# BEARINGS



Bearings allow smooth, low-friction motion between two surfaces loaded against each other. The motion can be either rotary (such as a shaft turning within a housing) or linear (one machine element moving back and forth across another). Linear-motion bearings are covered in the Linear Motion Devices Product Department of this handbook. In some applications, bearings accommodate linear and rotary motion simultaneously.

As with motion, load is applied to a bearing in either of two directions, or both. Radial loads act at right angles to a bearing's axis of rotation. Axial loads are applied parallel to, rather than at right angles to, the bearing's axis of rotation. In many situations, bearings must support radial and axial loads simultaneously. In fact, many bearings designed to carry primarily radial loads usually carry some axial load, too.

The most basic bearing is the plain type. It has no moving parts and it supports loads through sliding motion. Conversely, rolling-element bearings are subjected to very little sliding. Load is supported by numerous rolling members inside the bearing. In either situation, proper lubrication is essential to long bearing life.

Plain bearings generally cost less than similarly sized rolling-element bearings, but rolling-element bearings generally can tolerate heavier loads and higher speeds.

Bearings that support loads perpendicular to their axis of rotation are called radial-type. Bearings supporting loads parallel to their axis of rotation are termed thrust bearings. Bearings supporting both axial and radial loads simultaneously are known as combination bearings. Radial-type plain bearings often are referred to as journal or sleeve bearings. Plain and rolling-element bearings are rated according to their load and speed capacities and required life. Other factors affecting bearing selection include operating and ambient temperatures, type of lubrication, running clearance, nature of load, degree of contamination, and cost.

## PLAIN BEARINGS

In a plain bearing operating under hydrodynamic or full-film lubrication, a film of lubricant completely separates the shaft and bearing. It would therefore seem logical that any bearing material of required strength could be used because there is no metal-to-metal contact. However, because most applications exhibit less than full-film lubrication at least occasionally, a bearing of proper material and design must be selected to ensure satisfactory operation.

The type of lubrication may also make the difference between a successful application and one in which the bearing fails prematurely. For reference, lubrication principles are discussed in the PT Accessories Product Department of this handbook. For this discussion, however, a few terms are defined:

- Boundary lubrication — bearing and shaft surfaces rub together with only a thin film of lubricant separating them. Grease-lubricated bearings generally operate with a boundary film.
- Mixed-film lubrication — bearings support part of the load on a boundary film where the shaft is closest to the bearing. The remainder of the load is supported by hydrodynamic, or full-film, lubrication.
- Full-film or hydrodynamic — the shaft is separated from the bearing by a continuous film of self-pressurized lubricant with no metal-to-metal contact. This fluid film is generally about 0.001 in. thick, but films as thin as 0.0005 in. are sufficient if shaft surface finish is held within 10-μin. RMS and bearing inner surface is held to 30-μin. RMS maximum.

In many situations, the bearing itself contains or acts as the lubricant. Such prelubricated or self-lubricating bearings are discussed later in this bearing department.

### Loading

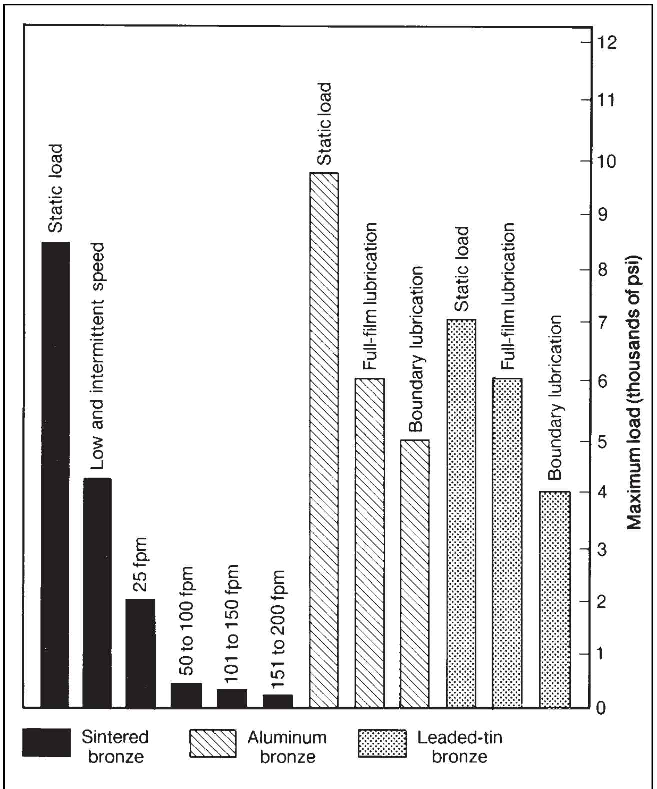
A bearing's load capacity is often determined through experience and generally is expressed as pounds per square inch (psi) of projected bearing area. A rule of thumb: maximum load capacity for static or very-low-speed applications is 1/3 the bearing material's compressive limit. Compressive limit is that which results in permanent deformation of 0.2%.

Rarely are industrial bearings loaded over 3,000 psi. In fact, most carry loads under 400 psi. A bearing's load capacity varies widely with its size and type of material. Figure 1 shows load capacities for three types of bronze, a material commonly used for plain bearings.

Another method of determining a bearing's load capacity is through maximum PV factor. This is the value of pressure on the bearing, in psi, times the shaft speed, in feet per minute. As with pressure, PV factors should be used only as a guide because other conditions also affect load capacity. Figure 2 shows maximum PV factors for three common types of bronze.

Although PV factor serves as a useful guide in determining bearing capacity, the factor can be misleading in some situations. For example, Figure 2 shows that lubricated sintered bronze accommodates a PV factor of 50,000. However, a load of 15,000 psi operating at 2 fpm would be unacceptable because the load exceeds the compressive strength of the material. Similarly, an application may have an acceptable PV factor, though speed,

**Figure 1 — Load ratings of three common bronzes. Temperatures should not exceed 300 F with most lubricants.**




rather than load, exceeds limitations. Maximum permissible speed is a function of lubrication, alignment, shaft surface finish, and hardness. Also, temperatures must stay within bearing and lubricant limits.

Though it must be understood that neither P nor V for a given material can be exceeded, the magnitude of heat generated for a high P in combination with a low V will be far less than a low P, high V, situation. Velocity, more than pressure, influences temperature due to sliding for the same product of P and V.

## Physical characteristics

Bearings operating with full-film lubrication typically exhibit a coefficient of friction between 0.001 and 0.020, depending on mating surfaces, lubricant, clearances, and speed. For a mixed-film bearing, the coefficient ranges between 0.02 and 0.08, and for boundary-lubricated bearings, between 0.08 and 0.14.

The coefficient of friction in a bearing application is important because the higher the coefficient of friction, the higher the heat generation. Excessive heat reduces life of the bearing. Excessive heat may also cause expansion of the shaft, housing, or bearing, or any combination of these.

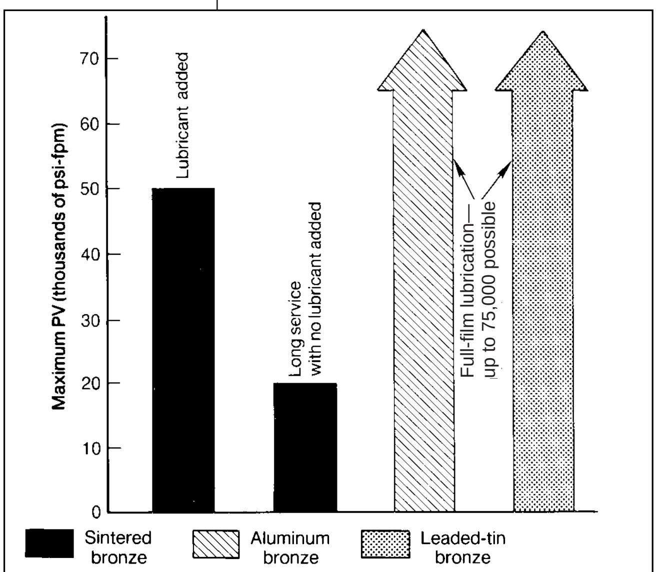



**Figure 2 — Maximum PV (psi X fpm) of three common bronzes.**

This expansion reduces the clearance between the shaft and bearing, further increasing operating temperature, resulting eventually in premature bearing failure.

## Materials

Many metallic, nonmetallic, and compound materials are available to designers. Bronze has probably been the most familiar plain bearing material because a variety of characteristics can be imparted to it by adding other metals. In general, softer materials are designed for lighter loads and higher speeds; harder materials for higher loads and lower speeds.

**Metallic** — The softest metallic bearing materials are babbitts. Both tin and lead-based babbitts have been widely used as bearing materials for years. They are much softer than bronze and are able to embed foreign particles, which helps prevent shaft scoring or wearing. Babbitt bearings offer excellent resistance to shaft scoring and seizing in boundary lubrication conditions. Because they are so soft, these materials usually serve as linings, with stronger material for support.

Copper-lead is also soft, though it approaches some of the softer bronzes in hardness. Steel backing is usually needed in copper-based bearings to raise strength. Another design has a thin babbitt bearing surface and steel backing, with copper-lead sandwiched between.

In terms of increasing hardness, the next material family is bronze alloys. They serve from very high-speed, light-load uses to very light-load, high-speed uses.

Leaded bronzes are widely used when start/stop cycles are high. But because these materials are soft, they are limited by low load-carrying and operating-temperature capacities. High lead content helps these bronzes resist seizing or scoring of the shaft. Maximum operating temperature of leaded bronzes runs typically from 400 to 450 F. Decreasing the lead concentration increases strength and hardness of the material, but decreases its conformability, scoring resistance, and ability to embed foreign particles.

Tin bronze contains much less lead than leaded bronze. This makes it more suitable for high loads at lower speeds. But lubrication is more important because tin bronze has less protection against seizing and scoring.

Manganese bronze is an alloy consisting mostly of copper and zinc. Addition of aluminum, iron, and manganese increases the material's hardness and strength. Thus, manganese bronzes can carry much heavier loads than the softer bronzes, but again, adequate lubrication must be provided. Also, higher quality shaft finish is required.

Aluminum bronze is a copper-based alloy containing up to 14% aluminum and various other metals. Aluminum bronze has become popular over the last few decades due mainly to its resistance to creep, corrosion, wear, and oxidation at high temperature, as well as its high strength .

Another popular bronze material is sintered bronze. It is made from powdered bronze which, when subjected to high pressure and temperature, forms a porous material. The finished material contains oil impregnated in the pores.

Sintered iron bearings, made similarly, have become a popular cost-effective alternative, especially in high-volume uses such as fhp motors. They also behave similarly in that either sintered bronze or sintered iron can operate in boundary (thin-film) or hydrodynamic (full-film) lubrication mode, depending on application parameters. In theory, the major differences between a porous and a non-porous bearing, presuming steady state and an adequate oil supply, are:

- In the "pressure wedge," oil escapes into the porous bearing's pores and reduces the hydrodynamic oil pressure available for load support.
- In the region of reduced pressure (the unloaded part of bearing clearance), oil is drawn from the pores and oil-film cavitation is reduced.

The two effects set up oil circulation in the pores.

Zinc-aluminum alloys have emerged in recent years as a cost-effective alternative to bronze alloys, However, successful application of zinc-aluminum alloys is restricted primarily to high-load, low-speed applications. Figure 3 shows the maximum load-speed-curves for two zinc-aluminum alloys plotted against SAE 660 bronze. The tests were conducted under the sponsorship of the International Lead Zinc Research Organization, by Battelle Institute, Columbus, Ohio.

Though the graph clearly shows higher load capacity of the zinc-aluminum alloys (which could also be interpreted as longer life under equal load), it should be pointed out that even though zinc-aluminum alloys cost much less than bronze, they are more limited by temperature than bronze, having maximum operating temperatures below 300 F. Zinc-aluminum alloys should therefore be limited to low-speed, low-temperature applications.

Because of high cost, other materials such as cadmium and silver are in only limited use. Cadmium can serve in high temperatures where no other material is satisfactory. Suspected toxicity of cadmium in some uses should be considered. Silver has good resistance to seizing and shaft scoring, and is usually electroplated onto a steel backing. When low cost is a prime concern, cast iron or steel bearings can be used at light loads. Flake graphite in the cast iron glazes the bearing surface, which is useful at speeds to about 130 fpm and loads to 150 psi.

**Nonmetallic** — Nonmetallic or self-lubricating bearings often require no liquid lubricant. Self-lubricating bearings are most effective in applications where relative motion is not sufficient to circulate oil or grease required for metallic bearings. Self-lubricating bearings are also used for temperatures beyond the scope of conventional lubricants. These temperatures may range from – 400 to 750 F or higher. Self-lubricating bearings are especially well suited for corrosive environments.

Friction, coupled with rapid wear, limits the application of self-lubricating bearings. The coefficient of friction of self-lubricating bearings running completely dry generally ranges from 0.1 to 0.4. The mechanical energy lost in the bearing is converted to heat, which must be dissipated. The materials generally are poor conductors of heat, so it is important to provide a means of dissipating heat from the bearing. Typically, about half the heat flows radially outward to the support housing, while the other half transfers to the shaft and flows axially away from the bearing.

The most common self-lubricating materials include polytetrafluoroethylene (PTFE), graphite, and molybdenum disulfide ($MoS_2$). PTFE is a soft, waxy solid, which is usually compounded with reinforcing materials such as composite fabrics with epoxy resins. It is also compounded with metal or ceramic powders to build strength and improve thermal conductivity, or is supported on a porous bronze substrate or stainless steel or bronze screen.

Graphite is too weak for use by itself. Tiny graphite flakes are generally bonded with carbon or thermosetting resins. Suppliers of carbon bearings offer scores of individual grades tailored to requirements of specific applications.

$MoS_2$ crystals are generally bonded with resins or metal. In many cases $MoS_2$ is incorporated into plastic bearings, such as nylon, to improve bearing life. Other plastics often used for bearings include Acetal and Polyimide.

Both wear rate and friction are greatly reduced when self-lubricating bearings run submerged in any liquid because the liquid cools the bearing. In fact, even poor lubricants — ammonia, propane, and water — form enough of a hydrodynamic film to carry part of the load. The self-lubricating benefits provide an "artificial" lubricant film for startups, shock loads, and other transients, while the fluid provides full-film lubrication once adequate speed is reached.

Self-lubricating bearings can improve performance even in fully lubricated applications. For example, with hydrodynamic lubrication, self-lubricating bearings have friction coef-

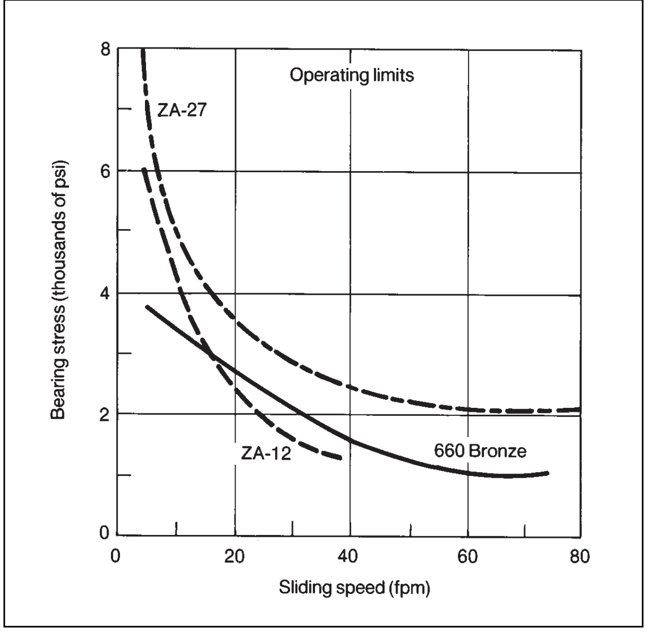



**Figure 3 — Maximum load-speed ratings for two common zinc alloys and SAE 660 bronze.**

ficients similar to those of lubricated metals. Yet, self-lubricating materials can provide longer life because they resist wear at startup when lubricants are not fully effective. Another advantage is lower startup torque, which reduces the system's power requirements.

A prelubricated bearing is made of a nonmetallic material with grease pockets. With this type of bearing, an initial supply of lubricant is applied at startup, and is gradually released as the bearing wears.

## Grooving for lubrication

Often, a metallic bearing's axial length must be large to carry the required load. To provide lubricant throughout the entire length of the bearing, the ID often contains oil grooves. Most short bearings have no grooves. However, most have an oil hole centrally located in the unloaded area of the bearing. In general, oil will flow unaided by grooves approximately 1/2 in. axially to each side of the oil hole. If the bearing has an axial length greater than 1 in. (not including the oil hole diameter) a groove is usually necessary. A groove may also be required to produce an oil film when the bearing length-to-diameter ratio is greater than 1:1. With a grease film, the ratio may approach 1.5:1 without a groove. To provide a complete and continuous film in a grease-lubricated bearing, grease must be pumped into the bearing continuously.

Groove depth is generally 1/16 in. or about 1/3 the wall thickness. Oil grooves are usually 1/8 in. wide. Grease grooves may be 1-1/2 times the width of an oil groove. The groove should come no closer to the end of the bearing than 0.05 times the length of the bearing, or a minimum of 1/8 in. The groove can penetrate one or both ends of the bearing if oil is introduced at these points.

Grease-lubricate sintered bronze bearings only if they are grooved. Ordinary soap-based grease should not impregnate the pores because the soap will clog the pores. Grease should be introduced through a hole drilled in the unloaded portion of the bearing.

## ROLLING-ELEMENT BEARINGS

Rolling-element bearings rely on either balls or rollers to support loads. The rolling motion produces much less friction than plain bearings. For this reason, rolling-element bearings are often called anti-friction bearings. As with plain bearings, rolling-element bearings are available for radial loads, thrust loads, or a combination of radial and thrust loads.

### Ball bearings

**Radial ball bearing** — There are two basic types of radial ball bearings: the non-filling slot or Conrad type, and the filling slot or maximum capacity type, Figure 4.

The Conrad bearing has a deep, uninterrupted raceway in inner and outer rings. This design carries heavy radial and moderate bidirectional thrust loads. The filling slot or maximum capacity bearing contains more balls than an equivalent-sized Conrad type, and therefore, a higher radial load capacity.

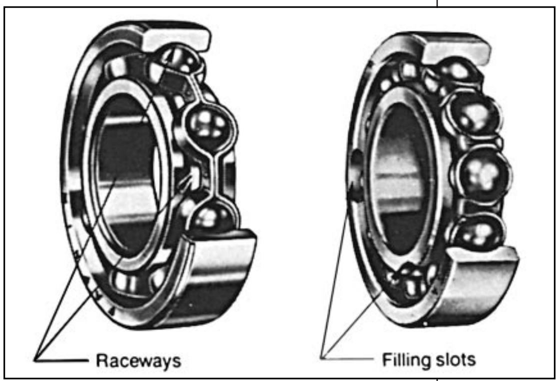



**Figure 4 — Conrad-type ball bearing, left, and maximum-capacity (filling slot) type, right.**

However, because of the filling slots, thrust loads must be light and applied only in combination with a heavier radial load. Exceeding rated thrust causes balls to roll over the filling slots, causing severe damage to the bearing. Bearing load capacity can also be increased by using a double row bearing instead of the max type.

To select a proper radial ball bearing for an application, analyze the following variables:

*Load:* Is load applied as radial, thrust, or a combination? What is its magnitude? What is its nature (uniform, light shock, heavy shock)? When load is applied as a combination of radial and thrust forces, convert these factors into a single equivalent radial load using formulas in the engineering section of manufacturers' catalogs.

*Speed:* How high is speed? Is it constant or variable? Bearing speeds are limited by tolerance grade, lubricant used, retainer design, and type of bearing seal.

Manufacturers offer a guide for maximum safe operating speeds. The speed value (DN) for inner ring rotation, is the product of bearing bore in millimeters and shaft speed in rpm. Compare DN values with the manufacturer's recommended value to determine type of lubrication and tolerance grade. Table 1 gives safe DN values for standard ball bearings.

*Required life:* How long must the bearing operate? Although it is impossible to predict the fatigue life of an individual bearing, lives of identical bearings from a representative lot tested at common conditions form a definite statistical distribution. Because of variations in individual bearing lives, fatigue life of a group of bearings is defined as the number of hours of operation at a given speed that 90% of the bearings in a lot can achieve before the onset of fatigue failure. This is called the $L_{10}$ life.

*Environment:* Environment takes into account ambient and operating temperatures, and degree and type of contamination. Speed, load, and external heat affect operating tempera-

**Table 1 — DN speed value (bore in mm × rpm)**

| Bearing type | Retainer type |
|---|---|
| Single row, Conrad type | Molded nylon<br>Pressed steel |
| Single row, filling slot type | Molded nylon<br>Pressed steel |
| Radial, single row | Molded nylon<br>Composition CR<br>(ring piloted) |

*Grease filled to 30 to 50% of capacity. Type of grease must be carefully chosen to achieve the above speed values.

ture. Contaminants, such as dirt, water, or corrosive chemicals, are present in most applications to some degree, and must be excluded from the bearing. The greater the potential of contaminants entering the bearing, the greater the sealing requirement to exclude contaminants and retain lubricant in the bearing. In cases of extreme infiltration of contaminants, a constant supply of pressurized lubricant can be introduced to the bearing to purge contaminants.

Common ball bearings are constructed of SAE 52100 chromium-alloy, high-carbon bearing steel, which is suitable for most applications. It offers satisfactory operation at temperatures approaching 250 F with no adverse effect on load capacity. Heat stabilized SAE 52100 steel operates in the 350 F range.

Contamination causes more bearing failures than fatigue. Specific seals protect against specific types of contamination. Select a seal that provides protection and lubricant retention for your specific application. Information on seals and seal selection is presented in the PT Accessories Product Department.

*Lubrication:* Bearings may be lubricated with either oil or grease. Although oil is preferred, grease is often used for convenience. Lubrication minimizes bearing rolling resistance due to deformation of the balls and raceways, and reduces sliding friction between the balls, raceways, and retainer. Lubricants carry heat away from the contact zone, prevent corrosion, and help exclude contaminants.

Grease quantity and characteristics must satisfy operating conditions. Too much or too viscous a lubricant generates heat due to friction within the lubricant itself or between lubricant and bearing. Too little or too light a lubricant provides insufficient film protection.

Many ball bearings are supplied factory-lubricated, also known as lubricated-for-life bearings. These bearings have seals and an initial supply of grease for inaccessible locations or where relubrication is impractical.

Another important characteristic of ball bearings is internal clearance. Radial ball bearings have internal clearances between rings and balls to absorb the effects of press fitting. They compensate for thermal expansion of bearing, shaft, and housing, and provide a contact angle in the bearing after mounting. Before mounting, check the manufacturer's specifications for required shaft and housing tolerances.

**Thrust ball bearings** — A thrust ball bearing provides axial shaft location and supports axial (thrust) load. Angular-contact ball bearings support radial as well as thrust loads. The ratio of radial to thrust loading depends on the angle of contact between the races and the bearing axis.

Flat race, flat seat bearings, Figure 5A, consist of two flat washers and a ball retainer assembly. They are used where the ball retainer assembly must carry thrust loads without restraining shaft oscillation or flexures. They serve best with light loads and are economical. This bearing's load capacity is approximately 28% that of a comparable grooved-race bearing.

Grooved race, flat-seat bearings, Figure 5B, are the most common thrust ball bearings. They consist of a shaft-mounted small-bore washer, a large housing-mounted bore washer, and a ball retainer assembly.

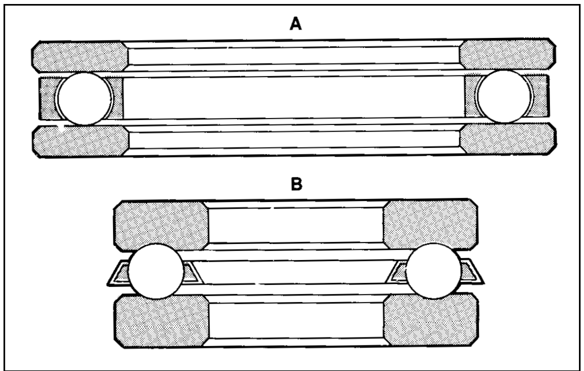



**Figure 5 — Flat-race, flat-seat thrust ball bearing, A, and grooved-race, flat-seat thrust ball bearing, B.**

Banded thrust ball bearings, Figure 6A, are self-contained, have grooved races, have a stationary and rotating race with full ball complement, and are encased in a containing band. These bearings are most commonly used where the bearing's outer circumference must be protected from contamination, for blind installation, or where separating forces cause substantial axial motion of bearing components.

Aligning, grooved race bearings, Figure 6B, are available in single and double-acting types. Double-acting thrust bearings consist of two retainer assemblies separated by a flat washer and have washers on the top and bottom of the unit. Aligning members compensate for initial misalignment due to shaft deflection or mismatch, while allowing uniform distribution of load through the bearing. Aligning, concave surface washers are generally soft, to ensure

| ABEC-1 | | ABEC-3 | | ABEC-7 | | |
|---|---|---|---|---|---|---|
| Grease | Oil† | Grease* | Oil† | Grease (selected) | Circulating oil | Oil mist |
| 200,000 | 250,000 | 200,000 | 250,000 | 250,000 | 250,000 | 250,000 |
| 250,000 | 300,000 | 250,000 | 300,000 | 300,000 | 350,000 | 400,000 |
| 200,000 | 200,000 | — | — | — | — | — |
| 200,000 | 250,000 | — | — | — | — | — |
| 300,000 | 350,000 | 300,000 | 400,000 | 400,000 | 600,000 | 750,000 |

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†For oil bath lubrication, oil level should be maintained between 1/3 to 1/2 from the bottom of the lowest ball.

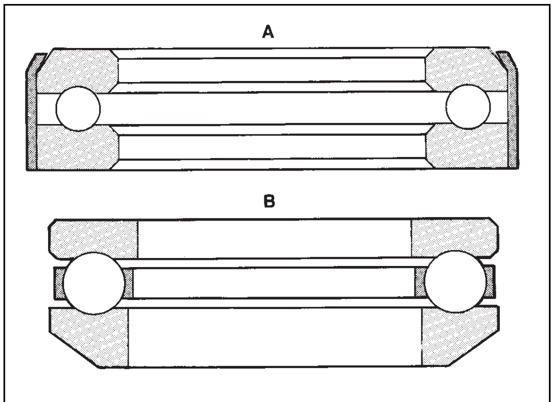



Figure 6 — Banded thrust ball bearing, A, and aligning, single-acting, grooved-race thrust ball bearing, B.

proper seating through wear-in.

Double-acting, grooved-race bearings, Figure 7, have two identical flat seat washers, two ball retainer assemblies, and a center washer. They carry thrust loads in either direction. One ball assembly carries load in one direction, the other assembly in the reverse direction.

**Unground ball bearings** — Commercial unground ball bearings can reduce cost of assemblies, decrease the number of parts required, and reduce labor costs by speeding assembly for original equipment manufacturers. Because tolerances are much looser than in precision bearings — commonly 0.005 in. for OD and ID — extra fasteners and locking plates are often unnecessary with unground ball bearings. A split race type simplifies assembly. A press-fitted flange radial bearing, for example, seats itself. Drilled and tapped inner races or square or hex bore inner races provide an inexpensive means of locating the bearing on the shaft. In many cases, the shaft itself serves as an inner race.

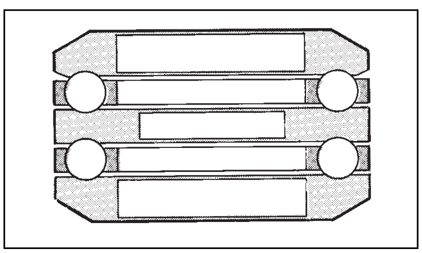


Figure 7 — Aligning, double-acting, grooved-race thrust ball bearing.

Commercial unground bearings are available as radial, thrust, or combination types. Basically, the bearing is made of a machined or stamped inner race, a full complement of hardened steel balls, and an outer race of one, two, or more machined or stamped parts. Race and casing material is usually carbon steel.

Because surfaces are unground, and because some parts are stamped, the bearing has greater radial and axial freedom than a precision bearing.

Unground ball bearings generally are suited to light loads at low speeds. The lower the speed, the greater the bearing's load capacity. Generally, the bearings are not suited to speeds above 1,200 to 1,500 rpm. At these speeds, loads may range from 50 to 500 lb, depending on bearing size and construction. On the other hand, loads of 2,500 lb may be practical with a bearing operating at 50 rpm.

Misalignment has little effect on commercial unground ball bearing assemblies because of their greater internal clearances. Excessive misalignment destroys any bearing, but far less production accuracy is required with unground bearings. As a result, the entire assembly can be much simpler in construction than a precision bearing.

The major advantage of unground ball bearings over the higher precision ball bearings discussed earlier is price. Unground ball bearings are far less expensive than the higher precision types. On the other hand, life of unground bearings is less than precision bearings. Also, unground bearings generally feature inch rather than metric external dimensions. Unground bearings also operate at higher noise than precision bearings. This may be overcome, when necessary, by using a nonmetallic material on outer cases.

**Thin-section bearings** — Thin-section bearings are used mainly where space and weight must be conserved. Cross-sectional area of these bearings remains constant within a series, regardless of bore diameter. Thin-section bearings have much lower inertia than conventional bearings of equal bore, and they require much smaller envelopes, which can significantly reduce overall drive weight.

Thin-section bearings come in ball and roller types. To choose a specific type, use the same criteria you would use to select a conventional bearing.

By nature, thin-section bearings have a much lower load capacity than equally sized conventional bearings, Figure 8. When load, life, and speed permit their use, thin-section bearings allow lighter, more compact designs than conventional extra-light series bearings, Table 2.

Thin-section bearings are designed for light to medium-duty drives operating at medium and slow speeds. Conversely, they are not well suited for heavy-duty or high-speed drives operating continuously. Speed limitations (DN) are shown in Table 3.

Because rolling elements and races are so small in thin-section bearings, they must be properly supported in the drive's assembly. Be sure that axial, radial, or moment deflection of the thin-section bearing does not prohibit its use. Also, imperfections in bore or shaft diameter will be transmitted to rolling paths, reducing life or increasing torque drag of the bearing.

Thin-section bearings may also reduce the number of required compo-

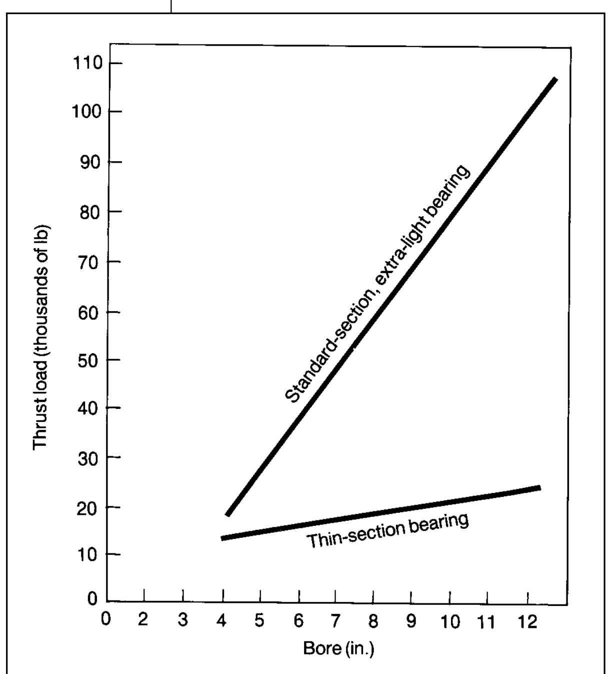



Figure 8 — Typical load capacities of thin-section and standard-section, extra-light series, angular-contact ball bearings.

**Table 2 — Weight comparisons between extra-light and thin-section bearings**

| Bore, in. | Thin section weight, lb | "Extra light" weight, lb | Weight savings, lb |
|---|---|---|---|
| 2.0 | 0.038 | 0.430 | 0.392 |
| 4.0 | 0.19 | 2.76 | 2.57 |
| 6.0 | 0.28 | 10.60 | 10.32 |
| 8.0 | 3.5 | 27.0 | 23.5 |
| 12.0 | 5.2 | 85.0 | 79.8 |
| 16.0 | 12.3 | 170.0 | 157.7 |
| 24.0 | 19.0 | 443.0 | 424.0 |
| 32.0 | 25.0 | 1000.0 | 975.0 |
| 40.0 | 31.0 | 1779.0 | 1748.0 |

**Table 3 — Limiting speeds for unsealed, thin-section bearings***

| Bore, in. | DN value † DN = Bearing bore (in.) × speed (rpm): Grease lubrication | Oil lubrication |
|---|---|---|
| Less than 10 | 20,000 | 28,000 |
| Greater than 10 but less than 20 | 16,000 | 24,000 |
| Greater than 20 but less than 30 | 12,000 | 20,000 |
| Greater than 30 | 8,000 | 16,000 |

*Angular contact ball bearing with 1/2-in. diam. balls and phenolic separator

| †For bearings loaded to the following percent of dynamic rating | Multiply DN values by the following factors |
|---|---|
| 20 | 1.0 |
| 33 | 0.9 |
| 50 | 0.8 |
| 67 | 0.7 |
| 100 | 0.5 |
| 150 | 0.2 |

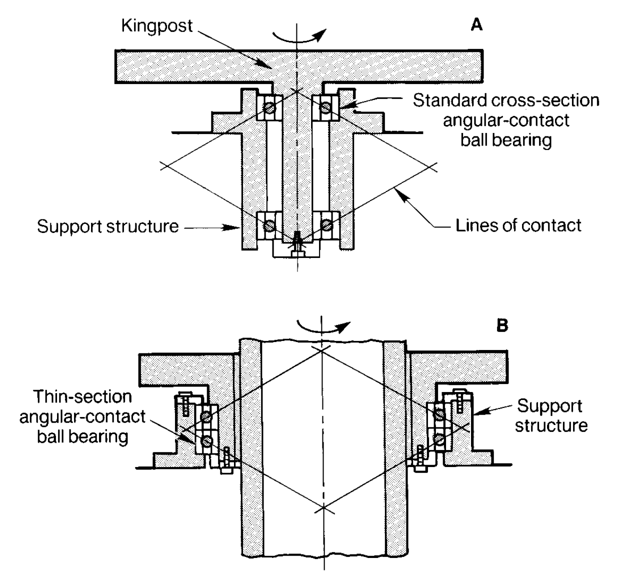



**Figure 9 — Rotating kingpost assemblies: conventional design, A, and improved design using thin-section bearings, B.**

nents in a design. For example, rotating kingpost assemblies using two standard bearings and a long shaft can be replaced with a more compact design using large diameter thin-section bearings. In the conventional kingpost design, Figure 9A, standard bearings are mounted back-to-back to maximize rigidity under moment loading. The thin-section design, Figure 9B, uses large-diameter thin-section bearings to increase rigidity of the structure. The bearings, mounted back-to-back, support a hollow shaft that is more rigid than the small diameter shaft. As an added benefit, wiring and hoses can be routed through the hollow shaft, protecting them from damage.

## Roller bearings

Because roller bearings have greater rolling surface area in contact with inner and outer races, they generally support greater loads than comparably sized ball bearings. Rolling-element geometries include cylindrical rollers, of rectangular cross section; spherical rollers, which are barrel or hourglass-shaped; and tapered rollers, of trapezoidal cross section.

Cylindrical roller bearings are designed primarily to carry heavy radial loads. Spherical roller bearings carry primarily radial loads but, in addition, accept some thrust loading and accommodate wide variation of shaft-to-housing misalignment. Tapered roller bearings carry radial and thrust loads.

**Cylindrical roller bearings** — Cylindrical roller bearings have the highest radial capacity for a given cross section, and the highest speed capability of any type of roller bearing.

A nonlocating bearing, Figure 10, allows axial movement of the inner or outer ring to accommodate thermal axial expansion of the shaft and tolerance buildup in an assembly. Cylindrical roller bearings with ridges on the inner and outer rings, Figure 11, accommodate some thrust. The amount depends primarily on the rate of heat generation and the rate of heat dissipation by conduction and oil circulation.

Limiting speed of a cylindrical roller bearing depends on the roller length-to-diameter ratio, precision grade, roller guidance, cage type and material, type of lubrication, shaft and housing accuracy, and heat dissipation properties of the overall mounting. For general use, roller length equal to roller diameter provides the best balance of load and speed capacities. The limiting speed of a "square" roller bearing is considered equal to that of a comparable series ball bearing. The limiting speed for outer ring rotation is about 2/3 the limiting speed for inner ring rotation. Because limiting speed depends on many variables, consult the bearing manufacturer's catalog for specific values.

The bearings must position a rigid shaft in a rigid housing so that the shaft rotates freely with minimum radial and axial movement. To do this, the bearings must support the shaft at only two points — usually at each end of the shaft. One bearing should locate the shaft axially, while the bearing at the other end of the shaft allows axial expansion or contraction.

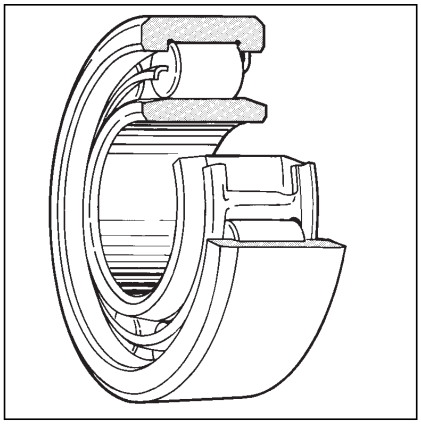


**Figure 10 — Nonlocating cylindrical roller bearing accommodates axial flotation by not restraining rollers axially on the inner ring. Similar bearings allow axial roller freedom on the outer ring.**

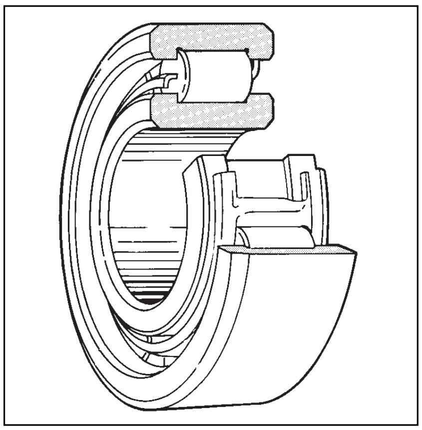


**Figure 11 — Cylindrical roller bearing with axially fixed inner and outer rings. This bearing allows no axial displacement of the shaft and is usually used in conjunction with an axially free bearing such as the one in Figure 10.**

Although roller bearings support greater loads than ball bearings, roller bearings are more sensitive to misalignment. Angular misalignment between the shaft and housing causes nonuniform loading of rollers, resulting in reduced bearing life. Poor alignment of the bearing on the shaft is another cause for misaligned inner and outer rings. Such misalignment occurs even with unloaded bearings. The external load may deflect the shaft or housing, which is another source of bearing misalignment.

**Needle roller bearings** — Similar in appearance to cylindrical roller bearings, needle roller bearings have a much smaller diameter-to-length ratio. By controlling circumferential clearance between rollers, or needles, rolling elements are kept parallel to the shaft axis.

A needle roller bearing's capacity is higher than most single-row ball or roller bearings of comparable OD. The bearing permits use of a larger, stiffer shaft for a given OD, and provides a low-friction rolling bearing in about the same space as a plain bearing.

The basic needle roller bearing is the full-complement, drawn-cup bearing, Figure 12. The outer race is a thin, drawn cup that has been surface hardened. Roller ends are shaped so that lips on the outer race keep them from falling out. Because the outer race is thin, it must be installed in a correctly sized and properly backed-up housing to transmit load effectively. In most instances, a hardened shaft acts as the bearing's inner race, although an inner race can be supplied when the shaft cannot be hardened.

The grease-retained, drawn-cup needle roller bearing, Figure 13, is not used as extensively as the basic, mechanically retained version because rollers may fall out if the shaft is removed. Also, the heavy grease that retains rollers is incompatible with some applications. The advantages of this type of bearing over the basic bearing is higher load-carrying capacity because rollers have spherical ends.

A caged needle roller bearing, Figure 14, is designed for heavier-duty, higher-speed applications. The heaviest-duty needle roller bearing, Figure 14, has a machined cage. Both machined-outer-race and drawn-cup caged bearings have sufficient voids to allow pregreasing the bearing for lifetime lubricated applications. Even with these bearings, operating life can be extended if provision is made for periodic relubrication.

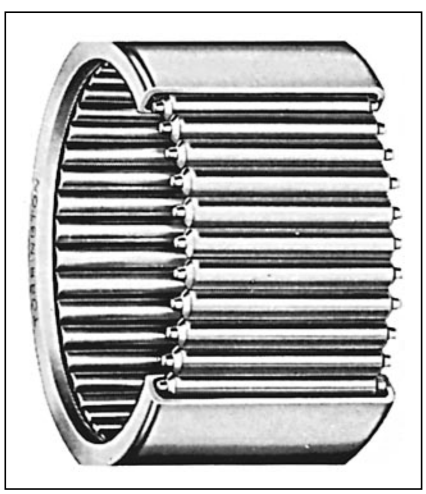


**Figure 12 — Drawn-cup needle roller bearing. Rollers are retained by lips at the ends of the outer casing and projections of the rollers.**

When selecting needle roller bearings, consider these guidelines:

- The most compact and economical arrangement uses the equipment shaft as the bearing's inner race. In this situation, manufacturer's requirements for shaft hardness and surface finish must be followed. Typical values for hardness range from Rockwell 58C to 60C; surface finish, 16 μin. or better. Keep shaft parallelism within 0.0003 in. for the full length of the bearing, or within half the shaft tolerance, whichever is less.

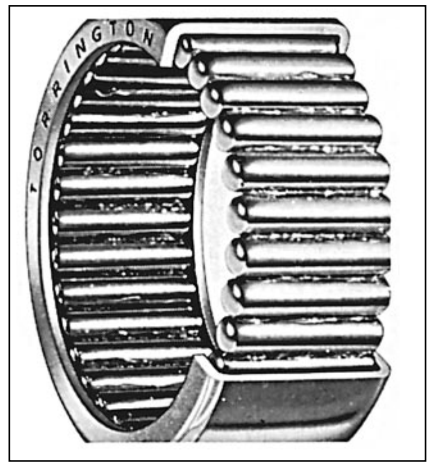


**Figure 13 — Because roller ends are spherically shaped, grease-retained drawn-cup needle roller bearing has slightly higher load rating than a mechanically retained bearing.**

- Do not exceed 0.0002 in. total indicator reading (TIR) for shaft out-of-roundness or 1/2 the shaft tolerance when measured by both two-point gaging and use of a 90-deg V-block in conjunction with a dial indicator.

**Cam followers** — A cam follower is a special, heavy-duty needle roller bearing with a heavy outer race section. There are two basic types: one with an integral stud for cantilever mounting; the other, an integral inner race for yoke mounting. Both types, Figure 15, may have a crowned OD, which compensates for a reasonable amount of bearing misalignment with the track or cam to prevent corner loading of the outer race. This helps maintain more uniform stress distribution over the track or cam surface, and increases assembly life. Crowning also minimizes skidding of the cam follower on flat circular tracks or cams.

To select a cam follower, evaluate

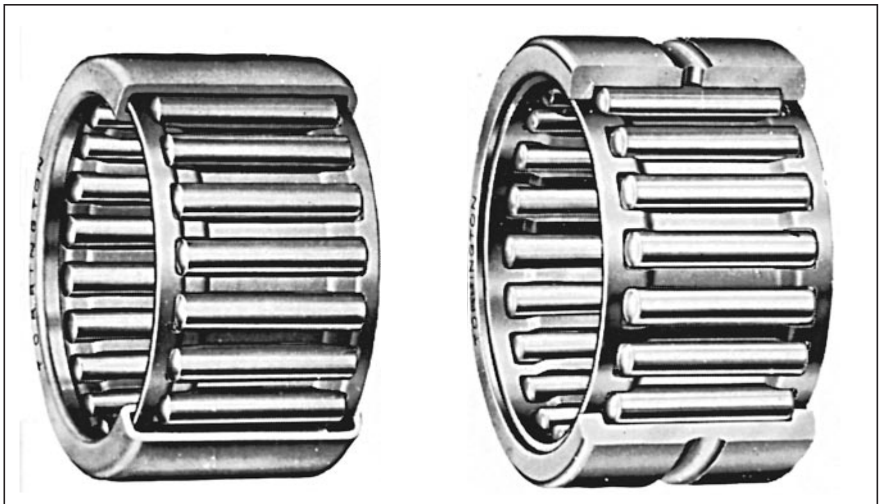


Figure 14 — Drawn-cup, caged needle roller bearing, left, and heavy-duty needle roller bearing with machined, hardened and ground inner race, right.

load, speed, alignment, track or cam design, and available lubrication. If operating speed is less than the maximum allowable speed, choose a bearing size from the given load and speed for a specific life requirement. For shock loads, consider a heavy stud cam follower or cam yoke roller.

To prevent galling between the follower OD and the track member, lubricate the track with grease of high enough consistency to adhere to the track during operation. For continuous rotation, provide continuous oil lubrication or frequent grease relubrication. Automatic lubrication devices are strongly recommended for intermittent lubrication.

**Spherical roller bearings** — The term spherical roller bearing generally refers to a single or double-row, internally self-aligning roller bearing. Self alignment is obtained by making one of the raceways a portion of a spherical surface, Figure 16. These bearings support high radial or combined radial-axial loads. The double-row type generally is not used for pure thrust load, but the single-row type can be used to support predominantly thrust load.

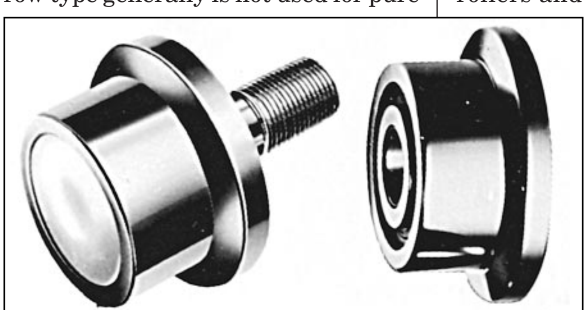


Figure 15 — Stud -type cam follower, left, and yoke-mounted type, right.

Probably the greatest advantage of spherical roller bearings is the ability to accommodate misalignment with no decrease in rating or life. They usually accept 1 or 2-deg misalignment.

As a rule, spherical roller bearings lubricated with grease are limited to a speed that produces a DN value no greater than 100,000. Oil-lubricated bearings generally operate up to 200,000 DN. Spherical roller bearings have operated successfully at 1 million DN. If speeds greater than these are expected, consult the bearing manufacturer.

**Tapered roller bearings** — Applications in a wide variety from appliances and aircraft wheels to machine tools, automotive transaxles, and industrial equipment of all types are served by tapered roller bearings.

In a tapered roller bearing, the rollers and races are built on a cone principle, Figure 17. Specifically, the apexes of the rollers and races meet at a common point on the bearing axis.

- Load-carrying capability: Because of this geometry, tapered roller bearings are the only type of bearing that can carry heavy radial loads, or thrust loads, or any combination of the two.

When a tapered roller bearing is loaded, the external load is transformed into three load components: a radial component perpendicular to the bearing axis; a thrust component parallel to the axis; and a smaller roller-seating force. This seating force keeps the large end of each roller in contact with a rib on the large end of the cone, providing positive roller guidance that keeps rollers aligned.

Because the tapers of the rollers, cup, and cone meet at a common apex on the bearing centerline, the rollers rotate with true rolling motion with no skidding of rollers over a raceway. Thus, tapered roller bearings perform well during the life of an application.

In addition, the race and roller angles can be matched to the loading situation — shallow angles for predominantly radial loads and steeper angles for greater thrust capacity.

- Speed capability: Tapered roller bearings can handle applications from low-speed railway axles to high-speed turbine shafts. For very high-speed applications, it may be necessary to make special lubrication and design provisions.

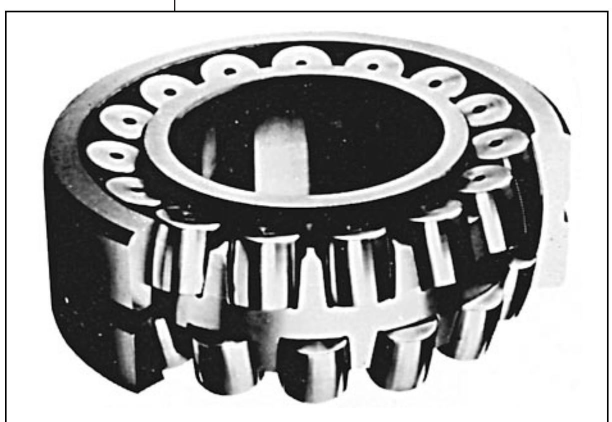


Figure 16 — Double-row, spherical roller bearing.

- Misalignment: Tapered roller bearings can be highly tolerant to misalignment and deflection for two basic reasons:

1. There is the ability to adjust internal clearance within a tapered roller bearing during installation.
2. Mounting arrangement can significantly increase stiffness of an assembly.

- Preload and end play control: A special characteristic of tapered roller bearings is that their internal clearance — or setting — is adjustable. It can be optimized for a given applica-

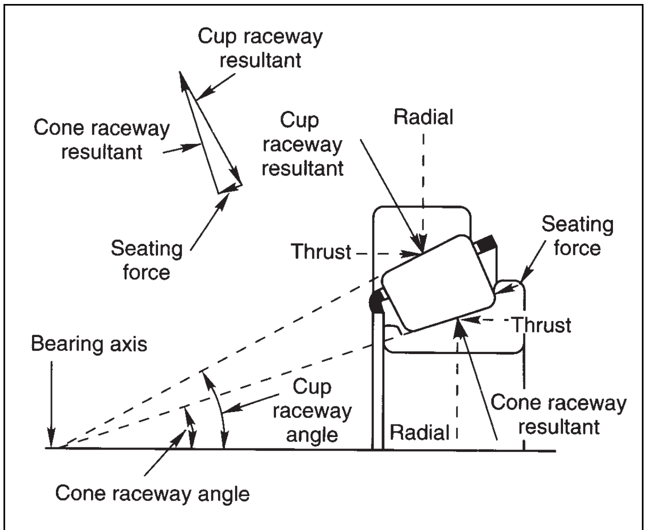



**Figure 17 — Cone-principle geometry of a tapered roller bearing results in its ability to accommodate any type of loading, operate with true rolling motion (no skidding), and provide positive alignment.**

tion without remachining shafts or housings, to provide the best performance and life in any given application.

Tapered roller bearings can be manually set, supplied as a preset assembly, or set by using one of several automated setting techniques. These methods are described later under Installation Methods.

- Precision: Tapered roller bearings in the "precision" class are produced with maximum radial runout (out-of-roundness) of 75 millionths of an inch. "Super-precision" bearings for the highest-accuracy applications such as machine-tool spindles, have maximum radial runout of just 40 millionths of an inch: $^1/_{60}$th diameter of a human hair.
- Profile control: The contact geometry between the large roller end and the cone rib is closely controlled to enhance lubrication. Special attention is paid to the roller body and cup and cone raceway profiles to ensure full-line contact for maximum load capacity.

For very high loads or misalignment, or both, the contact profiles can be modified to minimize stress concentrations and maximize performance.

- Materials: Cups, cones, and rollers of most tapered roller bearings are case carburized. The case carburization process produces hard, long-lasting contact surfaces that can carry heavy loads without distress and the tough, ductile core can endure heavy shock loads.
- Types: Tapered roller bearings come in a wide variety of types. The basic single-row bearing is available in many angles and roller lengths to provide a wide range of radial and thrust ratings. For more capacity, two-row bearings are used. For exceptionally rigorous service such as rolling mills, four-row bearings are used. Also available are a variety of thrust bearings, and packaged bearings with seals, lubrication, and preset adjustment.

## MOUNTED BEARINGS

Mounted bearing units are available with most types of plain and rolling-element bearings. They are convenient and economical, and reduce the time spent selecting and preparing bearing elements, housings, seals, and mounting methods. Mounted bearing units are available off-the-shelf and the only basic selection information generally necessary is shaft size, radial and thrust load, load characteristics, speed, mounting limitations, and environment.

**Mounted plain bearings** — Several types of mounting are available for plain bearings. A journal bearing mounting, Figure 18, may simply be a bored housing with bearing liner, or a split housing with solid or split internal bearing.

The outer surface of the bearing may have a spherical shape to accommodate a wide range of angular misalignment, Figure 19. These are known as spherical and rod-end bearings. They are commonly used in linkages and low-speed applications.

Hydrodynamic sleeve bearing pillow blocks, Figure 20, operate at low speeds in much the same way as grease-lubricated plain bearings. When speed becomes high enough, however, a full lubricant film is established, eliminating metal-to-metal contact.

Hydrostatic bearings have externally pressurized oil that separates shaft and bearing surfaces. Benefits include no metal-to-metal contact, high load capacity at all speeds, and very low coefficient of friction. The only limit to load and speed is the

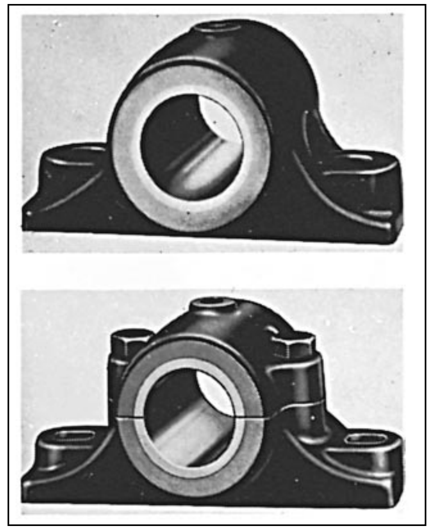


**Figure 18 — Solid and split-type pillow block plain (journal) bearings.**

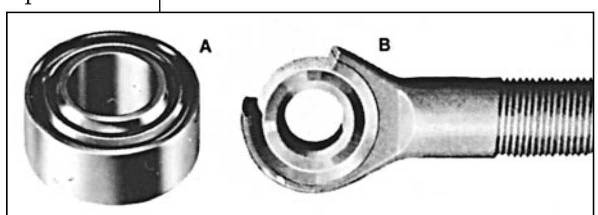



**Figure 19 — Spherical, A, and rod-end, B, plain bearings.**

ability of the external pump to supply pressure for overcoming load and to supply a flow rate sufficient to carry away generated heat. Because an external pump, motor, and other support devices are required, these bearings are impractical in many applications.

Besides providing a pre-engineered support housing for the bearing, mounted bearing units also provide a reservoir for lubricant storage. This reservoir extends relubrication intervals, or may serve as a lubricant supply for the life of the bearing. Mounted plain bearings are available in plain-bored, cast iron, solid pillow blocks; babbitt-lined, solid and split pillow blocks; flange bearings and

Figure 20 — Hydrodynamic pillow block bearing and internal components.

take ups; bronze-bushed split pillow blocks and take ups; solid-film and self-lubricating bushed pillow blocks; and hydrodynamic and hydrostatic pillow blocks.

Plain-bored iron units, babbitt and bronze-lined, are the simplest. Rigid units require accurate alignment, but babbitt and bronze-lined units wear in and ultimately distribute load over the bearing area. Most babbitt units conform to the shaft, have good embedability, and do not seriously score or damage the shaft under boundary lubrication. Bronze-lined units are recommended for heavier loads, higher temperatures, and shock loads. Most of these units are grease-lubricated. A lubricant film approaching that of hydrodynamic, full-film lubrication separates shaft from sleeve. Automatic lubrication increases life of mounted plain bearings. See the PT Accessories Product Department for lubrication methods and components.

**Mounted rolling-element bearings** — Most ball bearings used with housing units incorporate a wide inner ring with an integral locking collar device. There are two common types: the setscrew collar and the eccentric or cam locking collar, Figure 21. Either type accommodates a slip fit over commercially ground shafting.

The setscrew locking device has two setscrews threaded into drilled and tapped holes in an extension of the bearing's inner ring. An alternate design has a concentric collar that slips over the ring extension. The setscrews are then threaded into the collar, and contact the shaft through untapped holes in the collar extension.

In either case, when the screws are tightened, theoretically a three-point contact is established. These points are the actual two contact points of the setscrews and the one point on the opposite side of the shaft OD.

The eccentric locking collar uses an extended inner ring of the bearing that contains a channel eccentric to the shaft, and a matching channel in a collar that fits over the inner ring extension. The unit is secured to the shaft by rotating the collar relative to the inner ring. When this is done, the force introduced to the rotation is transmitted as holding force perpendicular to the shaft. A setscrew is supplied to prevent loosening of the collar during reverse rotation. This is a precautionary practice, and does not compensate for frequent reverse rotation. Manufacturers agree that eccentric locking collars should not be used for bidirectional applications.

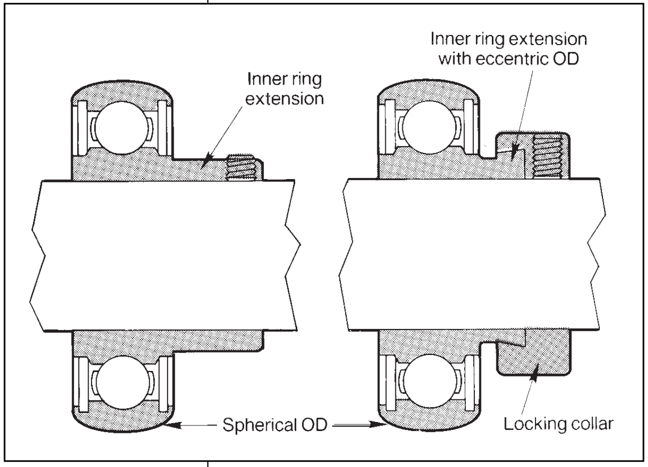



Figure 21 — The setscrew locking collar, left, and the eccentric collar, right, are the most common methods used to secure a mounted ball bearing to a shaft.

Most mounted ball bearing units have spherical ODs. This compensates for angular shaft misalignment. The bearing may also have a cylindrical OD with a slip-fit in the mounting to allow axial freedom.

Cylindrical, spherical, and tapered roller bearings also are readily available as mounted units. Roller bearings are often used for heavier-duty applications than ball bearings, and therefore may require more rigid locking to the shaft.

**Selection** — The first step in selecting a mounted bearing is determining shaft size, which considers bending and torsional load. However, overhung loads or loads between large centers may require large shaft diameters, while bearing loads are light. If so, consider light-duty bearings or machining shaft ends for smaller bearings. However, shafting is not always chosen on an optimum engineering basis. Design standardization, available stock sizes, and similar factors may dictate size.

Choice of the type of bearing is the next step. The prime consideration is to match bearing design capability to load operating characteristics and maintenance needs. Operating characteristics and allowable friction should lead to the fundamental choice between plain and rolling-element groups — with additional consideration to economy. Within the rolling-element group, selection often involves evaluating types available vs. requirements, then choice of the design that suits a multipurpose application.

The method of securing the bearing to the shaft is determined by considering performance vs. cost. Ease of installation is important to the builder and the maintainer. Maintenance of other portions of a machine may require bearing disassembly. Thus, bearings and bearing assemblies that can be easily installed and disassembled should be used when frequent disassembly is expected.

Choose the housing or mounting unit with regard to its support structure and surroundings as well as to its own strength requirements. Also, consider installation factors such as clearance and structural members required for mounting, because the housing is the interface between structure and power transmission system. In general, housings transfer load to the structure by surface support and contact. Mounting bolts simply locate and secure. When housings are applied so mounting bolts supply support, carefully consider bolt size, bolt hole fit, mounting procedure, or any other factor that may affect capacity.

Also consider housing material strength and configuration. A gray iron pillow block with a thick cross section and reinforcing web may be stronger than a thinner, steel housing, though the tensile strength of steel is greater.

## INSTALLATION METHODS

There are numerous ways to install a rolling-element bearing on a shaft. The following describes common methods used to install ball bearings and most roller bearings. Then the methods for installing tapered roller bearings are described last.

### Rolling element bearings other than tapered

When bearings are required in manufactured products, an installer on the production line is often responsible for final assembly of the bearing, and for greasing and sealing it. With some bearings (angular contact), this task includes adjusting the bearing carefully so that its internal clearances — radial and axial distances between inner and outer rings — meet the application requirements.

In many plants, subsequent product testing consists of an experienced worker listening closely to the product as it operates to determine if bearings and other components were installed properly.

With the number of tasks involved in this process, even an experienced worker can make a mistake that later surfaces in the form of poor bearing performance. Also, the sound test is often not sophisticated enough to detect signs of a bearing problem.

Today, unitized bearings, improved installation tools, and monitoring devices offer manufacturers more reliable alternatives to traditional installation methods. These new methods take less time, reduce errors, and improve the performance of the end products.

Large manufacturers of high-volume equipment are most likely to use the new concepts. But smaller OEMs can also benefit.

**Unitized bearings.** The use of self-contained unitized bearings is increasing. This is especially so in the automotive industry, where unitized wheel bearing assemblies, called hub units, have become virtually standard in domestic cars.

A hub unit incorporates all bearing components, and it is preset, greased, and sealed for life, Figure 22. Hub units greatly simplify the mounting process. The worker simply bolts the unit in place, reducing the risk of installation errors. Some hub units incorporate a wheel speed sensor, an important part of the anti-lock braking system.

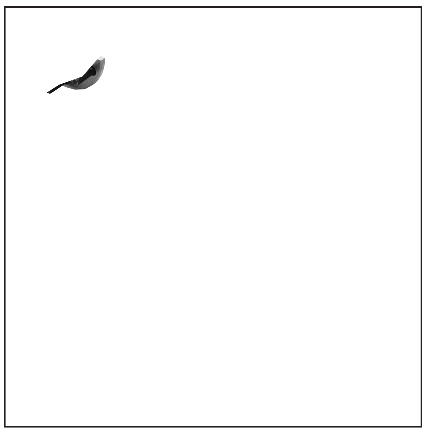


**Figure 22 — Hub unit for an automobile contains all bearing components in a unitized wheel bearing assembly. The flanged outer ring bolts to the car suspension.**

Companies in various industries, wanting to prevent machinery breakdowns, use sensor bearings to obtain feedback on machine functions, such as speed, load, force, and temperature.

In many cases, these sensors also provide information on the bearing's internal clearance — a critical parameter in bearing installation. In most applications, a bearing has a slight internal clearance after mounting. But in certain situations, a bearing is installed preloaded (no clearance). Preloading compensates for deflections and heat-related changes that occur in a bearing during operation, enhancing its stiffness and improving its running accuracy. Bearings that are commonly preloaded include spindle bearings in machine tools, pinion bearings in automotive axle drives, and printing press bearings.

**Installation tools.** Installers use four basic methods to mount bearings on shafts. First is mechanical mounting. The other three methods rely on newer techniques to increase reliability and ease mounting of large bearings: temperature mounting, which uses heat to expand the bearing and make it easier to mount; hydraulic mounting, which uses hydraulic pressure to impart mounting force; and an oil injection method, which introduces an oil film between the shaft and inner ring to reduce frictional resistance.

*Mechanical mounting* is generally suitable for bearings with small bore diameters — 80 mm or less. Small, straight-bore bearings are mounted with a hammer and an impact sleeve. Bearings with a tapered bore are mounted with a lock nut and spanner wrench. Table 4 shows the most common methods of securing a rolling-element bearing to a shaft, typically by mechanical means.

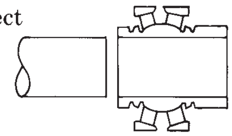
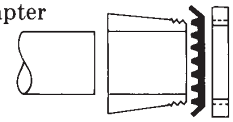
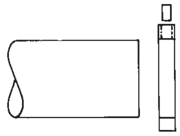
Many OEMs prefer a hammer for mounting bearings. But a poorly aimed hammer blow can cause brinelling damage — small dents in bearing balls or raceways that cause noise and eventual failure. Moreover, it is difficult to mechanically mount bearings with bore sizes over 80 mm. Consequently, OEMs are switching to installation tools, such as induction heaters and the hydraulic nut. These tools facilitate the mounting of medium and large bearings (80 to 200 mm or more) and reduce the potential for costly errors.

*Temperature mounting* uses heat to expand the bearing inner ring so it can be easily positioned on a shaft. It is best suited for straight bore arrangements.

One temperature mounting device is the induction heater. Some heaters have gages that monitor the heat cycle to prevent damaging a bearing by overheating. Other methods include hot plates, oil baths, and ovens.

*Hydraulic mounting* uses a hy-

**Table 4 — Common shaft mounting methods and their characteristics for rolling-element bearings**

| | Engineering considerations | | | Shaft conditions | | Installation and maintenance |
|---|---|---|---|---|---|---|
| **Mounting method** | **Contact area** | **Runout** | **Special machining** | **Tolerance required** | **Special equip. required** | **Ease of removal** |
| Direct  | Complete | Very good | Yes. Threads, key seat, multiple diameters, etc. | Tight. Comparable to bearing bore tolerances | Yes. Equipment varies widely. | Difficult. Requires extensive time and equipment |
| Adapter  | Almost complete | Good | No. Normal commercial shafting | Normal. Commercial shafting range | Some, feeler gage, spanner wrench, etc. | Not difficult if no fretting has occurred |
| Locking collar  | Limited areas | Fair | No. Normal commercial shafting | Normal. Commercial shafting range | None. Usually only an Allen wrench | Simple if no fretting has occurred |

draulic nut, which consists of a steel ring and an annular piston. Oil pumped into the nut pushes the piston out to mount the bearing. Pressure and travel gages help the worker in applying the right amount of force.

*Oil injection* is well-suited for installing large bearings (bore diameters over 200 mm). It delivers pressurized oil via connecting ducts in the shaft to shallow grooves on the shaft surface. The thin layer of oil reduces the fitting pressure and simplifies mounting.

**Condition monitoring.** Production line innovations aren't limited to improved installation tools. Condition monitoring devices are also gaining acceptance as a way to ensure proper bearing installation. By detecting vibration frequencies produced by machine components, these devices ensure that a product meets quality standards, and pinpoint defects that would be otherwise imperceptible.

*Excerpted from an article by SKF USA Inc. in the October 1995 issue of PTD.*

## Tapered roller bearings

To meet operating conditions and optimize bearing performance, tapered roller bearings can be set to any desired axial or radial clearance. These bearings can be set either manually, or by one of several automated methods as described later. You can also get them as preset assemblies.

Unlike other rolling-element bearings, tapered bearings don't require close control of shaft or housing fits to obtain an accurate setting. Because they are mounted in pairs, Figure 23, their setting depends mostly on the location of one bearing row relative to the other on the shaft.

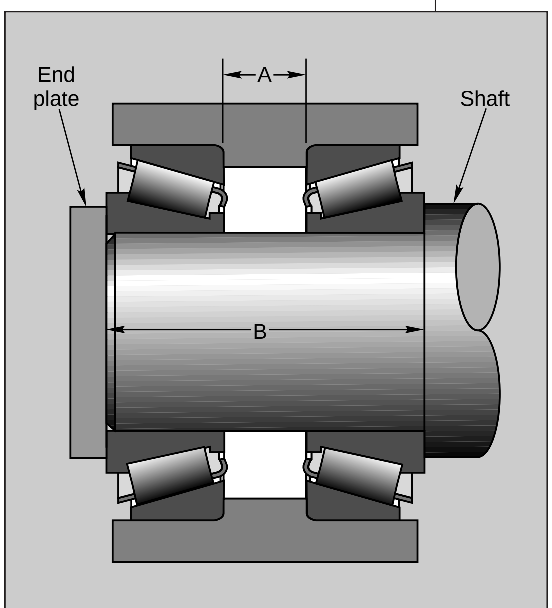



**Figure 23 — Tapered roller bearings are mounted in pairs. Bearing settings are affected by tolerances on mounting dimensions (A and B) as well as bearing tolerances.**

Tapered roller bearings are set to achieve one of two conditions:

- End play — Axial clearance between bearing rollers and races.
- Preload — Axial interference between rollers and races.

Generally, a setting ranging from near zero to slight preload maximizes bearing life. Some applications use moderate preload to increase rigidity of parts so they resist adverse affects of excessive deflection and misalignment. Excessive preload, though, can drastically reduce bearing fatigue life or cause high temperatures that lead to bearing damage.

**Manual setting.** Production-line workers often set bearings manually for equipment that is manufactured in low-to-moderate volume, and where a wider than normal range of end play (0.004-0.010 in.) is acceptable. No special tools or fixtures are typically required. In a truck wheel, for example, an assembler tightens an adjusting nut on the end of the shaft while rotating the wheel until a slight bind is felt. Then the assembler backs off the nut enough to let the wheel rotate freely and locks the adjusting nut in position.

For large, complex machines, or high-production applications, manual setting may be too troublesome, time-consuming, or inappropriate. In such cases, preset bearing assemblies and automated setting techniques offer better alternatives.

**Preset bearing assemblies.** Many machines require closely positioned bearing arrangements. In such cases, manufacturers often use preset bear-

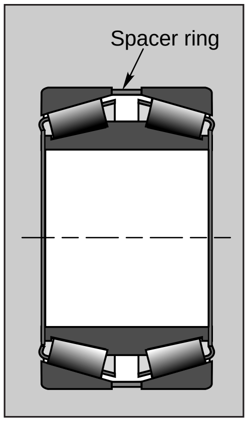



**Figure 24 — Preset bearing assembly with spacer ring between bearing rows.**

ings, which typically use spacer rings between bearing rows to control internal clearances, Figure 24.

The mounted bearing setting depends on this internal clearance plus the shaft and housing fits. Typically, assemblers tight-fit either the shaft or housing on the rotating bearing member, producing a mounted setting range of less than 0.008 in. To apply a preset assembly to a machine, simply mount and ensure clamping of the bearing components through the spacers.

Preset bearings are typically applied in transmission idler gears, sheaves, conveyer idlers, and large gearboxes, plus fan hub, water pump, and idler pulley shafts.

**Automated setting techniques.** Bearing manufacturers offer various automated bearing setting methods that give reduced set-up time and assembly cost, plus consistent and reliable settings. In many cases, they can be used in both production and field service environments. The best method for a particular application depends on the required setting range, load conditions, type and size of equipment in which the bearing is located, and the production volume.

These automated methods offer setting ranges from 0.008-0.014 in. down to as little as 0.002-0.004 in. They are used for lightly loaded conveyors, pumps, and air compressors, plus heavily loaded transmissions and axle assemblies.

*Excerpted from an article by The Timken Co. in the June 1995 issue of PTD.*

## PREDICTING LIFE

Over the years, engineers estimated the life of ball and roller bearings with the aid of ANSI/AFBMA standards for ball bearings (1950) and roller bearings (1953), which were updated in 1978 and 1990, plus ASME bearing life factors (1971).

Recently, the Society of Tribologist and Lubrication Engineers (STLE) developed new life factors that reflect improvements in steel manufacturing and lubrication over the last 50 years. These improvements increased bearing life substantially. The new life factors, which make it possible to predict bearing life much more accurately, are described in the book *STLE Life Factors for Rolling Bearings,* 1992 (STLE, 840 Busse Highway, Park Ridge, Ill., 60068-2376).

### Better steel and lubrication

Advances in steel manufacturing that contributed to improved bearing life have occurred in the areas of heat treatment, melting, testing, finishing, and metalworking. Lubrication advances include using lubricants with enhanced EHD oil film thickness between bearing components, and improved bearing finishes.

By the 1960s, NASA combined many of these advances to boost bearing life by 13 times the amount predicted by the 1950 standards. In 1973, the use of vacuum-induction-melted, vacuum-arc-remelted (VIM-VAR) AISI M-50 steel and improved oil filtration increased the life of angular-contact ball bearings by 100 times.

Lastly, in 1983, the General Electric Co. developed AISI M-50NiL steel, which exhibits more than twice the life of through-hardened VIM-VAR AISI M-50 steel.

### Updated life factors

Figure 25 shows how bearing life increased over 50 years and how that increase was reflected in the industry standards and life factors. The early ANSI/AFBMA standards (1950s) had no life adjustment factors.

In 1971, ASME introduced life adjustment factors of about 15 for both ball and roller bearings, reflecting improvements since 1940.

In 1978, the AFBMA introduced separate life factors for reliability, manufacturing, and operation. The 1990 ANSI/AFBMA standards incorporated life factors of 2.2 and 1.0 for ball and roller bearings respectively. These factors are more conservative than the ASME factors, but are to be used with other factors obtained from bearing manufacturers.

The 1992 STLE life adjustment factors reflect a life increase of over 60 times, compared to 1950 standards.

Using the original ANSI/AFBMA standards gives very conservative life estimates for ball bearings, Figure 26. Here, the life can be underpredicted by a factor of 100. By contrast, the new STLE factors give much more accurate, though still conservative, results for today's bearings. This method generally underpredicts bearing life by a factor of 2 or 3.

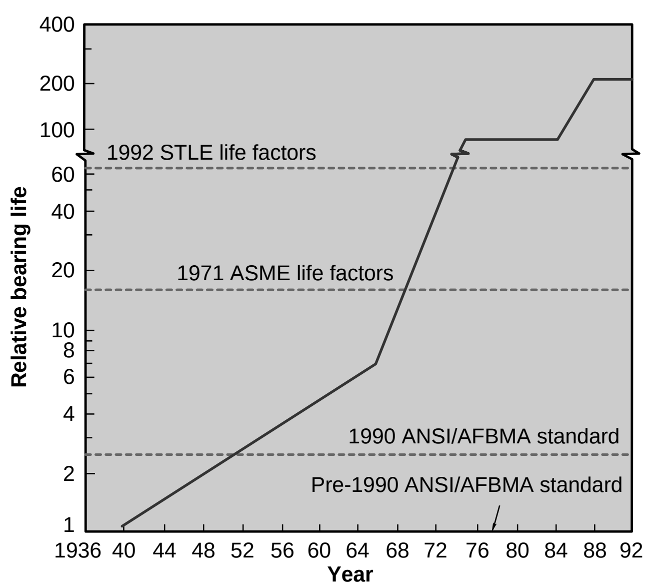



**Figure 25 — Rolling-element bearing life improvement over five decades.**

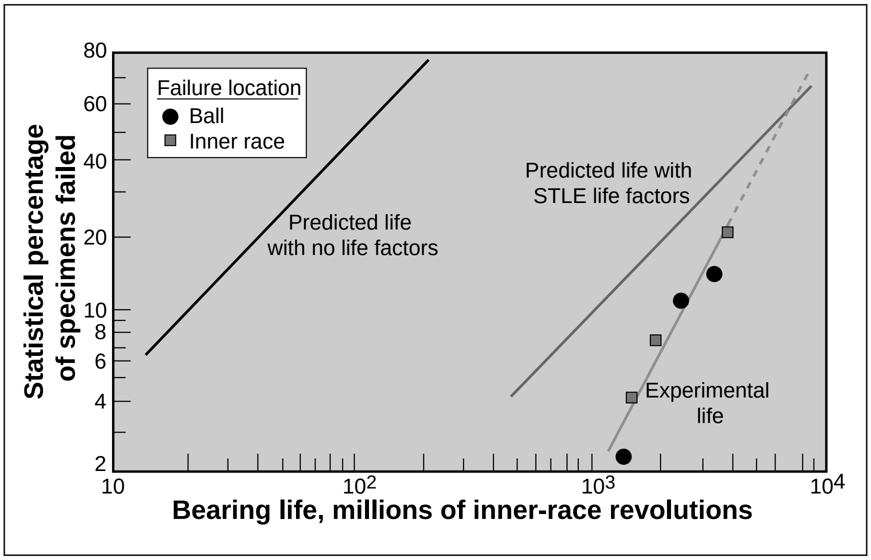



**Figure 26 — Predicted and experimental life of 120-mm bore, angular-contact ball bearings made from VIM-VAR AISI M-50 steel.**

## General calculation method

The ANSI/AFBMA standards combine three life factors in calculating bearing life:

$$L_{na} = a_1 a_2 a_3 L_{10} \qquad (1)$$

where:
$L_{na}$ = Adjusted life, hr
$a_1$ = Adjustment factor for reliability
$a_2$ = Adjustment factor for materials and processing
$a_3$ = Adjustment factor for operating conditions
$L_{10}$ = Basic rating life, hr

The STLE calculation method uses the same formula, but with more detailed life factors, as described in the STLE book. Here are the basic steps:

● First list the bearing design parameters (type, size, dimensions, materials, melting process, and hardness), and operating conditions (load, speed, temperature, $L_{10}$ life, and type of lubricant).

● Determine life factors $a_1$, $a_2$, and $a_3$ for these parameters. The first factor, $a_1$, depends only on the probability of survival that you select: at a 90% probability, $a_1$ is 1.

Determining $a_2$ and $a_3$ is more involved. For $a_2$, you obtain life factors for manufacturing variables from the STLE book, then combine them into one value. Life factor $a_3$, which applies to operating conditions, is determined in a similar manner.

● Finally, enter the three life factors, along with the $L_{10}$ value into equation (1) to obtain the predicted bearing life.

*Excerpted from an article by Erwin V. Zaretsky, NASA Lewis Research Center, in the March 1996 issue of PTD.*

## ANALYZING FAILURES

The most important tool in diagnosing why a bearing failed is a logical and comprehensive approach. The list of questions at the end of this section will give you a good start in determining why your bearings failed.

## Finding the real cause

Often, the real cause of failure is masked by a less-than-thorough analysis. In one example, a large industrial plant was experiencing short motor life ( 5 yr) due to bearing failures. The suppliers analyzed a dozen failed bearings and concluded that every failure was caused by "inadequate lubrication."

But, a closer investigation indicated that the bearings couldn't all fail for the same reason and should have lasted much longer.

Engineers then conducted a thorough analysis of hundreds of failed bearings, and they found a host of problems:

● Manufacturing defects such as missing and incorrect-size balls.

● Installation errors such as thrust bearings installed backwards.

● Operational errors such as washing bearings down with hot condensate.

The most serious problem was poor shaft and housing fits, which increased vibration and thereby raised bearing loads. The higher load caused more rapid bearing fatigue — doubling the load on a ball bearing cuts fatigue life by a factor of eight.

Also, abnormal clearances reduced heat transfer out of the bearings so they ran hotter than usual. The heat caused the lubricant to degrade faster than normal. Most bearing and lubricant manufacturers say that, based on 155 F, every 25 F increase in lubricant temperature cuts lubricant life in half.

## Questions to ask

Here is a list of questions to ask when analyzing a ball or roller bearing failure. After you get the answers, ask yourself "Why did it happen that way?" and "What can we do to keep it from happening again?"

**Background data.**

1. When was the bearing installed? By whom?
2. Was the original design changed?
3. How long did the previous bearing last? Why was it replaced?
4. What is the typical bearing life in similar machines at the same location?
5. What does the machine manufacturer say bearing life should be?
6. In the months before failure, were there any changes in vibration, temperature, equipment, speed, load, lubrication, or personnel?

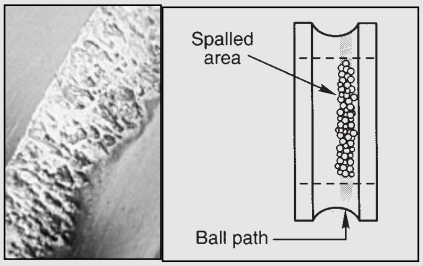
**Lubrication.**

1. Was their adequate lubricant in the bearing?
2. Does it look discolored, contaminated, or oxidized? Does it smell burned?
3. Is there water, free or emulsified, in the lubricant?
4. Are there traces of burned lubricant — a black, sooty deposit — on bearing-housing walls? (May indicate that lubricant was added after failure.)
5. Have a laboratory analyze a sample for viscosity and contamination.

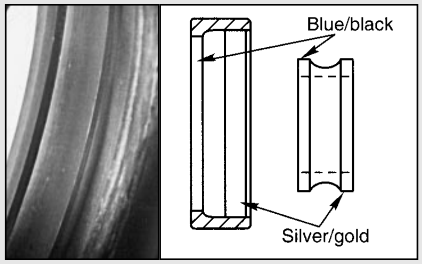
**Rotating race appearance.**

1. Is the appearance of the rotating race ball path (RBP) consistent around the race?
2. Is width normal? Does it fluctuate?

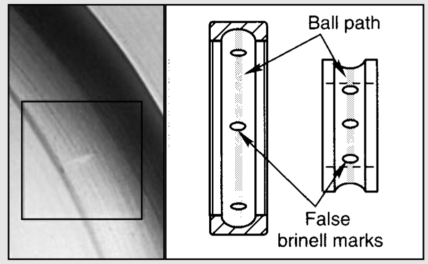
# Twelve major causes of bearing failure



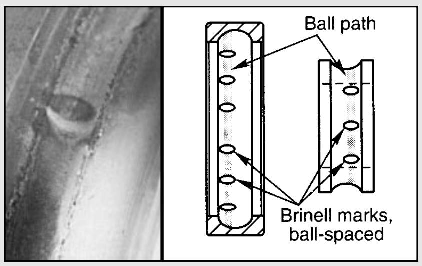

Excessive load causes premature fatigue. Tight fits, brinelling, and improper preload can also cause early fatigue failure. Looks like normal fatigue, but heavy ball wear paths, evidence of overheat, and more widespread spalling are usually evident.



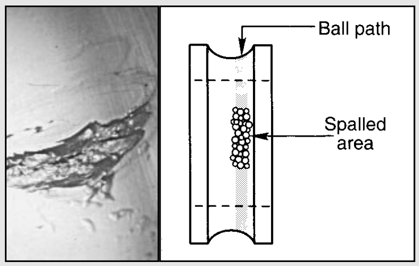

Overheating symptoms are discoloration of rings, balls, and cage from gold to blue. Temperatures over 400 F can reduce ring and ball hardness, and thus, capacity. Can also degrade or ruin lubricant.



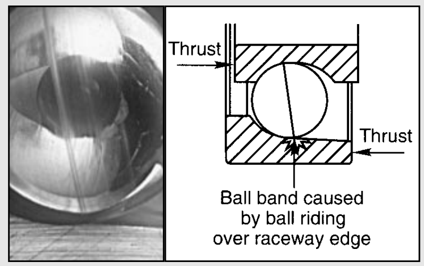

False brinelling — elliptical wear marks at each ball position with bright finish and sharp demarcation, often surrounded by a ring of brown debris — indicates excessive external vibration when bearing isn't turning.



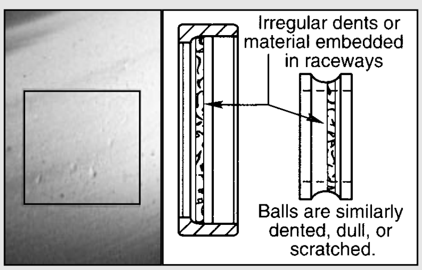

True brinelling occurs when load exceeds elastic limit of ring. Marks show as raceway indentations that increase bearing noise.



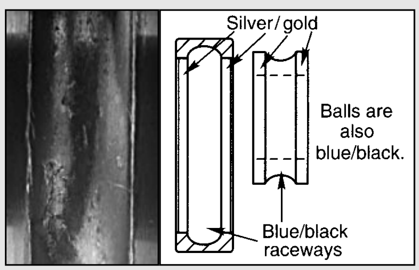

Normal fatigue failure — also called spalling — is fracture of running surfaces and subsequent removal of small particles.



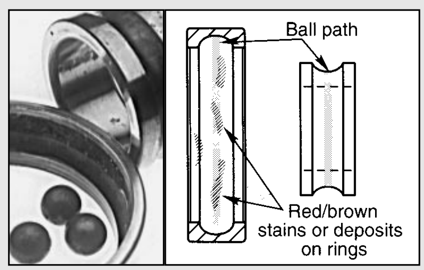

Reverse loading — Angular-contact bearings are meant to accept axial load in one direction only. When loaded opposite, elliptical contact area on outer ring is truncated by the low shoulder on that side. Result: high stress and temperature.



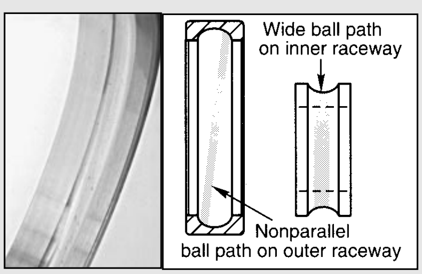

Contamination — Symptoms are denting of bearing raceways and balls causing high vibration and wear.



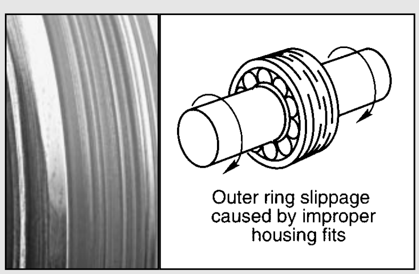

Lubricant failure — Discolored (blue/brown) ball tracks and balls are symptoms. Excessive wear of balls, ring, and cages will follow, bringing overheating and catastrophic failure.



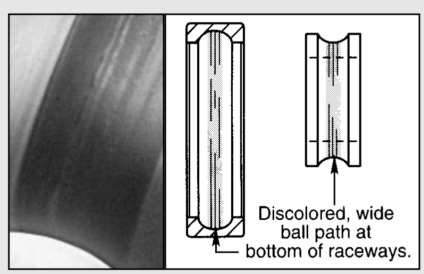

Corrosion — Red/brown areas on balls, raceways, cages, or bands are corrosion symptoms. Comes from exposing bearings to corrosive fluids or atmosphere.




Misalignment — You can detect it in raceway of nonrotating ring by a ball wear path that is not parallel to raceway edges. Could bring excessive temperature.




Loose fits cause relative motion of mating parts. Slight but continuous motion causes fretting — the generation of fine brown metal abrasive particles, which aggravate looseness.




Tight fits are signaled by a heavy ball wear path in the bottom of the raceway around circumference of both rings. Excessive interference can overload balls.

3. Does the RBP surface appear shiny, polished, water-marked, skid marked, discolored, ribbed or rippled, worn, etched, pitted, brinelled, dented, cracked, or gouged?

4. Where is the RBP located? On a Conrad-type ball bearing without thrust load, the RBP will be on the raceway centerline. If the RBP is more than 36% off center (between raceway centerline and edge), then it had a high thrust load.

5. Is there any spalling? What is the spacing of the spalls?

6. On ball bearings, are there any small depressions on the sides of the RBP groove that could indicate installation damage, such as hammering?

7. Look at the mounting surface of the rotating race:

- Check the diameter and width of the race at several points.
- What is the appearance? Are the original grinding marks visible? How much of the surface is fretted? Is there evidence that water was present?

8. Is there evidence of contact on either side of the race? Is the appearance consistent? Is there any sign of movement or installation damage?

9. Is race hardness within normal specifications?

**Fixed race appearance.** Apply the same questions listed under "Rotating race appearance." Then answer the following:

1. Compare the fixed race ball path (FBP) with the RBP to see how the two interact.

2. How does the thrust load pattern compare with the one on the rotating race?

3. If there is any spalling, is it the same as on the rotating race?

**Cage or retainer appearance.**

l. Is there any sign of distortion?

2. Is there evidence of wear or polishing? Has it been in contact with either race? If so, which?

3. The rivets that hold the cage together — are they tight? Is there any evidence of movement?

4. Does the cage show any sign of heating?

**Rolling elements.**

l. Is there any evidence of skidding or surface damage?

2. Is there any area where the element is not smooth?

3. Do the ends of the rollers show signs of excessive thrust load?

4. Is there any evidence of roller wear or distortion?

5. Are contact patterns on rollers all identical?

6. Is there any indication of lubrication problems?

7. Do the ball or roller surfaces appear shiny, polished, water-marked, skid marked, discolored, ribbed or rippled, worn, etched, pitted, brinelled, dented, cracked, or gouged?

8. What is the element hardness? Typical hardness of rolling element bearings is 60-62 Rockwell C. Even slightly reduced hardness in a new bearing shortens life significantly. If a used bearing is subjected to high temperature, it will have lower hardness, but will also show other symptoms such as discoloration and overheated lubricant.

*Extracted from an article by Sachs, Salvaterra & Associates in the October 1992 issue of PTD.*■