Fitting and Mounting of Angular Contact Ball Bearings

The Importance of Correct Fitting for Angular Contact Ball Bearings:

Selecting the proper shaft and housing fit is critical in optimizing a bearings performance and life. A bearing can only perform to its full capacity when it is correctly fitted on the shaft and in the housing. Conversely, improper bearing fits, too loose or too tight, can lead to undesirable operating conditions and early failure.

Problems with fits that are too loose include, damage to the bearing seat, excessive wear, noise, vibration, and reduced rotational accuracy. Problems with fits that are too tight include reduction in radial play, overheating, unintended preload, and heavy mounting forces (or dis-mounting) are required.

General Considerations for Angular Contact Ball Bearings:

The design should allow for support of the bearing rings across their entire width and circumference. This will allow for full utilization of the bearings load carrying capacity. The fits with the mating housing and shaft must be selected so that there is no creep, or slippage, between the components. For bearing arrangements with a "floating" bearing, one of the rings of the non-locating bearing must be able to move in the axial direction. Fits should be selected to ensure the bearings are easy to assemble, and in many cases dis-assemble for maintenance or replacement.

Considerations for Selecting Fits for Angular Contact Ball Bearings:

Direction, type, and magnitude of loads – Based on the actual applied axial and radial loads, an equivalent radial load is calculated. Generally, tighter fits are required as the load increases. Further, rings subjected to circumferential loading should have tight fits. For rings subjected to only point loading, a loose fit may be used.

Inner or outer ring rotation – Typically, the ring that is rotating requires an interference fit, and the non-rotating ring would have a slightly loose fit.

The size and type of bearing specified – Thin type and miniature bearings are very sensitive to interference fits due to loss of radial play. Bearings with heavier cross sections generally require tighter fits.

Material and manufacturing tolerances of mating components – Fit tolerances are based on cast iron or steel housings and shafts. For alloys such as aluminum (with a different modulus of elasticity), a tighter fit is required to achieve rigid seating.

Operating temperature – With tight fits and a temperature differential between the inner and outer ring, the radial internal clearance in the bearing is reduced. This must be taken into consideration when selecting the internal clearance. In addition, if the materials used for the housing or shaft are dis-similar, they will have different coefficients of thermal expansion than the bearing rings. This must be taken into consideration to achieve rigid seating.

Running accuracy required – In order to achieve high running accuracy, the same high standard of accuracy and surface quality expected in the bearing must be applied to the shaft and housing as well. In addition, with miniature and thin type bearings irregularities on the shaft or in the housing are transferred to the relatively thin walled bearing rings.

Types of Loading for Angular Contact Ball Bearings:

Circumferential loading occurs in the case of a rotating ring and a stationary load, or with a stationary ring and a rotating load. Under these conditions, forces are acting to displace the ring relative to its seating surface and every point on the raceway is subjected to load during one revolution of the bearing.

Point loading occurs in the case of a stationary ring and a stationary load, or a rotating ring and a rotating load. In these cases, the ring remains stationary relative to the direction of the load. Under these conditions, there are no forces acting to displace the ring relative to its seating surface.

For rings that are subjected to circumferential loading select a tight fit. Insufficient interference on fitting surfaces could cause bearing rings to creep in a circumferential direction. Once this happens, considerable wear occurs on the fitting surface and both shaft and housing are damaged. Furthermore, abrasive particles may enter the bearing causing vibration, excessive heat and damage to raceways. It is therefore necessary to provide bearing rings under rotating load with an adequate interference fit to prevent creep.

For rings that are subjected to point loading a loose fit is permissible. Statically loaded bearings generally do not need to be fitted with an interference fit. Only when subject to a high degree of vibration do both inner and outer rings require fitting with an interference fit.

ROTATING RING	LOAD	LOAD CONDITION	FITTING
Inner ring	static	Inner ring rotating load Outer ring static load	Interference fit for inner ring Clearance fit for outer ring
Outer ring	rotating		
Outer ring	static	Outer ring rotating load Inner ring static load	Clearance fit for inner ring Interference fit for outer ring
inner ring	rotating		
In the case of fluctuating load direction or unbalanced load	rotating or static	Indeterminate load direction	Interference fit for inner and outer ring

Magnitude of Load:

Light loading=	≤0.06 Cr
Standard or Normal Loading=	0.06-0.12 Cr
Heavy loading=	≥0.13 Cr

Cr= dynamic load rating of bearing

Higher loads require tighter fits

Types of Fits for Angular Contact Ball Bearings:

Loose (or clearance) - It is a fit that always enables a clearance between the hole and shaft in the coupling. The lower limit size of the hole is greater or at least equal to the upper limit size of the shaft

Transitional - It is a fit where (depending on the actual sizes of the hole and shaft) both clearance and interference may occur in the coupling. Tolerance zones of the hole and shaft partly or completely interfere.

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Tight (or interference) - It is a fit always ensuring some interference between the hole and shaft in the coupling. The upper limit size of the hole is smaller or at least equal to the lower limit size of the shaft.

Please contact AST Engineering for tolerances of shafts or housings for each type of fit.

Calculations of Fits

Fitting Pressure and Dimensional Changes of Inner and Outer Ring

The right fit for each application is established by taking various conditions into consideration such as load, temperature, mounting dismounting of the bearing. The interference fit should be greater than normal in thin housings, housings of soft material, or on hollow shafts.

Load of Interference

The interference fit of shaft and inner ring decreases under radial load. The decrease in fit of shaft and inner is calculated by the following formulas. Please note that the higher value from the two formulas shown below should be used.

$$\Delta dF = 0.08 \times \sqrt{d/B \cdot Fr} \times 10^{-3} \text{ (mm)}$$

or

$$\Delta dF = 0.02 \times Fr/B \times 10^{-3} \text{ (mm)}$$

Influence of Temperature on Bearings, Shafts, and Housings

Each inner ring, outer ring or rolling element of a bearing rotating under load generates heat which will affect interference fits of the shaft and the housing. Assuming a temperature difference within the bearing and the housing of ΔT (^oC), that of the mating surface of the shaft and of the bearing is (0.10-0.15) ΔT.

Consequently, ΔdT, the decrease of the inner ring interference fit due to temperature change is calculated from the following formula:

$$\Delta dT = (0.10 \sim 0.15) \times \Delta T \cdot a \cdot d = 0.0015 \times \Delta T \cdot d \times 10^{-3} \text{ (mm)}$$

Where

ΔdT = The decrease of interference due to temperature difference (mm)
ΔT = Temperature difference between bearing and surrounding housing (^oC)
a= Coefficient of thermal expansion for bearing steel = 12.5×10^{-6} (I/^oC)
Coefficient of thermal expansion for stainless steel = 10.3×10^{-6} (I/^oC)
d= Nominal bore diameter of bearing (mm)

It should also be noted that fit can increase due to temperature changes.

Effective Interference, Surface Roughness, and Accuracy

The surface roughness is smoothed during fitting and the effective interference becomes smaller than the theoretical interference. The surface roughness quality of a mating surface has an influence on how much this theoretical interference decreases. Effective interference can usually be calculated as follows:

$$\text{Ground Shaft: } \Delta d = d/(d+2) \cdot \Delta da \text{ (mm)}$$
$$\text{Turned Shaft: } \Delta d = d/(d+3) \cdot \Delta da \text{ (mm)}$$

Where

- Δd: Effective interference (mm)
- Δda: Theoretical interference (mm)
- d: Nominal bore diameter of bearing (mm)

By combining these factors, the theoretical interference fit required for inner ring and shaft where the inner ring is subjected to rotating load is calculated as follows:

$$\Delta da \geq (\Delta dF + \Delta\, dT)\,((d+3)/d \text{ or } (d+2)/d) \text{ (mm)}$$

Normally, shaft and housing seats have to meet the accuracy and roughness requirements as given below:

	SHAFT	HOUSING
Roundness	Below 50% Of Shaft Diameter Tolerance	Below 50 % Of Housing Bore Diameter Tolerance
Cylindricity	Below 50% Of Shaft Diameter Tolerance Within Bearing Width	Below 50 % Of Housing Bore Diameter Tolerance Within Bearing Width
Squareness	≤ 3/1000 (0.17^{o})	
Roughness Of Mating Surface	Rmax 3.2	Rmax 6.3

Accuracy and Roughness of Shaft and Housing Seats

Mounting bearings with extra tight or light interference fits can lead to early bearing failure. In order to ensure safe operating conditions the tolerance variations of shaft seats, housing bores and bearing bore and outside diameter need to be reduced.

The tolerance zones are divided into two bands and selective assembly is applied. Bearings sorted into two tolerance bands for inner and outer rings are available. These bearings are marked as follows:

	Tolerance Of Bore Diameter	0 ~ -D/2	-D/2 ~ -D	0 ~ -D
Tolerances of outer diameter	Mark	1	2	0
0~-d/2	1	C11	C12	C10
-d/2 ~ -d	2	C21	C22	C20
0 ~ -d	0	C01	C02	

Selective classification of outer and bore diameter tolerances and indication mark

D : Minimum value of outer diameter tolerance
d: Minimum value of bore diameter tolerance

Preloading

Preload: *The application of a prescribed axial load across a pair of bearings to force the rolling elements to assume a contact angle for the purpose of removing free internal clearance.*

When bearings are assembled, it is necessary to have a certain amount of free internal clearance, commonly referred to as radial play. This means that one bearing race can be moved radially and axially relative to the other. By applying an axial load across the two bearings and forcing the balls into contact with the raceways, a contact angle is formed. This axial load is commonly called preload.

Benefits of Preloading:

Preloading has many benefits, several of which may apply in any application. The principle benefits are as follows:

- Precise shaft positioning (no free motion); Shaft rotational accuracy is greatly improved by minimizing runout characteristics
- Control axial and radial movement.
- Provide axial and radial stiffness.
- Minimize ball skidding and related noise problems.
- Load sharing between bearings.

Spring Preloading Method

A spring is used to press the inner rings together, or can be positioned to push the outer rings apart. To achieve the desired preload, a coil spring, a Belleville washer, a wave spring, or a series of springs are compressed to a predetermined height. The spring(s) can be placed at either end or in the center of the bearing system. This method is can be used for noise sensitive applications as the floating ring reduces vibration levels transmitted from the bearings. This method can also compensate for thermal expansion, but has minimum stiffness.

Adhesive and Dead Weight Method

Adhesive may be used to secure the bearings to the housings and shafts. This method provides a rigid or fixed preload. Dead weight preloading requires the use of an adhesive to secure the rings in the preloaded position while held in place with a weight equal to the desired preload. Once the adhesive has cured the weight is removed. A spring force may be used instead of deadweight, and may be left in place. The use of adhesives in any bearing system requires careful handling and dispensing techniques. A small amount of adhesive inside the bearing can lead to bearing failure.

Duplex Bearings and Face Clamping Method

Face clamping a pair of duplex bearings is a commonly used method of preloading. The idea is to draw the rings together (inner rings for DB, outer rings for DF) to achieve the preload determined by the offset. This requires that bearings be supplied as matched sets with a controlled preload offset, achieved either by flush grinding ring faces under a load equal to other desired preload, or by matching the stick-in/stick-out of the abutting ring faces. Face clamping can be done with either a large nut threaded to the end of the shaft or with a heavy washer and several small screws attached to the end of the shaft. This method provides good stiffness.

Specifying Preload

Unfortunately, not many bearing systems use preload values that were determined analytically. Too often a specification is developed and a value chosen that seems reasonable at the time but turns up as a problem later. Generally the idea is to keep the preload as low as possible and still get the desired performance.

There are several factors to consider depending on what the performance expectations are. Following are a few questions that should be considered by the system designer and bearing engineer before choosing a preload value.

- Is a specific stiffness or minimum compliance rate required?
- Is there a maximum allowable torque for the bearing system?
- What are the operating temperatures of the mounting surfaces?
- What are the fits between the mounting surfaces?
- Are the bearings subjected to moment loading and/or misalignment?
- Are the acceleration/deceleration rates unusually high?
- What thrust loads must the bearing support?

With regard to duplex bearing pairs also note, that a preloaded bearing system will support an axial load equivalent to about three times the preload value before one bearing of the pair becomes completely unloaded. At this point the system deflection rate reverts to that of a single bearing. It is important to consider unloading in applications where the axial stability of the preloaded bearings is critical over the entire range of thrust loading. For example, if a preloaded system of instrument bearings is subjected to a 15 pound maximum operating axial force, the preload should be a minimum of 5 pounds.