RBC ®
B E A R I N G S
SPHERICAL PLAIN BEARING ENGINEERING

Basic Radial Bearing Design

Spherical plain bearings have spherical contact surfaces which permit the inner ring to rotate freely in all directions within bearing and application design constraints. This gives them the capability to self-align, which means, for example, to adjust automatically to misalignment stemming from inaccurate machining, frame distortions from welding, or deformations of pin and frame due to static and dynamic forces. Such misalign - ment would generate considerable end loading and cause early failure of plain cylindrical sleeve bearings. Thus spherical plain bearings are thought to have their origin as replacement for plain cylindrical sleeve bearings or bushings and are still occasionally called ball bushings.

The first modern radial spherical plain bearing had a non-fractured outer ring with a loading slot slightly wider than the inner ring width (figure 1). Such a bearing can easily be assembled and disassembled simply by rotating the inner ring 90 deg out of plane to where it fits through the loading slot. Because the loading slots take away a significant portion of the contact area, radial and thrust capacity in the direction of the loading slots are affected. The bearing is sensitive to the orientation of the loading slots with respect to the main load direction. Lubricating with grease is problematic. It may be lost prematurely by escaping through the loading slots. Yet, this type of bearing is still made today for applications where the outer ring cannot be fractured, either because the outer ring material is too soft for fracturing, or because of application requirements which cannot tolerate a fractured outer ring.
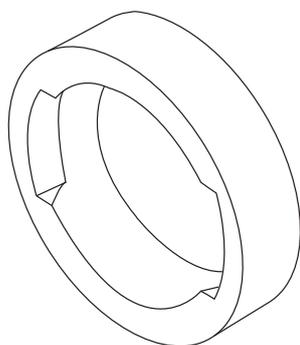

Figure 1: Outer Ring with Loading Slots

The loading slot bearing eventually evolved into a bearing with a fractured outer ring. Initially, outer rings were double fractured, followed later by a single fractured design. Both designs get by without a loading slot and are insensitive to the orientation of the fracture plane with respect to the load direction as long as the outer ring maintains a press fit inside a sufficiently rigid housing bore. A double fractured outer ring consists essentially of two segments of approxi-mately equal size and a means of holding the bearing assem-bly together (figure 2). After pressing the bearing into a housing bore, the fractured surfaces of the two outer ring halves interlock perfectly. The fracture line cannot be felt. It follows that outer ring halves cannot be interchanged among bearings and must not be inadvertently rotated 180° out of position.
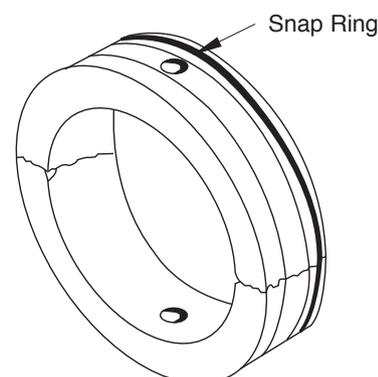

Figure 2: Double Fractured Outer Ring

The RBC Single Fracture Design

The requirement to keep outer ring halves together and properly aligned eventually spawned the single fracture design. This RBC feature is the industry standard today. After being fractured at a single point on its circumference, the outer ring is still a single piece (figure 3). To assemble the inner ring, the outer ring must be spread open far enough to let the inner ring pass through.

The plane of fracture is 90 deg from the lubricating holes for both single and double fractured outer rings.

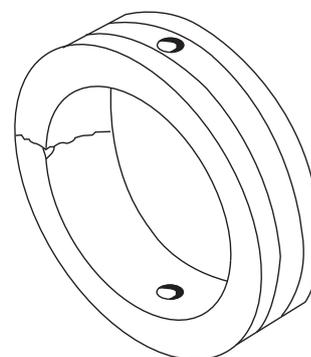*Note: The fracture in the outer ring is intentional.*

Figure 3: Single Fractured Outer Ring

It is not an indication of a defective bearing.

In typical applications, spherical plain bearings support heavy static loads allowing for initial misalignment. Dynamic applications are limited to slow oscillations and rotations below the recommended maximum pv-value (pressure*velocity). The pv-value is used to measure the amount of heat generated by the bearing. Spherical plain bearings can operate above the recommended pv-value, but only under special lubrication conditions.

Metric spherical plain bearings have evolved differently from inch dimensional bearings, not just in their geometry, but also in their load ratings. For comparable inner ring bores, metric bearings have a smaller outside diameter and a smaller width, but by convention, their permissible static contact pressure is higher. (See section LOAD RATING).

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More Radial Bearing Designs

RBC QuadLube® Design

With few exceptions, steel-on-steel spherical plain bearings used in dynamic applications must be relubricated periodically. To be effective, the grease must penetrate into the contact area between inner and outer ring. If a bearing is subject to a unidirectional load, it must be unloaded during relubrication or only a minimal amount of grease will ever reach the contact area. Most of the lubricant will accumulate in the unloaded zone and eventually exit without benefiting the bearing service life.

The QuadLube® design solves the lubricant flow problem of bearings where the load acts always in the same direction. The additional circular grooves on the spherical diameter of the inner ring allow grease to flow into the contact area even with the bearing under load. The grooves help to collect wear debris which is purged from the bearing during a subsequent relubrication cycle.

Heavy Section

In a typical bearing application, the inner ring mounts on a shaft and its face abuts against a shoulder. If the bearing must support significant thrust loads, the shoulder diameter should match the outside diameter of the inner ring at the face to minimize contact pressure. See the catalog pages for this dimension. A tilting outer ring will eventually make contact with this shaft shoulder, which defines the bearings maximum tilt angle (figure 4).

CAUTION: The actual tilt angle of a bearing assembly may be limited by the design of surrounding components.
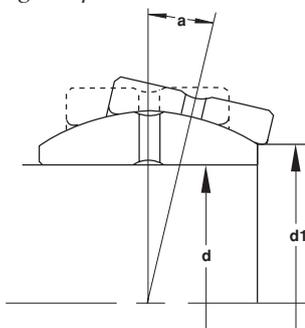

Figure 4: Maximum Tilt Angle

To increase the tilt angle of a standard bearing, the width of the inner ring must be increased. But simply increasing the width is not sufficient because there would be no inner ring face left if we did not also reduce the inside diameter of the inner ring. These inner rings with greater width and wall thickness form the heavy section series BH-L (figure 5). For a given shaft size, the heavy section bearings have greater misalignment capabilities and a greater load carrying capacity compared to the standard series at the cost of increased overall dimensions.
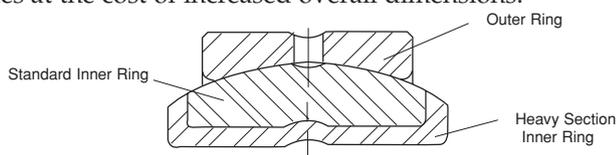

Figure 5: Standard vs. Heavy Section Inner Ring

Tapered Bore Inner Rings

Bearings with heavy section inner rings are also available with a tapered bore, see series BT-L (figure 6). The taper is 1:8 or 1.5" per ft on diameter. There are 2 main reasons for using a tapered bore bearing:
- To prevent rotation between inner ring bore and shaft.
- To control the diametral clearance of the bearing assembly. As the inner ring is forced up the tapered pin, its outside diameter expands effectively reducing the diametral clearance.

CAUTION: Reducing the operating clearance below 0.001" (0.025mm) may increase bearing friction and wear rate. A substantial thrust force in the direction of the large end of the taper may cause additional inner ring expansion which could lock up the bearing.
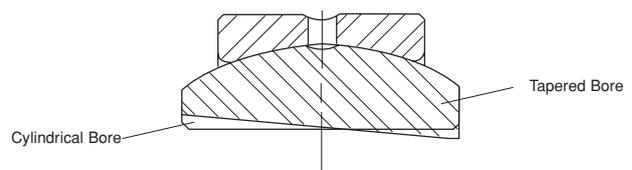

Figure 6: Heavy Section Inner Ring Cylindrical vs. Tapered Bore

Extended Inner Rings

For applications with substantial outer ring tilt, for example yoke supported rod ends of some hydraulic cylinders, RBC offers radial bearings with extended inner rings (figure 7). Using a bearing with an extended inner ring obviates the need to add separate spacers to the bearing assembly to create the axial space required by the outer ring housing.

CAUTION: Spacers and inner ring extensions increase the distance between pin supports. At high loads, pin deflection may become a problem.
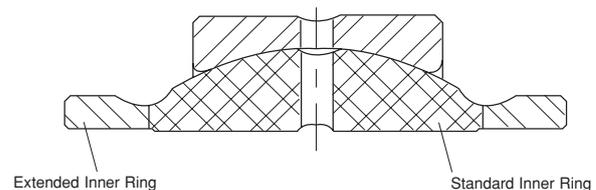

Figure 7: Standard vs. Extended Inner Ring

DuraLube™ Maintenance-Free Bearings

RBC offers maintenance-free bearings consisting of a chromium plated inner ring, an outer ring with a bonded PTFE liner and seals. The liner provides excellent load bearing capacity and a low wear rate (figure 8).
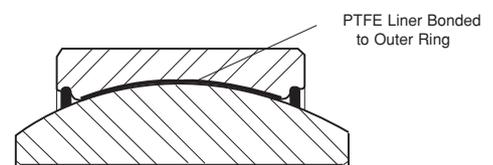

Figure 8: Maintenance-Free Bearings

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Sealed Bearings

Except for the very small sizes, all radial spherical plain bearings can be ordered with integral seals. Their function is twofold, retain the lubricant as much as possible inside the bearing and slow the ingress of contaminants. Rubber or plastic seals work best in bearings which experience circumferential motion or very frequent tilting, which tends to keep the contact surfaces clean. The seals are not effective at scraping off paint or accumulated and hardened dirt during an occasional tilting motion.

Angular Contact Bearings

Single Acting

Angular contact bearings, RBC series B-SA, are intended for applications with thrust loads exceeding the capability of a radial bearing. Angular contact bearings can support both radial and thrust loads. Single acting bearings are separable and support thrust loads in only one direction (figure 9). To support heavy thrust loads in both directions, use either 2 single acting bearings mounted in an "O" or "X" configuration (figure 10) or consider a double acting bearing, see below. Angular contact bearings do not have the misalignment capabilities of radial bearings, in fact, the angle of misalignment is generally quite small.
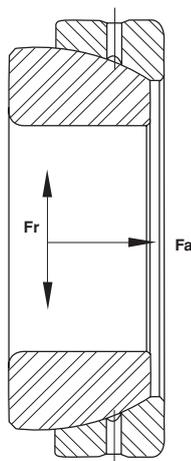

Figure 9: Angular Contact Bearing. Single Acting. Permissible Load Directions

Double Acting

Combining two single acting angular contact bearings into a singular unit yields a double acting bearing with a heavy section inner ring, the RBC series B-DSA3 (figure 11). This type of bearing is often used as a locating bearing because it can support much heavier thrust loads than a standard radial bearing. Like a single acting bearing its angle of misalignment is limited. The heavy section inner ring allows a tapered bore with the same advantages and disadvantages as described above.

As in all angular contact bearings, the proper axial clearance after assembly is critical. To eliminate the need for external shims, RBC produces these bearing assemblies

CAUTION: 2 single acting angular contact bearings mounted in an "X" configuration a fair distance apart may bind if there is an appreciable temperature difference between shaft and housing. Allow for thermal expansion or use "O" configuration.
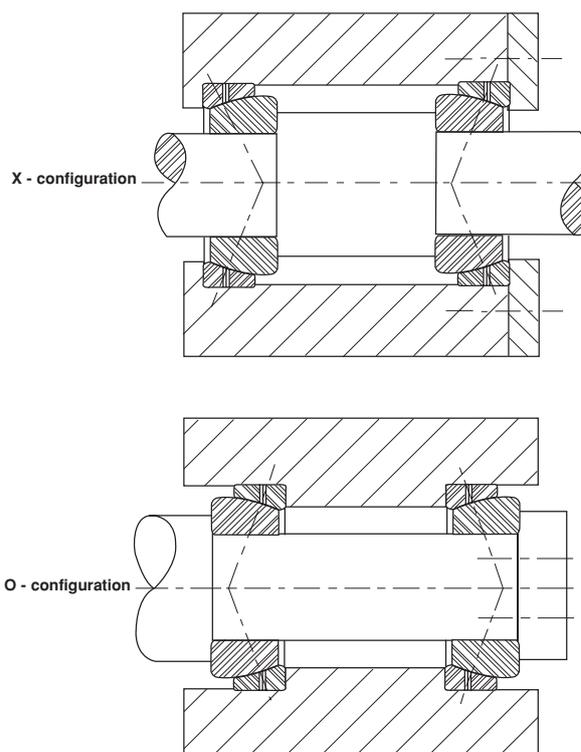

X - configuration

O - configuration

Figure 10: Bearing Arrangement

with an axial clearance preset at the factory. A shim pack inserted between the two outer rings determines the actual clearance. The thickness of this shim pack may differ from one bearing assembly to the next, therefore care must be taken not to mix components from different assemblies. The ties of each bearing should only be cut immediately before installation.

CAUTION: Do not interchange components of ShimPack® Bearings.

The shim pack spacer is an elastic component. To prevent excessive elastic or plastic deformations, the catalog pages list a recommended shim pack compression force (figure 12). Such a compression force could be generated by an end plate being tightened down with a number of bolts. As long as the clamping force does not exceed the recommended shim pack compression force, the listed axial bearing clearance will be maintained. Clamping beyond that limit will start to plastically deform the shim pack spacer and reduce the axial bearing clearance accordingly. Unless such an effect is actually intended, the assembly instructions should specify a maximum tightening torque for the bolts.

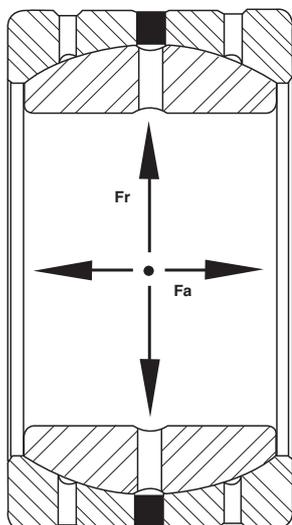*CAUTION: Observe the maximum recommended shim pack compression force.*

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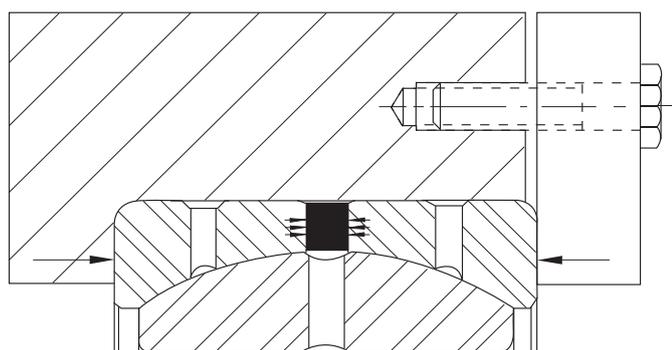**Figure 11: Angular Contact Bearing, Double Acting. Permissible Load Directions.**

Figure 12: ShimPack® Compression Force=Fc

Material and Specifications

Inner and outer rings are manufactured from through hardened bearing quality steel per ASTM A485, and, unless otherwise specified, heat treated to HRc 56 minimum for optimum wear resistance. The spherical contact surfaces are precision ground. Inner and outer rings are phosphate treated prior to coating with a dry film lubricant (MoS$_2$).

The inch and metric radial bearings described in this catalog meet the requirements of series 3 of ANSI/ABMA Std 22.

Except for the larger sizes, the outer rings of radial bearings are single fractured which allows assembly of the inner ring. Larger bearing sizes have double fractured outer rings and can be disassembled if necessary. These bearings carry the suffix -9L. The fractured rings may be slightly out-of-round in the free state, but will round up when mounted in a proper housing bore. It is generally not necessary to orient the fracture plane relative to the load direction.

![RBC BEARINGS logo]

Load Ratings

Both inch and metric bearings consist of the same high quality, high strength bearing steel, with a strength of material of 285,000 to 300,000 psi [1965 to 2069 MPa].

In most applications the bearings are mated with shafts and housings made of lower strength steel, which makes it impossible to realize a contact stress level approaching this magnitude. For practical purposes, the bearings must be down rated to a level where they can safely work with lower strength mating components. (See also sections on housing design, shaft design, typical failure modes). Applications with loads in excess of the recommended load limits are possible but should be reviewed by RBC engineering.

By convention, the permissible contact stress has been defined differently for metric and inch dimensional bearings. The definitions given apply to radial bearings, they are similar for other bearing types.

A) Inch Dimensional Bearings

The maximum recommended static contact pressure is 50,000 psi [345 MPa]. The maximum recommended dynamic contact pressure is 25% of that or 12,500 psi [86 MPa].

The radial and thrust ratings are based on the projected area and can be derived with the following equations:

$$C_O = 50,000 * K * C * f_r$$
$$C_{OA} = 35,000 * (K^2 - f_a * (K^2 - C^2)) * (\pi/4)$$

C_O = recommended static radial load limit [lbf]
C_{OA} = recommended static axial load limit [lbf]
K = spherical diameter [in]
C = outer ring width [in]
f_r = geometry factor, typically f_r = 0.7. Makes allowance for lube grooves & undercuts.
f_a = geometry factor,
  f_a = 1.17 approx., for single fractured,
  f_a = 1.04 approx., for double fractured bearings

B) Metric Bearings

The static radial load limit is given at a pressure of 430 MPa [62,370 psi]. The maximum recommended dynamic contact pressure is 20% of that or 86 MPa [12,470 psi]. The static thrust load limit is based on a contact pressure of 215 MPa [31,185 psi]. No allowance is made to account for the effects of lubricating groove and undercuts. The equations are then:

$$C_O = 430 * K * C / 1000 \ [kN]$$
$$C_{OA} = 215 * C^2 * (\pi/4) / 1000 \ [kN]$$

C_O = recommended static radial load limit [kN]
C_{OA} = recommended static axial load limit [kN]
K = spherical diameter [mm]
C = outer ring width [mm]

For comparable bearing inside diameters, e.g. 2.000" and 50mm, inch dimensional bearings typically have a somewhat larger outside diameter and considerably greater width. In this particular case, the projected gross radial contact area for the 2" bearing is 4.3125 in^2 (2782 mm^2) compared to 2.9078 in^2 (1876 mm^2) for the 50 mm bearing. For a given load, the inch dimensional bearing typically sees a much lower contact pressure but requires more mounting space.

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Working Loads

STATIC - The static load limits given in the tables are safe bearing operating loads, provided housing and shaft are sufficiently rigid to prevent excessive deformation. The safety factor against static fracture is greater than 1.5. See the sections on shaft and housing designs to check for conditions which could require reducing the bearing load.

DYNAMIC - Applications are considered to be dynamic if the bearing is subject to more than initial misalignment or an occasional oscillation. Spherical plain bearings are best suited for oscillating motion as in hydraulic cylinders.

The dynamic bearing load for grease lubrication should not exceed:
a) the dynamic capacity given in the tables and
b) a pv value (pressure*velocity) of 10,000 psi*ft/min.
These limits do not apply to oil lubrication. To find the p*v-value, use the following equation:

$p*v$ = $46.5 * (F/C_O) * K * ß * f <= 10,000$ psi $* $ ft/min
F = dynamic radial Load [lbf]
C_O = recommended static radial load limit [lbf]
K = spherical diameter [in]
$ß$ = angle of oscillation side to side [deg]
f = frequency of oscillation [1/min]

The above equation applies to radial bearings under radial load. Please contact RBC engineering for an estimate of service life and for other operating conditions and bearing types.
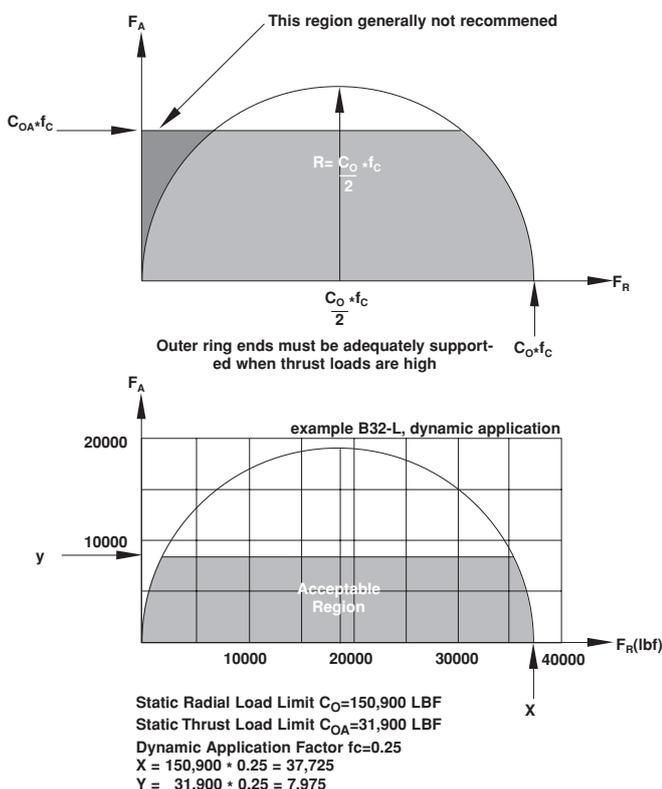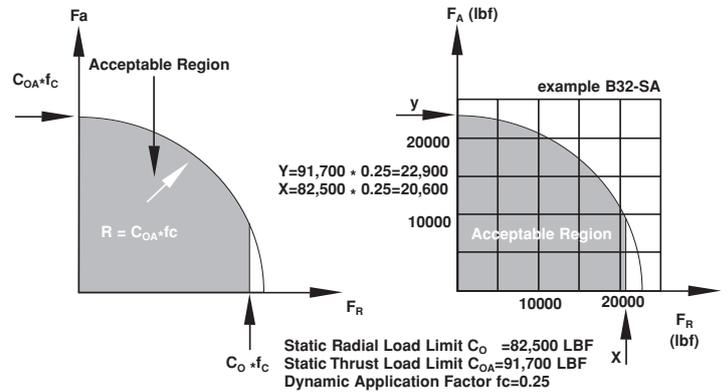

Figure 13: Radial Bearings

Figure 14: Angular Contact Bearings, Single Acting

COMBINATION RADIAL AND AXIAL LOADS - To determine the acceptability of a combination radial and thrust load under static and dynamic operating conditions, diagrams of acceptable regions may be constructed for radial and angular contact bearings as shown in figures 13 - 15. Any load whose radial and thrust components plot in the hatched area is permissible. The inequalities in numerical form are as follows:

Radial Bearings

$$F_r^2 + F_a^2 <= F_r * C_O * f_C \quad \text{and} \quad F_a <= C_{OA} * f_C$$

Angular Contact Bearings, single acting

$$F_r^2 + F_a^2 <= C_{OA} * f_C \quad \text{and} \quad F_r <= C_O * f_C$$

Angular Contact Bearings, double acting

If $F_r <= (C_O - C_{OA}) * f_C$ then $F_a <= C_{OA} * f_C$

If $F_r > (C_O - C_{OA}) * f_C$ then $(F_r - (C_O - C_{OA}) * f_C)^2 + F^2_a <= (C_{OA} * f_C)^2$

F_r = radial load component
F_a = thrust load component
C_O = static radial load limit
C_{OA} = static thrust load limit
f_C = 1 for static operating condition
f_C = 0.25 dynamic operation, inch dimensional bearings
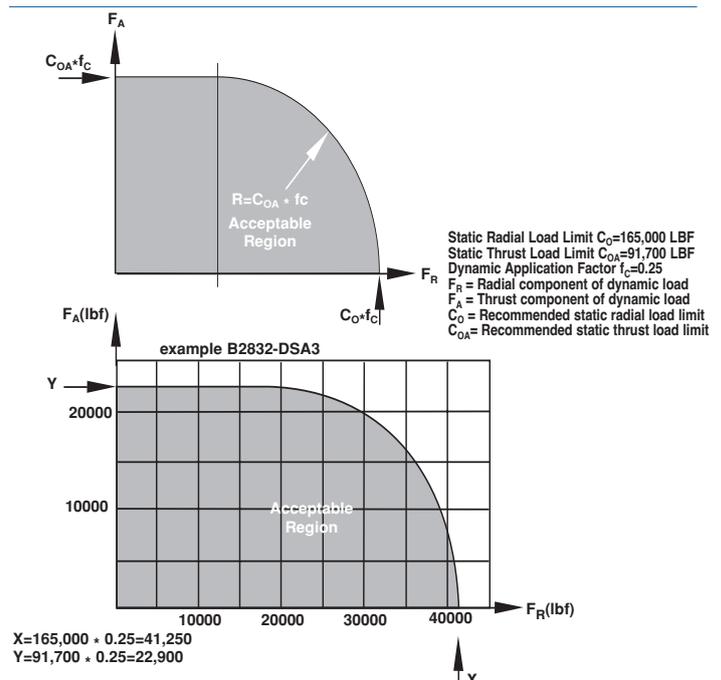f_C = 0.20 dynamic operation, metric bearings

Fig. 15: Angular Contact Bearings, Double Acting

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Operating Conditions

TEMPERATURE - The maximum operating temperature of sealed bearings is limited by the seal to 250 deg F. Standard bearings without seals can operate without modifications from -60 deg F to + 350 deg F. For operation below -60 deg F and above +350 deg F, up to +500 deg F, it is recommended to use bearings temperature stabilized at the factory. For operation to +1000 deg F and at cryogenic temperatures, contact RBC engineering.

ENVIRONMENT - Standard bearings are phosphate treated and coated with a dry film lubricant (MOS_2). This surface treatment provides a certain protection against corrosion from atmospheric conditions and an occasional splash. Additional protection should be supplied for operation in continuously wet environments by adding internal or external seals. RBC can supply bearings with special coatings for underwater applications.

Ingress of hard solid particles like debris, sand, grit and mud will accelerate the bearing wear and may clog lubricating holes. The bearing should be protected from exposure to solid particles.

Mounting - Fractured Outer Rings

Bearings with single or double fractured outer rings (series B-L, BH-L, MB, MBH) should be mounted with an interference fit in the housing. The interference fit corrects any out-of-roundness of the outer ring due to the fracturing process and will make the fracture line functionally invisible. For light loads of less than 20% of dynamic capacity, an ISO N7 fit may be used. RBC recommends using an ISO R7 fit whenever possible. The internal bearing clearance can accommodate the reduced spherical diameter of the outer ring caused by an R7 press fit. An even heavier press fit may be required in applications with heavy shock loads, a rotating load on the outer ring, or when the housing is made from a light metal. In the case of heavier fits, the mounted diametral clearance must be reviewed.

Mounting - Solid Outer Rings

The bearings with non-fractured outer rings are the single and double acting angular contact series B-SA, MB-SA, B-DSA3. While the outer rings of single acting angular contact bearings may be heavily press fitted, it is often desirable to maintain axial adjustability for double acting bearings. An ISO N7 fit is still light enough to move outer rings axially in the housing bore without too great a force.

CAUTION: Outer rings of angular contact bearings subject to heavy thrust loads must not be clearance fitted.

Mounting - Inner Rings, Cylindrical Bore

It is generally recommended to press fit the inner rings where feasible to prevent rotation taking place between inner ring bore and shaft. If assembly or operating conditions require a loose fit, it is preferable to let the inner ring slide on the shaft rather than the outer ring rotate in the housing.

Mounting - Inner Rings, Tapered Bore

Heavy section inner rings of the series BT-L and BT-DSA3 feature a tapered bore with a taper of 1:8 (1.5" per ft on diameter). Tapered bores are useful to prevent inner ring rotation on the pin and to control the diametral bearing clearance by expanding the inner ring.

To ensure sufficient operating clearance for the bearing, the inner ring clamping forces given in the table should normally not be exceeded.

Housing Design

To safely support the high load capacity of spherical plain bearings, the housing must have sufficient strength to avoid excessive deformation and fatigue failure. Certain housing types like cylinder rod eyes and pivot brackets under tensile stress experience maximum stress at points perpendicular to the line of force. To obtain the maximum tensile stress, multiply the normal tensile stress of the total cross section by a factor "K" found in figure 16. The result must be less than the endurance limit of the housing material.
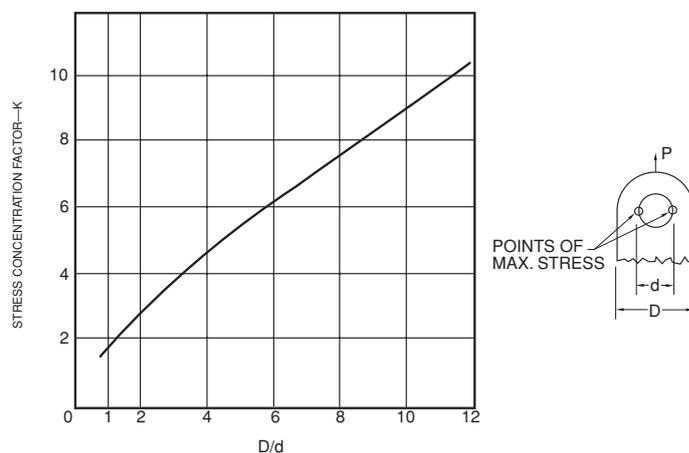

Figure 16: Stress Concentration Factor

Housings must be sufficiently strong to prevent excessive outer ring deformation. Sufficient housing strength can be achieved either by a great enough wall thickness, here expressed as a ratio of housing outside diameter divided by housing bore, or by selecting a higher strength material. The effects of housing wall thickness and strength on available bearing capacity can be observed in figure 17.
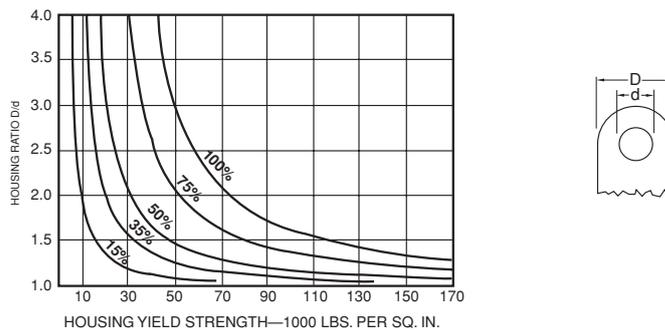

Figure 17: Influence of Housing Design on Bearing Capacity
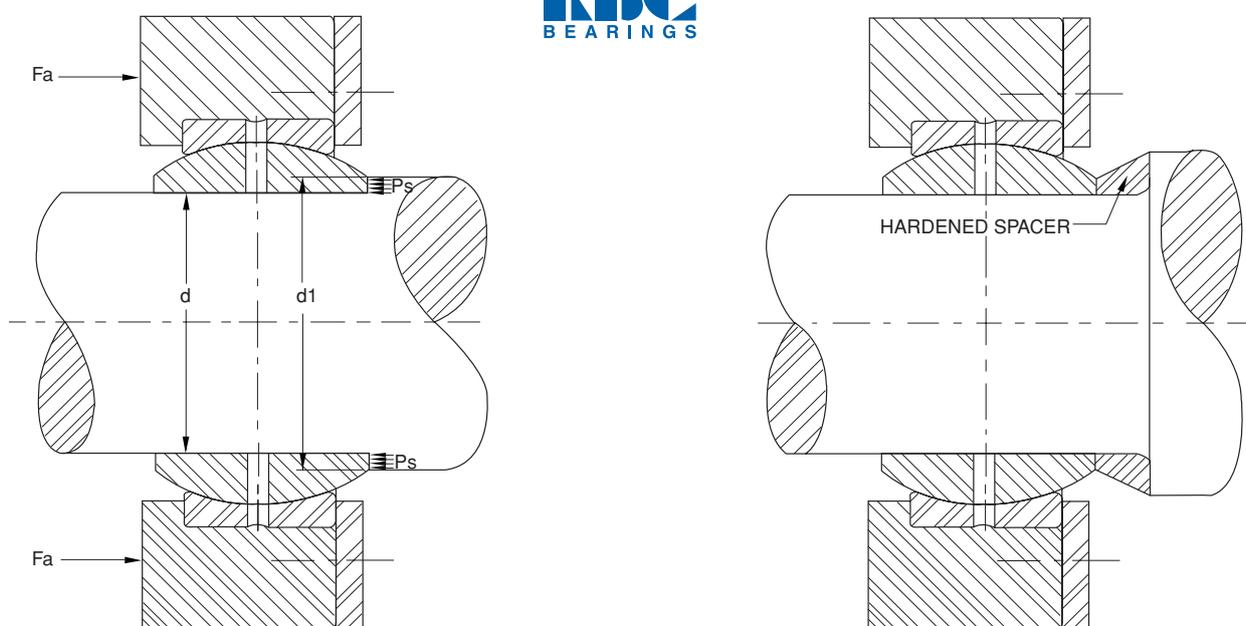
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**Figure 18: Reduce Contact Pressure by Using a
Hardened and Tapered Spacer**

Shaft Design

With the exception of bearings under light load and press fitted inner rings, it is generally recommended that shafts or pins be heat treated to a surface hardness of HRc 55 min and have a surface finish of 32 rms. Under dynamic operating conditions and with a loosely fitted inner ring, it must be expected that rotation takes place between inner ring and shaft. Under very heavy loads, even an interference fit does not guarantee that the inner ring will not rotate on the shaft.

Thrust loads on radial bearings are transmitted via the face of the inner ring. The contact stress of this annular area should be checked against the yield strength in compression of the shaft material or any spacer which may be used. Even under static conditions, it may be necessary to harden the shaft shoulder to prevent plastic deformation. Hardened spacers with a tapered OD may be used if the shoulder cannot be heat treated (figure 18).

Lubrication

Standard RBC spherical plain bearings are phosphate treated and coated with a dry film lubricant (MoS_2). This surface treatment is sufficient for static applications and occasional movements. If used in a dynamic application, the bearings must be lubricated with oil or grease.

Oil Lubrication - Steel-on-steel bearings operating in an oil bath can be essentially maintenance-free. This can be accomplished by enclosing the entire bearing assembly in a gearbox style structure or by mounting spring loaded lip seals next to the bearings. The latter is only feasible in applications with very little tilting motion. Bearings subject to large degrees of tilting will require an oil filled boot.

> *Note: The integral seals of spherical plain bearings are not suitable for sealing against oil pressure.*

For oil lubrication at ambient temperature use #90 gear oil.

Grease Lubrication - It is recommended that the bearings be thoroughly lubricated with grease at the time of installation. Lubrication after installation may make it difficult for the grease to penetrate into the load zone. Failure to do so may cause surface damage to the bearing rings during the critical run-in period. Steel-on-steel bearings must be relubricated periodically depending on operating conditions. The frequency and efficacy of relubrication greatly influence the ultimate bearing service life. For example, more frequent relubrication is necessary if the bearings operate in a dirty and dusty environment. The grease flow through the bearing helps purge contaminants.

Radial bearings can be relubricated either through the shaft or the housing. In those cases where rotation between inner ring bore and shaft must be expected, relubrication through the shaft helps to lubricate that interface.

To become effective, the grease must be able to reach the contact area between inner and outer ring. In applications where the load direction alternates, e.g. the push-pull type action of a hydraulic cylinder, the grease will be moved around due to the different inner ring positions.

By contrast, in applications where the load always acts in the same direction, e.g. in some suspension systems, grease will not be able to flow into the load zone, if the bearing is relubricated under load. For effective lubrication, the bearing must be unloaded. Alternatively, use the RBC developed bearing with special lubricating grooves, the QuadLube® series, which permits relubrication under load. See also section "More Radial Bearing Designs".

Angular contact bearings with extended lubrication grooves, series B-SA-1 and B-DSA3-1, have lubricating grooves extended to the small diameter of the outer ring to facilitate grease flow through the bearing while under load. Angular contact bearings without these lube groove extensions should not be relubricated while under heavy thrust load or air may become trapped in the grease passages which will expell the grease promptly.

Recommended grease type: for operating temperatures between -40 deg F and +250 deg F, use a lithium based grease, NLGI Grade 2, with EP and MoS_2 additives.

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Bearing Failure Modes

This section is intended to help the user identify bearing problems and correct or prevent their causes. By definition, the useful service life of a spherical plain bearing has ended after one of the following condition occurs:
- Outer ring, inner ring, or both are broken.

- The coefficient of friction exceeds 0.22.

- The diametral clearance has grown to more than the application can tolerate.

1. Component Fracture

1.1 Causes of outer ring failure
- During assembly:
  Pressing the outer ring into the housing bore at an angle, trying to press fit the outer ring by pushing against the inner ring face, trying to press fit the outer ring with hammer blows.

- During operation:
  Excessive outer ring deformation due to shock loads, thin walled housing, partial outer ring support, insufficient interference fit.

1.2 Causes of inner ring failure
- During assembly:
  Attempting to mount bearing in the housing by pushing against the inner ring face.

- During operation:
  Excessive clearance between shaft and inner ring bore. Excessive shaft deflection.

2. Excessive Friction Due to Adhesive Wear

- Appearance:
  Inner and outer ring spherical surfaces have deep gouge marks, chunks of metal are torn out of the surface. The bearing makes a screeching noise during operation.

- Causes:
  Excessive pv-value, excessive dynamic load, lack of maintenance, insufficient lubrication where lubricant does not reach the load zone, contamination by hard particles, rust and corrosion.

3. Excessive Diametral Bearing Clearance Due to Abrasive Wear

- Appearance:
  Inner and outer ring spherical surfaces are shiny, appear polished. Ridges are worn into the contact area.

- Causes:
  Contamination by a powdery substance or mud, lubrication insufficient to flush wear particles from the contact area.

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