Fitting and Mounting of Radial Ball Bearings

The Importance of Correct Fitting for Radial 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 Radial 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 Radial 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.

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Types of Loading for Radial 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 Radial 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.

Shaft and Housing Tolerances:

The fit of the bearing bore with a shaft, or the bearing outer diameter with a housing, is determined by the ISO 286 tolerances for shafts and housings in conjunction with the actual bore and OD tolerances of the bearing. The ISO tolerances are defined as tolerance zones. They are determined by their position relative to the zero line (=tolerance position) and their size (=tolerance grade per ISO 286). The tolerance position is denoted by letters (upper case for housings and lower case for shafts).

The following tables are recommendations for shaft and housing tolerances that apply to both normal fitting and operating conditions. Based on particular conditions or requirements it may be necessary to deviate from these recommendations. For example, if during operation there is an increase in temperature of the inner ring, the seating with the shaft may loosen. Then a tighter then recommended fit must be selected.

In these cases, all of the requirements must be weighed against each other. The fit that provides the best solution and performance should be selected.

Fitting of Bearing and Shaft:

CONDITION (Steel shaft)		SHAFT BORE DIAMETER	SHAFT TOLERANCE CLASS	
			THIN TYPE	OTHERS
Inner Ring Rotating Or Indeterminate Load Direction	Light Load ≤0.06 Cr Or Fluctuating Load	10≤d≤18 18≤d≤30 30≤d≤50	h5 h5 h5	js5 js5 js5
	Standard Load = 0.06-0.12 CR	10≤d≤18 18≤d≤30 30≤d≤50	js5 js5 js5	j5 k5 k5
Outer Ring Rotating Load	Necessary For Inner Ring Turning Easily Around Shaft	All Bore Diameter	g5	g6
	Unnecessary For Inner Ring Turning Easily Around Shaft	All Bore Diamter	h5	h6

Fitting of Housing and Bearing:

CONDITION (ONE PIECE HOUSING)		AXIAL DIRECTIONAL MOVEMENT OF OUTER RING	TOLERANCE CLASS OF SHAFT HOUSING SEATS	
			THIN TYPE	OTHERS
Inner Ring Rotating Load	Varying Loads	Easy To Move	H6	H7
	Light Or Standard Load	Easy To Move	H7	H8
	High Temperature Of Inner Ring And Shaft	Easy To Move	G6	G7
	Light Or Standard Load Precise Rotation	Impossible To Move	K5	K6
		Possible To Move	JS6	J6
	Quiet Operation	Easy To Move	H6	H6
Indeterminate Load Direction	Light Or Standard Load	Possible To Move	JS6	J7
	Standard Or Heavy Load	Impossible To Move	K5	K7
	Large Shock Load	Impossible To Move	M5	M7
	Light Or Fluctuating Load	Impossible To Move	M5	M7
Outer Ring Rotating Load	Standard Or Heavy Load	Impossible To Move	N5	N7
	Thin Type Housing Seats Heavy Load Or Large Shock Load	Impossible To Move	P6	P7

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

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

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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 (°C), 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 (°C)
a= Coefficient of thermal expansion for bearing steel = 12.5×10^{-6} (I/°C)
Coefficient of thermal expansion for stainless steel = 10.3×10^{-6} (I/°C)
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°)	
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

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