimony, and copper (or derivative bronze adaptations) on the bearing assembly's sleeve ID that allows fluid-film lubrication upon axis rotation at operating speed.

Shown here are sleeve bearings made of bronze.

(continued)

INTRODUCTION TO PLAIN ROTARY BEARINGS

Not all plastic bearings are plain bearings. As we'll explore in a later section of this Design Guide, some plastic rotary bearings come in versions that are rolling-element types. Others are adapted bearing designs that integrate rollers (embedded over an internal working surface) to serve as deep-groove, thrust, angular-contact, and miniature rolling-element rotary bearings.

Plane bearings can be made of brass and include internal channels and small through-cylinder holes to allow lubrication distribution. Internal grooving or channels can also serve to hold lubricant to sustain a hydrodynamic state at various speeds. External plain-bearing channels mate with other parts of the machine assembly to keep the bearing centered.

Many plain bearings customizable. Though some plain bearings are commodity items, many are customizable. For example, some plain rotary bearings have modified geometries and washers to work as thrust bearings that prevent metal-to-metal contact between machine subsystems. Such plain thrust bearings are especially useful where zero-maintenance easy-install options are needed. Design engineers can work with bearing suppliers offering these and other series to get working-surface liners and other features for optimizing the motion axis.

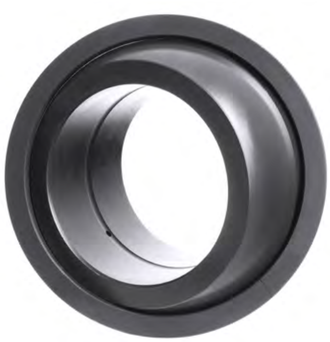
Other plain rotary bearing terms dominate outside motion-control contexts. In some industries — including the energy and HVAC industries involving turbines and compressors — it's most common to see the term *journal bearing* instead of sleeve bearing or plain bearing. That can indicate a design for which the journal (as mentioned before, the round shaft's section machined and often polished for bearing load) is the most highly engineered element of the shaft-sleeve assembly. Off-highway and automotive applications regularly employ journal bearings in which the sleeve rides an oil wedge that's *hydrodynamic* — present when the shaft spins. Otherwise, oil films are *hydrostatic* and persist even during zero rpm. Both rely on the precisely engineered shaft finish for oil-film maintenance.

Plain rotary bearings can also sport a spherical shape to allow angular rotation. As we'll explore in the next section of this Design Guide, these plain bearings actually allow movement about two orthogonal degrees of freedom (DOFs) about a central location in 3D space. That in turn accommodates shaft misalignment and other design geometries causing movements in multiple directions.

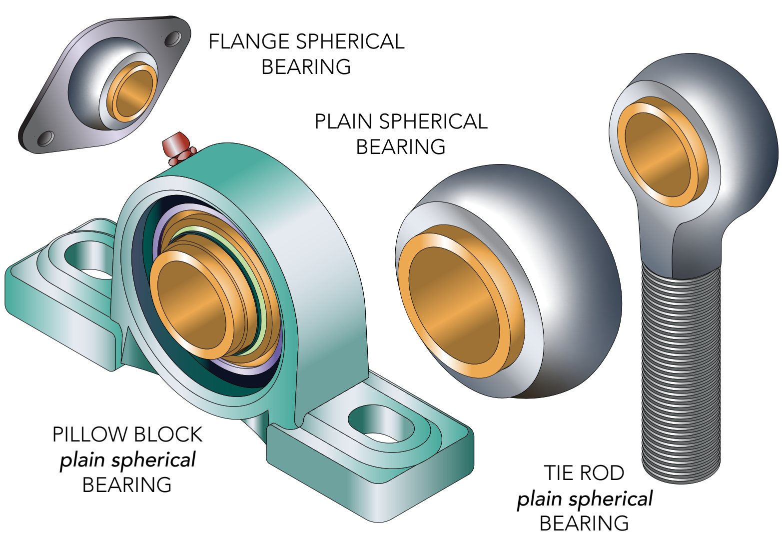
SPHERICAL AND SELF-ALIGNING ROTARY BEARINGS IN PLAIN AND ROLLING-ELEMENT VARIATIONS

Spherical bearings — whether plain or rolling element — are rotary bearings sometimes called *ball bushings* that have a ball-and-socket assembly … which is often a self-aligning arrangement. The inner bearing element or roller array is a ball or spherical assembly that installs into an outer ring (sometimes called a bushing) having a concave inner raceway. This curved assembly geometry allows the movements associated with multi-directional assemblies as well as single-direction motion axes with misalignment between machine subcomponents. Common applications are in:

- Rod ends — articulating Heim or rose joints in innumerable assemblies
- Machine axes needing (relative) angular rotation between kinematic linkages
- Motion assemblies with slightly misaligned housings and shafts
- Oscillating end effectors
- Slow-speed tilting elements



Shown here is a plain bearing designed to primarily carry radial loads.



DESIGN VARIATION ONE: SPHERICAL PLAIN BEARINGS

Spherical plain bearings rely on sliding between the convex and outer-element concave surfaces. These spherical-bearing elements can be made of steel, high-temperature PH13-8Mo martensitic stainless steel, beryllium copper, bronze, aluminum, titanium, various cadmium-plated metals, or plastic. Spherical bearings made entirely of metal are sometimes called metal-to-metal bearings. Here, the ball element is usually made of a softer metal than the outer ring element. In other contexts when the component is a ring-and-ball assembly with no other flanges, it's called a spherical plain bearing. Any additional shaft section or mountable bracketry usually makes the spherical plain bearing qualify as a rod end, flange bearing, or pillow-block bearing.

Side note on pillow blocks: Recall that a pillow-block bearing consists of a mounting bracket in the shape of a pedestal with a rounded center elevation. This center portion houses a either a plain or rolling-element bearing assembly to bear loads on axes usually involving relatively low torques and light loads. The pillow block pedestal base bolts to some portion of the machine while the opening through its bearing assembly accommodates a shaft. It and the bearing assembly's inner ring are free to rotate.

When mentally conjuring pillow-block bearings, many engineers picture fairly large versions having gray cast-iron pedestals with a split SAF, SAW, or SDAF design for easy assembly and use in rugged power-transmission applications. However, precision and plastic and customized pillow-block designs abound in both split and unsplit (one-piece pedestal) versions.

Resembling the pillow blocks of pillow-block bearings are plummer (not plumber) block. The latter also mount to machines via mounting holes on the pedestal … but they are generally more rugged and don't include a bearing assembly pre-integrated into the rounded center elevation.

Metal and plastic options: All-metal spherical plain bearings can be self-lubricating (often incorporating some dry-film lubricant coating on the ball) or complemented with nipples, grooves, and ports for (usually grease-based) lubrication. Spherical plain bearings having outer-ring elements of stainless steel exhibit reliable resistance to corrosion, galling, scratching, and other forms of wear. The softer metals usually employed for the inner ball element is usually chosen for their resistance to abrasion, fatigue, and material stress relaxation.

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SPHERICAL AND SELF-ALIGNING ROTARY BEARINGS IN PLAIN AND ROLLING-ELEMENT VARIATIONS

Shown here is a component that qualifies as a rotary bearing serving a linear-bearing application. The igus drylin W carriage for curved rails includes plain spherical bearings with rounded ODs. The bearings pivot rotationally in their carriage mounts to automatically adjust to straight and curved rail radii — down to a bending radius of 250 mm.

Externally lubricated all-metal spherical plain bearings excel in hot settings where grease-based lubrication is acceptable and physically possible — especially in the aerospace industry. One caveat is that (because dissimilar metals are used for the outer ring and ball elements) the final bearing design must accommodate multiple rates of thermal expansion to prevent binding … with proper clearance between the bearing elements as well as proper clearance between the spherical bearing's inner bore and the shaft onto which it installs.

In many cases, plastic spherical self-aligning bearings offer comparable or better performance than that of all-metal spherical plain bearings … without external lubrication or maintenance. The self-lubricating nature of these bearings is useful where grease might otherwise attract dirt and dust that could in turn degrade the bearing function. It's also useful in food and beverage packaging machinery or any laboratory setting where grease contamination (as well as dust from corrosion) would ruin the produced product or test samples. No wonder plastic spherical bearings are so common in settings subject to washdown or the presence of saltwater and caustic chemicals.

Plastic spherical bearings can also:

- Eliminate the risk of chattering and damp vibrations originating elsewhere in the machine assembly — useful in medical equipment that must be quiet to reduce patient stress … and in settings where vibration would destroy equivalent spherical bearings made of metal
- Reduce overall machine cost and weight — as they're up to 40% less costly and 80% lighter than equivalent spherical bearings made of steel
- Satisfy disparate design loads, speeds, and shaft and housing arrangements
- Deliver long life — even to hundreds of millions of cycles

DESIGN VARIATION TWO: SPHERICAL ROLLER (ROLLING-ELEMENT) BEARINGS

In contrast with these plain spherical bearings are roller-based spherical bearings — a rolling-element rotary bearing subtype. These include three subcomponents … an inner ring, outer ring, and roller array that get sandwiched between them. Their self-aligning nature lets these bearings accept shaft misalignment caused by shaft deflection, mounting inaccuracies, and similar issues with the potential to induce excess friction and heat generation. No wonder spherical roller bearings are a natural fit for vibrating equipment and other applications in which misalignment is an unavoidable problem.

One common roller-based spherical bearing design has twin rows of barrel-shaped rollers inclined to the bearing axis at mirrored angles. A guide ring holds the rollers in the assembly. These two roller rows ride separate inner-ring raceways and one outer-ring raceway … with the outer-raceway center inline with the primary axis. That means spherical roller bearings can accept deviations while concurrently handling significant radial loads. Many spherical bearings based on this design can accommodate misalignment to 2° with no degradation of life or performance. One caveat is that

Shown here (right) is an igubal ball from igus that's integrated into a cost-effective sheetmetal housing to serve as a spherical bearing. The ball is made of high-performance iglide J plastic that's specifically engineered for sheetmetal applications. The balls come in Ø20, Ø25, and Ø30-mm versions as well as for cast housings (UC204-210) and mount in seconds.

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SPHERICAL AND SELF-ALIGNING ROTARY BEARINGS IN PLAIN AND ROLLING-ELEMENT VARIATIONS

Spherical bearings (including the two rolling-element variations shown here) are capable of self-aligning. These have an inner ring (with two raceways) and an outer ring with a single spherical raceway having a center of curvature coincident with the bearing axis. This is what lets the axis of the inner ring, rolling elements, and cage deflect around the bearing center to automatically correct misalignment arising from errors in installation or housing and shaft geometries.

the bearing diameter D and speed N factor (called the DN factor) dictates the correct lubricant viscosity for these bearings … and spherical bearings that absolutely require grease (and not oil) may need to keep below a 100,000 DN factor.

The self-aligning capabilities of some rotary bearings often complement assemblies for which the shaft and housing are difficult to align … or axes involving a shaft that may bend during otherwise normal operation. Similar to deep-groove ball bearings, most self-aligning spherical rotary bearings are considered a general-use option specified to satisfy various load, speed, and space constraints. Those with common straight (cylindrical) bores require no special mounting techniques; in contrast, self-aligning bearings with a tapered bore (not to be confused with tapered bearings) must be driven up the tapered shaft (or straight shaft with tapered sleeve) a precise amount.

Refer to this Design Guide's section on sizing and selection for more information on how most self-aligning rotary bearings are interchangeable with conventional rotary bearings of the same industry-standard series — so that 6200 and 6300 self-aligning bearings are interchangeable with regular 1200 and 1300 series bearings, for example.

One self-aligning cylindrical-roller bearing alternative is the toroidal bearing. Recall from solid geometry that a toroid is a 3D donut-shaped object. In the case of this bearing design, the torus-shaped element is actually the empty donut shape created between the two mating rings — a toroidal volume to accommodate the roller array.

In contrast, some spherical bearings we've already detailed include a spherical spacer cage that staggers the barrel-shaped cylindrical rollers of the rolling-element array. Such designs accommodate misalignment and axial shaft growth arising from machine heat generation. However, the spacer ring limits bearing radial capacity by limiting the roller diameter that can fit into the predefined bearing envelope. After all, smaller rollers have less load capacity.

One alternative to avoid this problem associated with roller-based spherical bearings is toroidal bearings. First introduced in the 1990s, toroidal bearings have cylindrical rollers that are fatter at their centers and tapered at both their ends. These center-bulging rollers run on profiled inner and outer rings with mating concave shapes for an assembly that has axial float as well as static and dynamic misalignment capabilities.

One caveat is that these capabilities are interrelated — so maximum misalignment isn't allowable during a maximum axial-float condition. In addition, these bearings need relatively large radial internal clearances to deliver sufficient misalignment and float capabilities in demanding applications. Another caveat: Toroidal bearings typically install with the inner ring slightly offset … so that ring aligns with the other bearing subcomponents when the shaft expands upon normal operating temperature. That means bearing operation may be compromised during machine warmup … and care must be taken to prevent roller skew and the potential for bearing lockup. In addition, full-complement versions of toroidal bearings (omitting a cage or roller retainer to fit the "full complement" of rollers possible in the bearing geometry) there's a risk the rollers will fall out during installation — and sustain damage. Sometimes a snap ring on one side of the bearing helps retain the rollers, but it requires correctly oriented installation. Otherwise, the snap ring may inadvertently contact the rollers as the axis shaft expands during operation.

One final note on *toroid*s in another bearing context: Some rotary bearings taking the form of angular-contact ball bearings actually use torus-shaped (toroidal) cages to space the balls inside the bearing assembly. This is a set of rounded donut-shaped rings to prevent ball-to-ball contact.

DESIGN VARIATION THREE: HYBRID SPHERICAL BEARINGS

A third type of spherical bearing is a two-element hybrid of plain and rolling-element versions. These spherical bearings have an inner spherical element studded with ball bearings over its whole convex-curved surface. The outer ring element accommodates this inner spherical element for the types of motion described above. One top application for such spherical bearings is in aerospace control linkages.

DIFFERENT TYPES OF ROLLING-ELEMENT

ROTARY BEARINGS

Rotary bearings based on rolling elements abound … and include designs made for specific mounting configurations, environments, and applications. That said, most all rolling-element rotary bearings are categorized by whether they use balls rollers or cylindrical rollers … and then by the type of load they're designed to support — whether radial or axial (thrust). Further classification of **ball**-based rotary bearings is based on the configuration of the bearing outer ring. Further classification of **roller**-based rotary bearings is based on the shape of the rollers — whether cylindrical (having a rectangular cross-section) or tapered (having a trapezoidal cross-section) or spherical (having a barrel or hourglass cross-section). Sometimes the geometries and other features are concurrently specified in an iterative process.

RADIAL-LOAD ROTARY BEARINGS WITH BALL ELEMENTS

Within the ball-bearing family, deep-groove ball bearings are the simplest type. They have raceways that nearly match or conform to the balls' common diameter. This bearing type is suitable to bear radial loads and axial loads in either direction … though load capacity is modest compared to that of other bearing types. Single-row deep-groove ball bearings are perhaps the most common of all rolling-element bearings — and the design hasn't changed much over the decades. That said, advances in materials and lubrication have extended their average efficiency and life … which is particularly helpful when they're installed on high-speed axes.

For higher load capacity in a relatively small footprint, deep-groove ball bearings are also available in a double-row design with two rows of balls instead of one.

Angular-contact ball bearings have geometry such that an imaginary line through the contact points between inner ring, ball, and outer ring runs at an angle radially to the assembly's primary axis. Larger contact angle makes for larger load capacity but renders the bearing incapable of withstanding axial load in more than one direction. That's why angular-contact ball bearings are often found in pairs or double-row designs — which is essentially two angular contact bearings mounted back-to-back. These ganged bearing arrangements withstand axial loads in both directions.

Four-point contact ball bearings are single angular-contact rolling-element rotary bearings that are designed to withstand high axial loads in both directions. They can also withstand combined axial and radial loads, as long as the axial component is predominant.

THRUST-LOAD ROTARY BEARINGS WITH BALL ELEMENTS

These are made of two relatively thin bearing rings (sometimes called bearing plates or washers) with raceways designed to take axial loads, in either one direction or both directions. Radial loads are typically not permissible for thrust bearings, and speed capabilities are limited — as low as 20 to 30% of their radial bearing counterparts in some cases.

RADIAL-LOAD ROTARY BEARINGS WITH CYLINDRICAL ROLLERS

With rollers supporting the load, these have higher load capacities and higher rigidity than ball bearings of similar sizes. The type of load they can support depends primarily on the shape of the roller.

Cylindrical roller bearings can withstand high radial loads, while double-row cylindrical versions having extremely high radial load capacity and high rigidity in the radial direction. Although standard cylindrical roller bearings are not capable of taking axial loads, some designs include internal ribs or collars that allow them to handle relatively small axial loads in one or both directions.

Needle-roller rotary bearings use long, thin rollers, with a length that is anywhere between three and ten times the diameter. They have good radial load capacity, but the primary benefit of the needle design is that it has a thin cross-section, for applications where high radial capacity is required but space is limited.

Unlike cylindrical and needle roller bearings, tapered roller bearings (which use conical rolling elements to support the load) can withstand axial loads in one direction. In fact, a tapered roller bearing can be thought of as the roller version of an angular-contact ball bearing. Like their ball-bearing counterparts, tapered roller bearings often gang in pairs or double-row designs to counteract axial forces produced in the bearing upon radial loading. The tapered design also improves rolling properties and reduces internal bearing friction.

Spherical roller bearings use barrel-shaped rollers and have two inner raceways (inclined at an angle to the bearing axis) and one spherical-shaped outer raceway. This gives these bearings a self-alignment capability as well as very high radial load capacities … and the ability to withstand axial loads in both directions.

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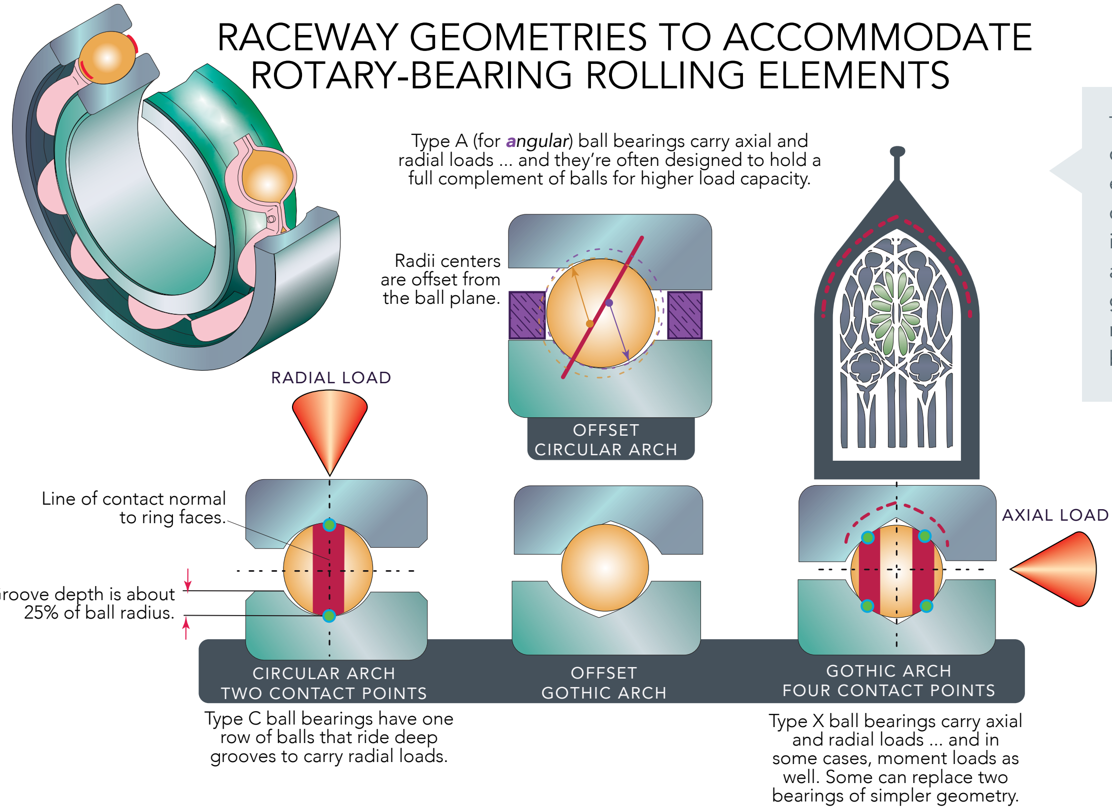
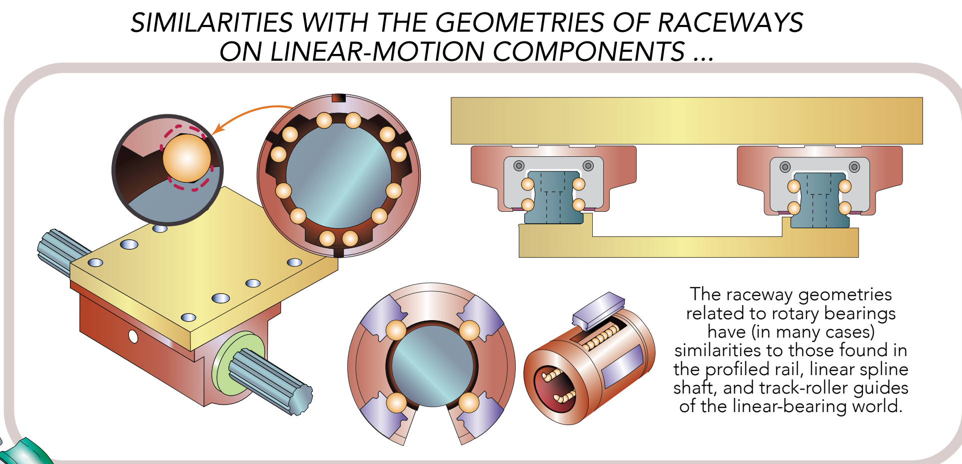
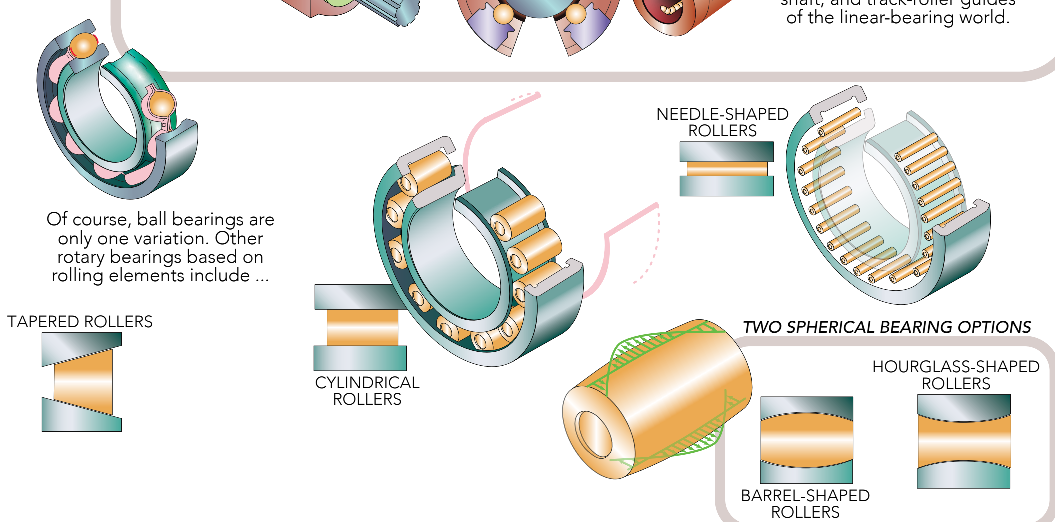
DIFFERENT TYPES OF ROLLING-ELEMENT ROTARY BEARINGS



There's a lot of coverage of ball-element and race-contact arrangements in linear bearings … and in fact, these geometries are relevant to rotary bearings as well.





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DIFFERENT TYPES OF ROLLING-ELEMENT ROTARY BEARINGS

THRUST-LOAD ROTARY BEARINGS WITH CYLINDRICAL ROLLERS

Tapered thrust roller bearings have pure rolling motion, so they produce less heat and wear than other options. Thrust versions of roller bearings generally follow the strengths of their radial counterparts but with thrust (axial) load capabilities. These roller bearings can accommodate high thrust loads and can withstand impact loads, although without additional design features, radial loads are not permissible. Similarly, needle thrust roller bearings can withstand high axial loads … albeit in a much smaller form factor due to the use of needle bearings.

Tapered thrust roller bearings can be single-direction or double-direction type, indicating whether they can accommodate axial loads in one direction or in both directions. Like their radial counterparts, the rolling elements in these bearings move with pure rolling for less heat and wear than other bearing options.

Spherical thrust roller bearings can carry very high axial loads (and small to moderate radial loads) and withstand some misalignment. For the latter capability, one common expression is minute of arc or *MOA* — expressed as 3 minutes of maximum allowable misalignment, for example. This expression derives from how a circle is divided into 360° (angular segments) around the circumference — and each degree is further divided into 60 smaller angular segments called minutes. A minute of arc is a unit of angular measurement equal to 1/60 of one degree … with 21,600 minutes in a circle. Refer to this Design Guide's section titled **More on rotary bearings that function as thrust bearings** for additional information on this.

THE SPECIAL CASE OF SLEWING RINGS

Slewing rings (also called slewing bearings) are large-diameter bearings with thin cross sections (in other words, large bores) as well as flanges or even teeth for tight integration into the designs they complement. They usually install on large rotary axes (direct-drive or geared) in wind turbines, the bases of construction cranes, spinning off-highway equipment such as excavators, research-grade telescopes, and the turrets of military tank vehicles. Based on either ball or crossed cylindrical rolling elements, they include geometries to bear axial and radial loads while simultaneously resolving the loads associated with tipping. Read more at the following links.

- What slewing ring bearing installation measures are you missing?
- When should you select a slewing ring bearing?
- What questions should I ask when specifying a slewing ring bearing?

A FEW MORE WORDS ON PLASTIC ROTARY BEARINGS

Shown here is a magnetically detectable rolling-element xiros M180 rotary bearing and a spherical-bearing rod end from igus. Neither require additional lubrication.

As mentioned earlier in this Design Guide, not all plastic rotary bearings are plain bearings. Some plastic rotary bearings are rolling-element bearings with balls to bear the axis loads. Others are adapted bearing designs that integrate rollers (embedded over an internal working surface) to serve as deep-groove, thrust, angular-contact, and miniature rolling-element rotary bearings.

In the past, some engineers (especially those most familiar with bronze and steel options) hesitated to specify these various types of plastic bearings. However, that's changed with increased market familiarity with engineered plastics over the last couple decades and exhaustive documentation of industrial-grade plastics' capabilities. There's also more engineering support than ever from manufacturers specializing in supplying plastic bearings — so OEMs needn't start from scratch with mechanical components from injection-molding service providers.

THE MATERIAL-SCIENCE FOUNDATIONS OF PLASTIC BEARINGS

Plastic bearings (whether plain or combined with steel or ceramic ball arrays for rolling-element bearing designs) incorporate elements made of a wide range of polymers in various grades as well as hybrid polymer blends. Many proprietary materials (engineered to satisfy specific design objectives related to load and speed ratings as well as heat, chemical, moisture, and even radiation resistance) are typically sold under trademarked names.

Shown here is a plastic rotary bearing from igus with glass rollers to reduce friction and allow clean running.

Polyacetal — sometimes just called *acetal* — and polyoxymethylene or POM are all-purpose semicrystalline polymers with excellent chemical, impact, and cold resistance. The opaque white material can be injection molded into even complex shapes with accuracy … and colorized and blended for aesthetic as well as performance objectives. Some thrust washers and flanged plain bearings are made of engineered POM formulations.

Polyamides or *PAs* classified as nylons (a DuPont trademark though now widely used as a generic term) come in various grades and formulas that are particularly useful in rotary-bearing applications. The International Organization for Standardization (ISO) 1043-1 standard defines how base formulations are labeled. For example, PA66-GF40 is a heat-stabilized nylon 66 — which indicates a molecular structure having two six-carbon-atom monomers — that's reinforced by glass fibers constituting 40% of the material by weight. Many PA formulas are a dull greyish color and recognized for their bending stiffness and high tensile strength … even beyond 200 MPa in some instances.

Polyimides or *PIs* (not to be confused with polyamides) are imide monomers … with *imide* being a chemistry term indicating two acyl groups (C=O) bound to nitrogen. This chemical makeup is suitable for ball bearings with plastic bodies (and plastic plain bearings) that excel on robotics and other mobile automation. Complicating classifications somewhat are proprietary polymers that are actually polyamide-imide or *PAI* plastics — so designated for their alternating imide links and amide links. Bearings made of some such PAIs can survive impact loading and temperatures to 250° C though at the design tradeoff of vulnerability to moisture absorption.

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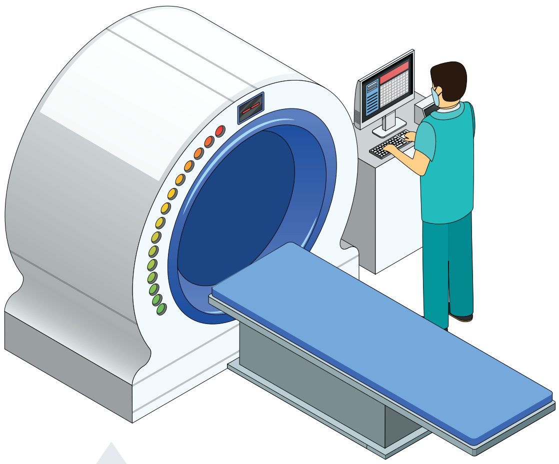
A FEW MORE WORDS ON PLASTIC ROTARY BEARINGS



Because plastic generates none of the sounds of metal subcomponents, plastic bearings of various types are useful in medical-device and consumer designs that must be quiet. Their nonmagnetic nature is indispensable in magnetic resonance imaging (MRI) machines.

Polysulfone (PSU) as well as the newer **polyethersulfone** (PES or PESU) and polyphenylsulfone (PPSU) polymers are amorphous (non-crystalline) plastics — so clear or pale yellow in common formulations. Though more brittle and delivering less tensile strength than some other alternatives, bearings made of these thermoformable plastics can also maintain high stiffness even in hot settings to 160° C and beyond.

Polytetrafluoroethylene or PTFE is a synthetic flurocarbon polymer with exceptionally low static and dynamic friction coefficients than only decrease under compressive stress. Sometimes PTFE is compounded with pigmented additives when used in rotary-bearing construction for enhanced wear resistance. Glass-filled PTFE is also common where stiffness is a design objective. One challenge with PTFE is that it can necessitate special cold molding, sintering, or extruding manufacturing processes. Another challenge is temperature-related dimensional changes even to 1.5% or more in drastic cases.

The work-assist Airframe human exoskeleton from Levitate Technologies uses a wide array of plastic bearings from igus to keep the design light.

Polyether etherketone or PEEK is a thermoplastic that's colorless until formulated into blends for mechanical applications. It's most common in rotary ball bearings (with either ceramic or stainless balls) that need to withstand steamy or otherwise hot settings that may damage components made of standard acetal or other materials. Such bearings usually include inner ring, outer ring, and ball-roller cage made of some engineered version of PEEK. Certain high-performance bearings needing high stiffness and load capacity are made of carbon-fiber-reinforced PEEK.

THE VARIOUS BENEFITS OF PLASTIC BEARINGS

Besides the design benefits outlined earlier in this Design Guide, bearings incorporating plastic offer still other advantages.

1. Bearings incorporating plastic elements leverage how plastic is far lighter than the metals typically used in bearing construction. That in turn can trim machine weight and (in mobile designs such as warehouse robotics or other battery-powered vehicles) can trim energy consumption too.

2. Plastic bearings are more corrosion resistant than metal to better survive food-processing washdown and semiconductor-manufacturing cleanroom conditions. Some settings even allow the water present on a machine axis to serve as the plastic bearing's lubricant.

3. Most plastic bearings can also function sans added lubricant because of plastic's low coefficient of friction and minimal wear during normal use. This can be helpful for applications that are either difficult to maintain or unlikely to receive maintenance.

Just consider how a plain plastic bearing might outperform a steel bearing with a porous bronze sinter layer impregnated and overlaid with polytetrafluoroethylene (PTFE) material. The linings on such layered bearings can sustain damage upon impact or wear off … especially if abrasive contaminants get between the bearing's inner lining and shaft.

In contrast, self-lubricating plastic plain bearings in such settings — especially monolithic offerings constructed of a homogeneously blended base, fiber, and solid-lubricant materials — induce no shaft wear and maintain the specified coefficient of friction over the entire design life. That's true even on reciprocating or oscillating axes. Such plain bearings carry solid lubricant in the fiber-reinforced material of their inner lining to transfer onto the shaft, no matter the axis rpm or shaft type.

4. Bearings incorporating plastic elements don't conduct electricity and are nonmagnetic. This is extremely important for any market where the bearings will be near sensitive electronic components or electromagnetic operations.

5. Plastic bearings are maximally configurable with materials, geometries, and treatments to satisfy very specific design life, speed, load, temperature, and shaft requirements. Decades of testing mean that even customized plastic bearings often come with extensive documentation regarding material performance.

6. Plastic bearings are often less costly than their metal equivalents — up to a quarter less costly in some cases.

SIZING AND SPECIFYING ROLLING-ELEMENT ROTARY BEARINGS

Rolling-element rotary bearings on rotating machine sections support shaft loads, reduce friction with rolling elements, and provide shaft location and system rigidity. Whether a bearing will be suitable for an application depends in part on the application requirements and the bearing's design features and associated capabilities. When specifying bearings, designers must consider and evaluate myriad of application-related factors to specify an optimal match. Here's an overview of some important factors to consider when selecting a rolling-element rotary bearing for an application.

Shown here are stainless-steel thrust bearings with rolling balls for carrying axial loads … as well as rotary bearings (also incorporating balls as the rolling elements) assembled into carriages to facilitate linear motion.

Design consideration one — available space (design envelope) for the rotary bearing: In many cases, one of the principal dimensions of a bearing — the bore diameter — is predetermined by a machine's power design and the resulting required shaft diameter. In general, small-diameter shafts typically incorporate all types of ball bearings … and roller bearing types often install on machine axes featuring larger-diameter shafts. Where radial space is limited, bearings with a small cross section (especially those with a low cross-sectional height) may be suitable. Where axial space is limited, designers often specify low-profile bearings to handle radial, axial, or combined loads.

Shown here are needle-roller rotary bearings with plastic cages to keep the thin cylindrical rollers suitably spaced.

Bearings on electric motors radially support the output shafts and (in many cases) resolve axial loads as well.

(continued)

SIZING AND SPECIFYING ROLLING-ELEMENT ROTARY BEARINGS

Systems with the wrong bearing can fail to deliver the required design life.

Design consideration two — rotary bearing installation arrangements: Commonly specified arrangements include locating and non-locating bearings as well as adjusted bearings and floating bearings.

Locating bearings install at one end of an axis shaft to provide radial support while axially locating that shaft — and carrying any axial loading as well. This requires that locating bearings be fixed in position both on the shaft and in the housing. Suitable bearing solutions for this use include:

- Rotary bearings capable of carrying combined loads or
- Radial bearings (capable of supporting pure radial load) used in pairs

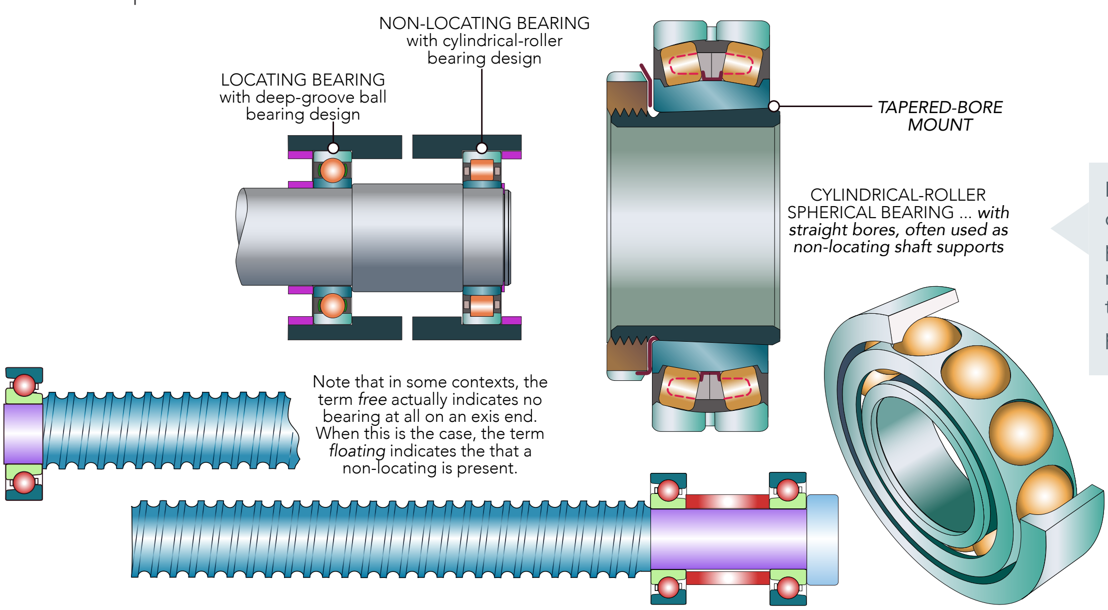
On installations featuring a locating bearing, a non-locating bearing at the shaft's other end provides radial support even while allowing some axial displacement — but (to be clear) carrying no axial load. Non-locating bearings don't carry axial load because if they did, it would stress it and the locating bearing too — especially upon any shaft-length changes due to thermal expansion.

With ***adjusted*** bearing arrangements, the shaft is axially located in one direction by the one bearing and in the opposite direction by the other bearing. This type of cross-located arrangement excels on short shafts. Suitable bearings for this kind of arrangement include all radial bearings capable of accommodating axial load in at least one direction.

Floating bearing arrangements are similarly cross-located and usually specified where axial location requirements are moderate … or where other components on the shaft serve to axially locate it. In these arrangements, one ring of each bearing (preferably the housing's outer ring) should be able to move on or in its seat.

Of course, there are other rotary-bearing installation factors to consider. Case in point: Mounting a single-row tapered roller bearing often involves press fitting the bearing's rotating ring … and leaving a clearance fit on the stationary ring to allow for temperature expansion. Options include:

- Cold mounting via use of a press and fixtures (or nuts and bolts)
- Temperature control by heating the bearing rings with oil, a hot plate, oven or an induction heater to expand them enough to slip them onto the shaft
- Hydraulic pressure injection between the bearing bore and shaft to lessen the friction and reduce the force required for mounting. This last option is often used to mount tapered-bore bearings.



Design engineers can choose from various pairings of locating and non-locating bearings to satisfy specific performance objectives.

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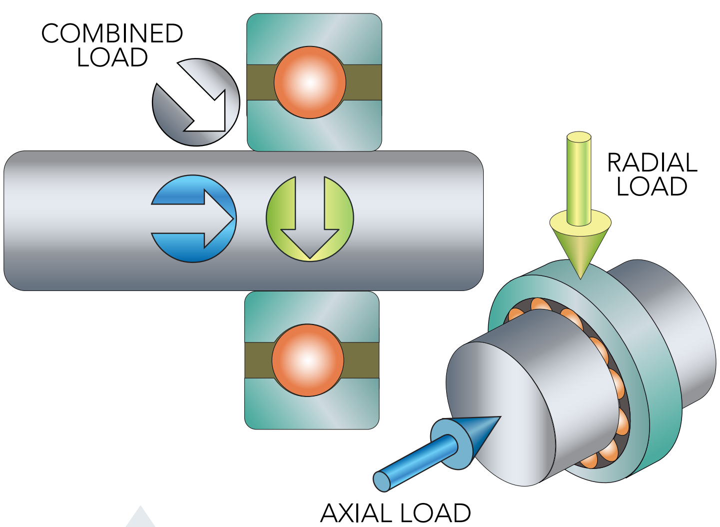
SIZING AND SPECIFYING ROLLING-ELEMENT ROTARY BEARINGS

Acceptable bearing fits are only possible if the shaft and housing to which the bearing mounts have the right geometries with the right tolerances. All bearing manufacturers follow (and publish) an International Organization for Standardization (ISO) fits system to specify these tolerance ranges.

Bearings with interference fits can be easily damaged during the installation process and during removal … so assembly and plant personnel should use caution and employ the proper tools and procedures. To facilitate the removal of outer bearing rings installed with interference fits (especially on machines that require regular bearing servicing) design engineers should specify the inclusion of:

- Notches on housing shoulders to allow clearance for a puller to grab the bearing's outer ring for removal or
- Bolt holes and bolts — so personnel can use the bolts to jack the bearing out of the housing. Tapped holes in the housing at the bearing outer race face let personnel perform this operation.

Design consideration three — applied loads: Bearings must always receive at least some minimum load to provide for proper rolling element rotation and (if applicable) proper lubricant-film formation in rolling-contact areas. That's because even though rolling-element rotary bearings reduce the total friction in a system, the individual rolling elements within the bearing still require a certain amount of friction to roll rather than slide. This internal friction is created by applying load to the bearing. This load can either be generated internally (with a preload — covered later in this Design Guide section) or it can be generated by an externally applied load.



Rotary bearings may need to bear axial and radial loads.

The magnitude of allowable external load is one factor that usually dictates the type and size of the bearing for an application. Read more about this topic: How do I determine the loads on a bearing? Generally, roller bearings can support heavier loads than similarly sized bearings based on ball rollers … and bearings incorporating a full complement of rolling elements can accommodate heavier loads than corresponding caged bearings. Ball rolling-element bearings are mostly used where loads will be relatively light or moderate. For heavy loads and where shaft diameters are large, roller bearings typically will be recommended.

The direction of the load also will affect bearing type and size selection. Some bearings can only support pure radial loads, while all other radial bearings can accommodate some axial loads in addition to radial loads. Other types have been engineered to handle purely axial light or moderate loads.

Many rotary bearings to carry radial loads feature slight internal clearance between the rolling elements and raceways to allow thermal expansion and prevent seizure. Unfortunately, this internal bearing clearance in underloaded bearings creates loaded and unloaded zones. Here as the shaft rotates, the bearing's rolling elements pass into and out of the load zone. While the rolling elements do this, they also experience a concurrent change in speed … a kind of squirting out of the rolling element from the loaded area each cycle. These minute accelerations can be very detrimental. Underloaded bearings can also exhibit skidding — sliding between the bearings' rolling elements and the raceways. That in turn can disrupt the lubricant film and cause smearing damage to the rolling surfaces … and excessive heat generation.

Fortunately, application of a bearing's specified minimum load can prevent these problems.

Design consideration four — temperature: Excessive heat in a design can damage bearings' seals, polymer cages, and even steel elements. In addition, temperature differentials across a bearing — as when there's a hot shaft and cold housing — can reduce internal bearing clearances … and change the load zone with it. Bearings with tighter load zones (of say 150°) run coolly. Bearings with tighter load zones (even approaching 360°) have better load distribution but run hotter. Of course, with no internal clearance and a 360° load zone, internal bearing loads and friction can dramatically increase — even risking a thermal-runaway condition and failure in the form of seizure.

Design consideration five — life: Properly specified and installed bearings are incredibly reliable. Of course, some do necessitate proper maintenance (including lubrication). The latter requires the correct type and quantity of oil or grease; consistent application; and careful recording of conditions that may have degraded the lubricant (and necessitate replacement). No wonder engineered-plastic, ceramic-roller, and other self-lubricating options have seen

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SIZING AND SPECIFYING ROLLING-ELEMENT ROTARY BEARINGS

increased use where suitable. Other factors and expressions related to rotary-bearing life include dynamic bearing loads, the basic dynamic rating of a bearing, and L10 life values. Read more about quantifying modes of failure for rolling-element rotary bearings:

- Bearing currents and what causes them
- Three causes of bearing failure
- How Anderon meters are used to measure bearing noise
- Best maintenance strategy for rotary bearings

Design consideration six — rotational speed: Bearing speed limits depend on the specific design and material — and the permissible operating temperature for the type of lubricant and lubrication system if applicable. Bearing type and size, internal design, precision, loads, lubrication regimens, and cooling conditions (as well as cage design, accuracy, and internal clearance) ultimately dictate a bearing's speed capabilities. Check out the following articles on rotary bearing applications for some examples: Integrated bearing assemblies in wind turbines • Bearings in aerospace applications • Bearings in drones • Bearings for a greener aerospace sector • Industries influencing new bearing designs • Engineering support from the bearing industry

Basic thermal-reference speeds provide values (according to ISO standards) for the permissible operating speed of a bearing at a defined operating temperature when subjected to various loads and lubrication conditions. Bearings can potentially operate at speeds above the reference speed when:

- Bearing friction is reduced using lubrication systems dispensing small and accurately measured quantities of lubricant … or
- When heat is removed using circulating oil lubrication, cooling ribs on the housing, or with directed cooling airstreams.

In some cases, changes in component designs and materials can yield even higher permissible operating speeds.

Design consideration seven — stiffness: Bearing stiffness is similar to the stiffness of a spring. It's characterized by the magnitude of elastic deformation (resilience) in the bearing under load. In general, this deformation is small and can be neglected. However, in some instances (as in spindle bearings for the machine-tool industry or pinion-bearing arrangements in automotive axle drives) bearing stiffness is critical.

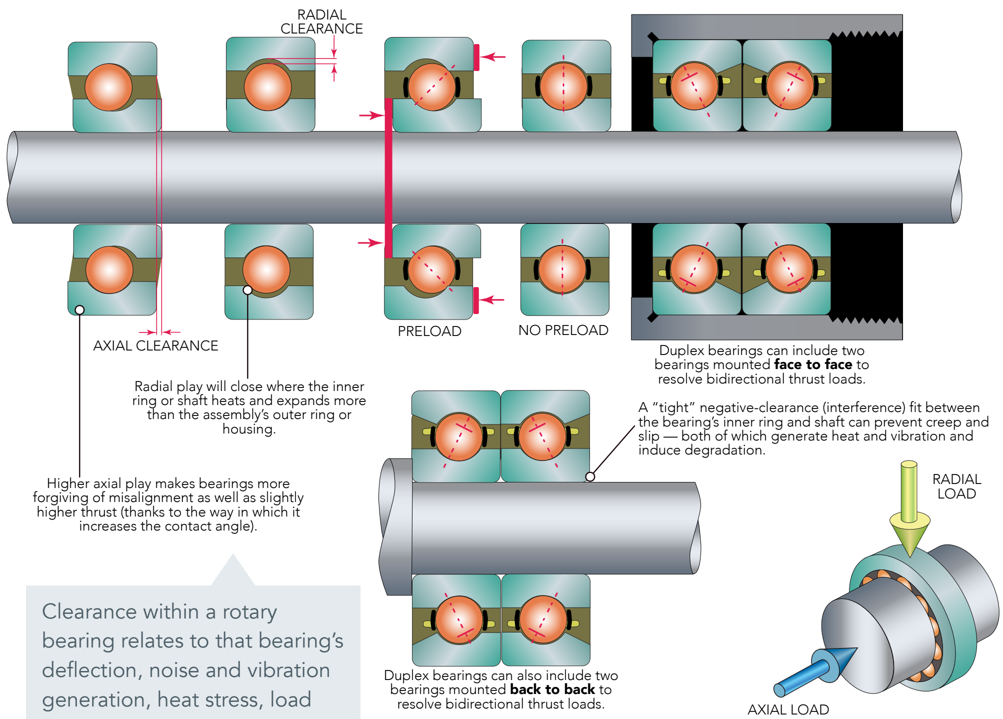
Because of the way they distribute the carried load, cylindrical-roller rotary bearings generally provide more stiffness than similarly sized ball bearings. Bearing stiffness can also be affected by preload …

Design consideration eight — preload: Rotary-bearing preload boosts system stiffness and shaft-guidance accuracy even while minimizing running noise and compensating for wear and settling (relaxation) to extend service life. Preload in rotary bearings basically imposes a negative operational clearance. Depending on bearing type, the preload may be either radial or axial.

A fit between the shaft and inner bearing ring that is too loose can cause corrosion fretting … or (worst-case scenario) a bearing race capable of freely spinning on the shaft. On the other hand, overly tight fits can impinge on internal bearing clearances. Proper fits are defined by tolerance standards set forth by American Bearing Manufacturers Association (ABMA) and ISO standards. Ultimately, proper fit depends on the load direction, bearing geometries such as ring wall thickness, operating temperature, materials and tendencies to thermally expand, and required running accuracy.

When bearings operate without any load or under light loads and at high speeds, preload should be set to provide minimum load to prevent damage from sliding of rolling elements.

Another benefit of preload is protection of the roller-separating cage (where present). After all, insufficient loading on a bearing means there's no roller traction force with the raceways — and so the cage ends up dragging the rolling elements through their circuit. This generates unpredictable load conditions that cause premature cage failure.



Clearance within a rotary bearing relates to that bearing's deflection, noise and vibration generation, heat stress, load distribution, and fatigue life.

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SIZING AND SPECIFYING ROLLING-ELEMENT ROTARY BEARINGS

Preload can be applied via springs, washers, friction torque, or adjustment procedures. Application parameters must be clearly understood when specifying preloaded bearing arrangements. That's because the increased friction associated with preloading can induce hotter bearing operation.

Using springs (especially wave springs) to apply preload usually involves the spring installed to apply force at a bearing outer ring. That in turn causes a slight axial displacement that stays fairly consistent … even if thermal elongation affects the assembly geometry. Here, preload force $F = k \cdot d$ where F = Preload force in kN; k = Application factor; and d = Bearing bore in millimeters. The factor k = 0.005 to 0.01 for small electric motors or up to 0.02 where the preload serves to protect the design against the detrimental effects of vibrations.

Spring-based preloading on angular-contact ball-element rotary bearings is common where they support high-speed machine-tool spindles. It's unsuitable for bearings needing high stiffness or axial-load reversals.

Manufacturers supplying preloaded assemblies often employ adjustments to bearings' frictional moment to set those preloading values. In contrast, using physical adjustments to apply preload often involves in-field closing a bearing's internal clearances by slightly displacing one bearing ring in the axial direction (to be in tighter with the other) during assembly. Adjustment-based preloading might also involve the addition of crush sleeves, spacer rings, nuts, shims, or spacer sleeves acting on housing shoulders. Expressed as a negative distance (sometimes quantified with laser-based indicator tools) this induces elastic deformation in the bearing subcomponents.

Preloading through manufacturing can employ universally matchable bearings that (when ganged in close proximity on an axis) impart a given preload. Otherwise, matched bearing pairs or triplets are specially designed by the bearing supplier to (upon installation in a certain sequence) impart a fairy exact preload.

Design consideration nine — standardized bearing codes: As mentioned earlier in this Design Guide, much of the motion industry employs a fairly standard naming convention for rolling-element rotary bearings. This is a five or six-value alphanumeric coding system — such as W-6200-VV or 6203-2RS, for example. If the code begins with a letter, it indicates some special design feature:

K — A cage holds the bearing rollers
L — Removable bearing ring
R — Roller-set assembly
S — Stainless-steel roll body
W — Stainless-steel construction with deep grooves

Next in the code is the bearing type:
1 — Self-aligning bearing with balls
2 — Spherical bearing with cylindrical rollers
3 — Double row angular contact bearing with balls
4 — Double row bearing with balls
5 — Thrust bearing with balls
6 — Single-row deep groove ball bearing
7 — Single-row angular contact bearing
8 — Felt seal bearing

Next in the code is rotary-bearing toughness:
0 — Extra light
1 — Extra light thrust
2 — Light
3 — Medium
4 — Heavy
8 — Extra thin bearing section
9 — Very thin bearing section

Next in the code is the bearing bore size in millimeters:
Bore size (mm)
00 — 10
01 — 12
02 — 15

Any suffix indicates sealing:
Z — One shielded side
ZZ — Both sides shielded
RS — One side sealed
2RS — Both sides sealed
V — Single noncontact side seal
VV — Both sides sealed (noncontact)
NR — Snap ring and groove

DIFFERENCE BETWEEN RADIAL PLAY AND TOLERANCE

There are distinct differences between a bearing's tolerances, precision, and internal clearances. Employing true position measures (as defined by the field of geometric dimensioning and tolerancing or GD&T) can help clarify these differences.

Internal rotary-bearing clearances: As explained above, these quantify internal looseness in the form of radial play (perpendicular

(continued)

SIZING AND SPECIFYING ROLLING-ELEMENT ROTARY BEARINGS

to the bearing axis) and axial play (parallel to the bearing axis). Play can let bearings support loads under various temperatures and other conditions.

Internal rotary-bearing tolerances: Confusion about clearances contributes to confusion about precision — especially that from better manufacturing tolerances. Consider how some engineers assume precision bearings shouldn't exhibit play … and should deliver very precise rotation. Any looseness gives the impression of low quality — even if the bearing is of exceptionally high precision deliberately designed with loose play.

In fact, tighter tolerances improve precision. After all, it's impossible to manufacture (through mass production or other means) two truly identical bearings. Instead, inevitable irregularities are kept within allowable tolerances … in turn defined by tolerance classes. There are ISO metric and ABEC inch-based ratings that regulate allowable deviations related to the geometries of inner and outer ring sizes as well as the roundness of those same bearing rings and raceways. Higher classes (and tighter tolerances) make for more precise bearing assemblies.

DIFFERENCE BETWEEN PRECISION AND SUPER-PRECISION BEARINGS

Rotary rolling-element bearings that qualify as precision are those meeting or exceeding standard ISO P5 or ABEC 3 precision levels. Adhering to even more stringent requirements are super-precision bearings satisfying ISO P4 or ABEC 7 or better. The farther down this table, the higher the bearing's precision:

ABEC	ISO 492
ABEC1	Normal class 6X
ABEC 3	Class 6
ABEC5	Class 5
ABEC 7	Class 4
ABEC 9	Class 2

Find additional information about storing, installing, and servicing rotary bearings at these links: The basics of bearing heaters • How bearings should be stored when not in use • Bearing obsolescence management • The shelf life for bearing lubricants

MORE ON ROTARY BEARINGS THAT FUNCTION AS **THRUST BEARINGS**

Rotary bearings that function as thrust (axial-load) bearings take various forms — including:

1. Spherical-bearing designs mentioned earlier in this Design Guide
2. Bearings with straight-tapered rings (called tapered roller bearings)
3. Angular-contact or Type A rotary bearings employing balls
4. Flat-face plain bearings sometimes called thrust washers
5. Flat-face thrust ball bearings and (cylindrical) roller bearings

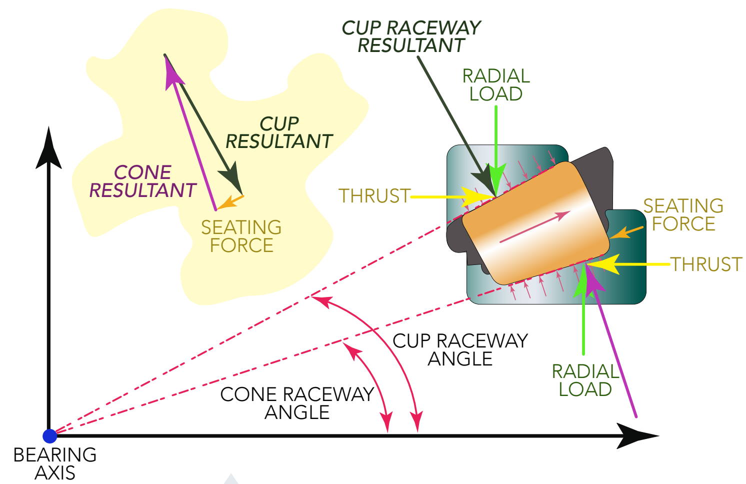
This is a ball bearing (rotary bearing with ball rollers) that works as a thrust bearing. It has a flat seat and grooved races. Other versions of this bearing type have flat (not grooved) races.

1. Spherical roller bearings as explained earlier in this Design Guide have curved mating ring ODs and IDs with barrel-shaped rollers to primarily carry radial loads and loads associated with misalignments … as well as thrust loads. Double-row arrangements have the highest combination-load (including thrust load) capacities.

Another related design is that of **spherical roller thrust bearings**. These have asymmetrical (rounded trapezoidal profile) rollers that ride between specially flanged and rounded raceways of nesting rings — sometimes called the cup and the cone for the way they fit together. Spherical roller thrust bearings can carry exceptionally heavy axial loads and also permit relatively high-speed operation. One caveat is that high rpms or sudden reversals can cause inertia-related issues. These manifest as accelerated wear, increased lubricant friction, and shortened bearing life. Spherical roller thrust bearings are typically manufactured in two designs depending on the size and series.

Tapered roller bearings come in a wide variety of sizes and variations. They're suitable in automated packaging equipment, machine-tool arrangements, consumer appliances, and various aerospace applications.

2. Bearings with straight-angled rings (called tapered roller bearings) carry radial and thrust loads. In these bearings, an array of cylindrical rollers rides (with pure rolling) between the cup and cone … more specifically, between the two rings' mating (ID and OD) straight-ramped raceways. Thanks to their tilt — with the roller and raceway apexes converging at one point on the axis —tapered roller bearings can bear exceptionally heavy radial and thrust loads. The load components resolve into axial and radial along with a modest roller-seating force. The latter helps the rollers maintain contact with a rib on larger-diameter end of the internal bearing geometry — and proper alignment. What's more, tapered roller bearings come in a wide array of sizes and geometries … with raceways at shallower angles to predominantly carry radial loads and steeper angles for more axial-load capacity.



Though the term *tapered roller bearing* can sometimes refer to self-aligning bearings with tapered bores, usually it indicates rotary bearings containing cylindrical rollers that themselves have diameters that gently narrow along their lengths. Bearings with these rollers can carry axial, radial, and combination loads.

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MORE ON ROTARY BEARINGS THAT FUNCTION AS THRUST BEARINGS

This is the roller cage of a spherical roller thrust bearing.

3. Of course, many ball bearings (rotary bearings employing balls and not cylindrical rollers) can carry some amount of thrust. Recall that designs only involving radial load can use deep groove ball bearings. In contrast, deep-groove ball bearings can carry a thrust load up to 10% of the bearings rated load.

Angular-contact rotary bearings (ball bearings) support both axial and radial loads. They come in a single-direction (single row) or double direction (double row) versions with the latter recommended where axial loading in both directions is present. The magnitudes of maximum radial and thrust loading are

> Single-row angular-contact ball bearings can carry radial as well as thrust loads in one direction. Applications involving thrust in both directions and a using traditional ball bearing will require one having four-point contact — or multiple opposing angular-contact ball bearings.

interdependent and are partially defined by the contact angle between the bearing axis and raceways. Most angular-contact thrust ball bearings are separable — letting machine technicians independently mount their separate elements. Although originally designed to support the rotary tables of drilling rigs, these bearings are also suitable on automated machine axes needing axial stiffness and high-speed performance.

This is a closeup of the cylindrical rollers of a thrust bearing held in their cage.

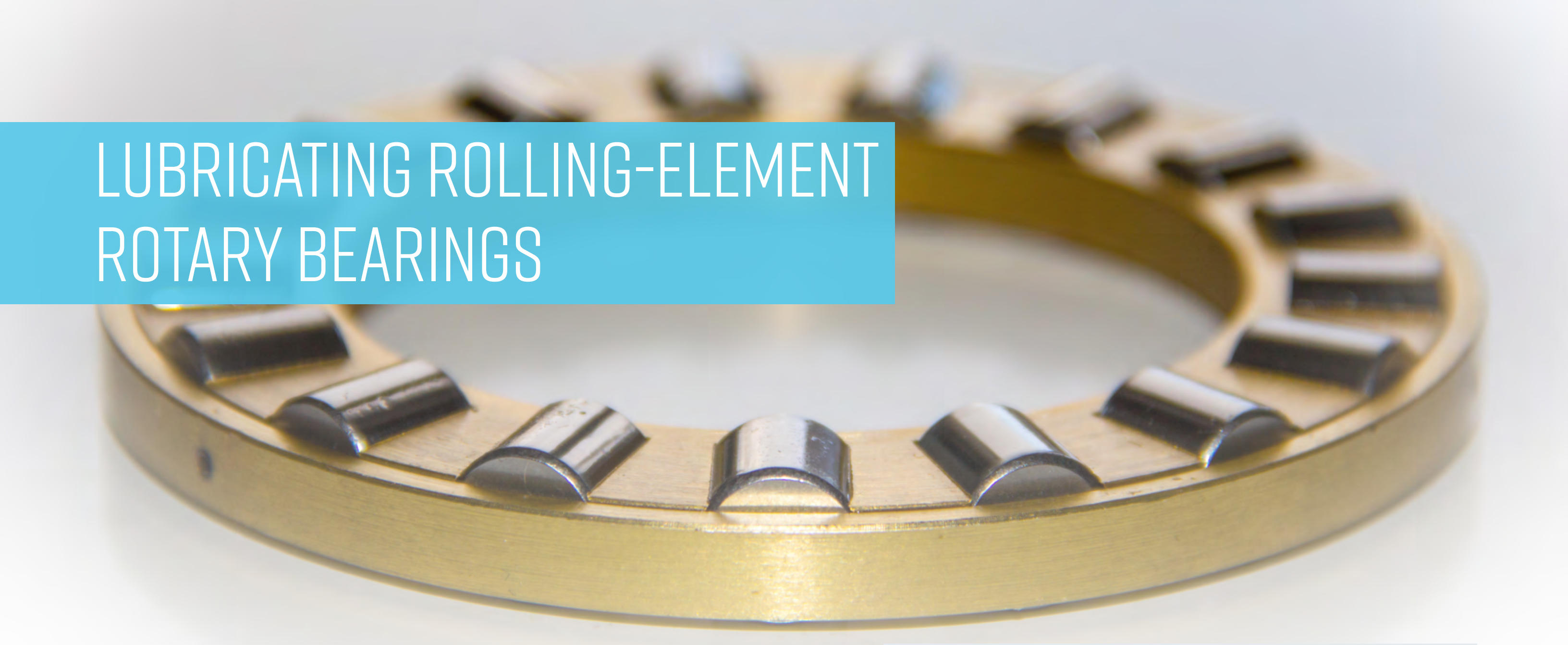
4. Flat-face plain bearings (sometimes called thrust washers) primarily work to support and prevent wear from axial loads on a shaft — whether associated with a design that stays put on a shaft or slides along it … as a carriage in a linear-motion application. No matter the variation thrust washers typically install between rotating and stationary assembly sections.

When they take the form of a flange on a plain sleeve bearing, thrust bearings can also do double duty to prevent dust and moisture ingress into assembly holes. That's especially useful in the wheel assemblies of mobile designs.

As covered earlier in this Design Guide, thrust washers made of engineered plastic offer unique benefits — including low weight and dry (oil-free) low-friction operation. Other thrust-washer options include various grades of steel, brass, bronze, and graphite.

5. Flat thrust bearings (sometimes called pancake thrust bearings) contain an array of balls or cylindrical rollers (held in a cage or retainer) that rides two circular platters or washers. That's in contrast with more common radial-load-bearing designs in which balls or cylindrical rollers ride raceways on bearing rings' inner and outer diameters. Most flat thrust bearings have flat seats and grooved or flat raceways. Flat platter raceways let bearings accommodate light loads and slight shaft flexures. In contrast, grooved platter raceways carry about 350% the load of comparable flat-platter variations. In typical applications, one platter mounts to the shaft and the other to the machine housing with the rolling-element assembly between them. Flat thrust bearings with needle rollers (along with similar needle-roller bearings for carrying radial loads) are in some contexts are generically called Torrington bearings — though that name is actually a trademark and owned (and archived) by Koyo of JTECT.

LUBRICATING ROLLING-ELEMENT ROTARY BEARINGS



The wrought and cast brass elements found in some rotary bearings (including the cage of the thrust bearing shown here) are chemically unaffected by most bearing oils and greases — even those that are synthetic. Brass also allows for solvent-based cleaning during regular maintenance.

Improper or insufficient lubrication is one of the leading causes of equipment failures in industrial applications. Without lubrication, all the sliding and rolling and meshing of mechanical motion assemblies would generate significant friction, heat, and wear — as well as noise, loss of accuracy, and reduced equipment life.

One of the most important characteristics of a lubricant is its viscosity — or in the case of grease lubricant, the viscosity of the base oil. But viscosity is analogous to friction in fluids … so why do design engineers need lubrication friction to counterintuitively reduce the friction in rotary bearings?

First some basics: Tribology is the study and application of the principles of friction, lubrication, and wear between two surfaces in relative motion.

Viscosity = Friction in fluids.

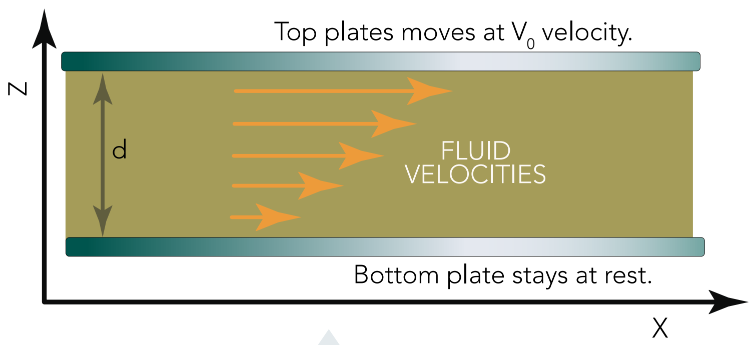
Viscosity is a property of fluids caused by their internal resistance to shear. When a fluid is moving under laminar flow conditions with no turbulence (as is the case with most bearing lubrication scenarios) microscopic layers of the fluid flow over one another, much like a stack of paper, with each sheet moving slightly faster than the one below it. Cohesive forces between these microscopically thin fluid layers must be overcome as the layers move past one another. The resistance caused by these cohesive forces is the primary determinant of the fluid's viscosity.

Additional reading: When should grease be used for bearings? • More on bearing grease • When should oil be used for bearings? • What is an oil leveler? • What are the different types of bearing lubricants? • What characteristics are specific to yaw grease? • High-temperature lubricants for bearings • What is the NLGI scale?

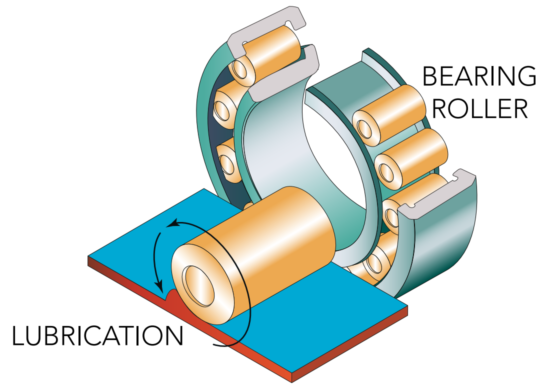
Most igus bearings — including smart iglide plain bearings that incorporate feedback to support predictive maintenance — need no lubrication. That said, the manufacturer does sometimes recommend high-performance mineral-oil-based or MoS_2 greases for exceptionally low friction and long bearing life. For more information, visit www.igus.com/info/news-2018-smart-plastics.

(continued)

LUBRICATING ROLLING-ELEMENT ROTARY BEARINGS



In laminar flow, microscopic layers of fluid flow over one another. The layers' internal resistance to this shear force gives rise to viscosity.



As bearing speed increases, lubrication is pulled into the contact zone.

VISCOSITY FOR REDUCING BEARING FRICTION

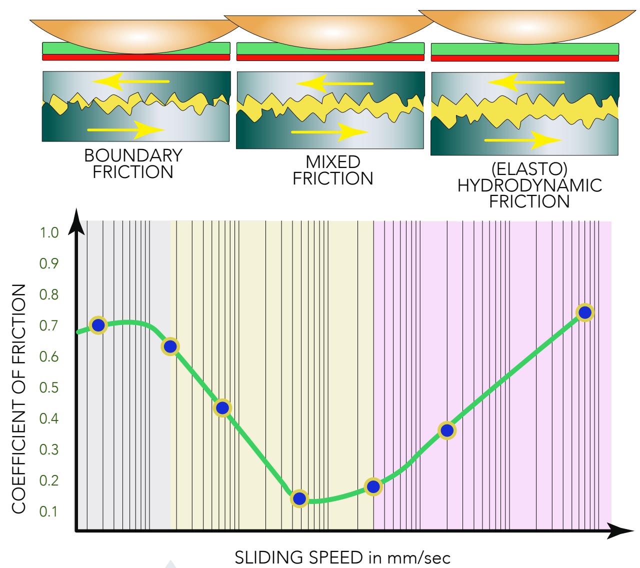
No matter how well bearing surfaces are machined, finished, and cleaned, they'll always have peaks called asperities and valleys. When two bearing surfaces such as the ball or roller and raceway contact, the asperities of the surfaces interfere with each other. A primary role of lubrication is to separate the surfaces and reduce or eliminate the interference of their asperities to significantly minimize friction and wear.

But when bearing surfaces are stationary (or moving at very low speeds) the pressure between them essentially squeezes the lubrication out from between the surfaces. There is a very thin lubricating film, but it's insufficient to separate the asperities of the two surfaces … and significant contact still exists. This is called *boundary lubrication*.

In boundary lubrication the generated friction, heat, and wear primarily depend on the interactions between the surfaces. That said, chemical reactions between the lubricant and surfaces can also contribute to wear. Time spent in a boundary-lubrication condition significantly affects bearing performance and life.

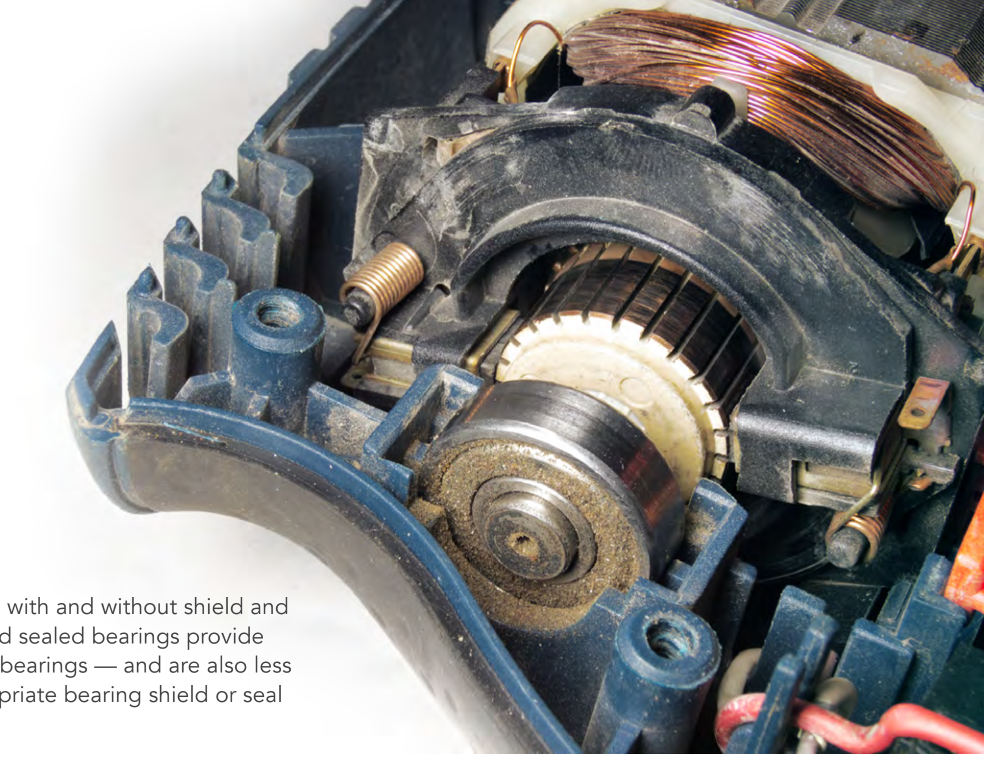
As velocity increases, more lubrication is pulled into the space between the bearing surfaces, allowing a thicker lubrication film to develop. This causes the pressure on the lubrication film to increase, which in turn increases the lubricant's viscosity according to the lubricant's pressure-viscosity coefficient. But there is a transition period where (as velocity increases) the surfaces separate in some places … though interference between asperities still occurs in other places. This is called mixed lubrication.

Finally, when a sufficient velocity is reached, the lubricating layer becomes large enough to separate the asperities of the two surfaces, and the increased viscosity gives the lubricant sufficient film strength to support the load, by elastically deforming the bearing surface. This lubrication regime is called elasto-hydrodynamic lubrication.



A Stribeck curve shows the development of the lubrication film and the resulting change in friction. As velocity increases, the bearing surfaces draw in more lubricant, creating a thicker lubricating layer under higher pressure, which results in higher viscosity. Finally, the layer is thick enough to separate the asperities of the surfaces … and the viscosity provides sufficient film strength for the lubricant to support the load.

SEALING AND PROTECTING ROTARY BEARINGS



This handheld power drill is one example of a brushmotor-driven design that can subject the shaft support bearing to quite a lot of contamination. Here, end seals are essential to extending rotary bearing life.

Rotary bearings with rolling elements are supplied with and without shield and seal enclosures. It's unsurprising that shielded and sealed bearings provide better protection from contamination than open bearings — and are also less likely to exhibit lubrication migration. The most appropriate bearing shield or seal depends on the application and environment.

Metallic shields are the most common and affordable bearing enclosure type. Most involve no contact between the shield bore and bearing inner ring. Of course, the exact permutation depends on the bearing geometry: For example, pancake thrust bearings are often self-contained units with a circumferential band. Here, the band actually shields the bearing's outer circumference from contamination and does double duty to address separating forces from axial assembly motion.

Additional reading:

- Are bearings with fluoro rubber seals safe?
- What's the best seal design for my bearing application?
- Selecting the proper radial shaft seal for a bearing

Seals are constructed from various elastomeric materials. The most suitable seal material primarily depends on application temperature and compatibility with other adjacent substances. Seals can be either noncontact or contact by design. Noncontact bearing seals (just like bearing shields) introduce no contact with the bearing's inner ring. In contrast, contact seals have a lip that touches the bearing inner ring … for better protection but a small amount of friction between the seal lip and bearing inner ring. The seal lip can be further optimized by selecting either standard contact or light seal lip design which is dependent on torque and contamination conditions.

Noncontact seals and shields introduce no drag so can spin with less rotational torque loss than contacting variations. The tradeoff is that noncontact bearing enclosures generally provide less protection against contamination than contact seals.

When in doubt, design engineers should consult with a bearing application engineer to select the appropriate enclosure for a given rolling-element rotary-bearing use.