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DESIGN FACTORS WHEN USING SMALL BEARINGS

Part 1: Bearing Geometry

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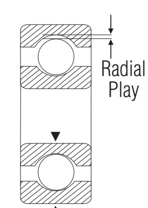
Miniature single-row deep-groove ball bearings are made to extremely high levels of precision and have an OD of 1/2 inch or less. Because of their small size, these bearings are generally used in applications where accurate, repeatable rotational performance and low torque are a necessity and load carrying capacity is a secondary issue. Miniature bearings are typically used in disk drives, positioning systems, medical equipment, guidance system components and other high-precision applications.

In order to optimize a design using miniature bearings, it is necessary to consider how the internal geometry of the bearings affects their performance in an assembly. This article addresses some fundamentals of bearing geometry and its implications on performance that an engineer might want to consider in selecting and using a particular miniature bearing.

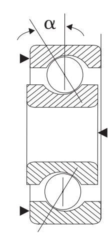
Radial Play and Contact Angle

For a single-row deep-groove ball bearing, one of the major design parameters is *radial play*. This is defined as the maximum distance that one bearing ring can be displaced relative to the other ring in a direction perpendicular to the axis of rotation of the bearing.



Radial Play

Radial play can be thought of as the natural looseness of the bearing. The amount of looseness is controlled during manufacture and is specified by the user through selection of a given radial play for the bearing. Radial play is an important factor in the performance of a bearing since it affects the contact angle between the balls and the raceways.



Contact Angle

Common radial play values are given in the table below:

STANDARD RADIAL PLAY RANGES AND APPLICATIONS Dimensions in .0001 inch (.001 mm)

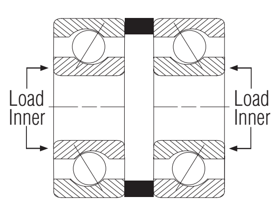
DYNAROLL CODE	DESCRIPTION	RADIAL PLAY RANGE		APPLICATION
MIN	MAX			
MC2	Tight	1 (3)	3 (8)	Low backlash gear systems with predominantly radial loading.
MC3	Standard	2 (5)	4 (10)	Low speed electric motors.
MC4	Standard	3 (8)	5 (13)	Gears, belt drive, tape guides, synchros, servos.
MC5	Loose	5 (13)	8 (20)	High speed electric motors, tape guides, radial and axial loading.

Note: final radial play *after assembly* is the important operating condition, therefore, compensation for interference must be made in the bearing specification.

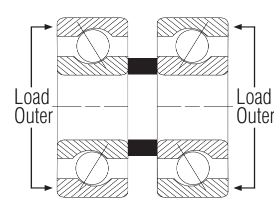
Note that bearing manufacturers' radial play values are given as a range. Tighter tolerance of the radial play may be specified, but it will increase the cost of the bearing since a sorting process is used to select specific radial play values.

Preload and Axial Play

In an application where accurate rotation is needed, the radial play must be removed from the bearing. Unless this is done, the races can bounce around relative to each other. The radial play is normally removed by using a pair of bearings which are preloaded to remove the play by pressing the races together axially until the balls are in firm contact with the raceways.



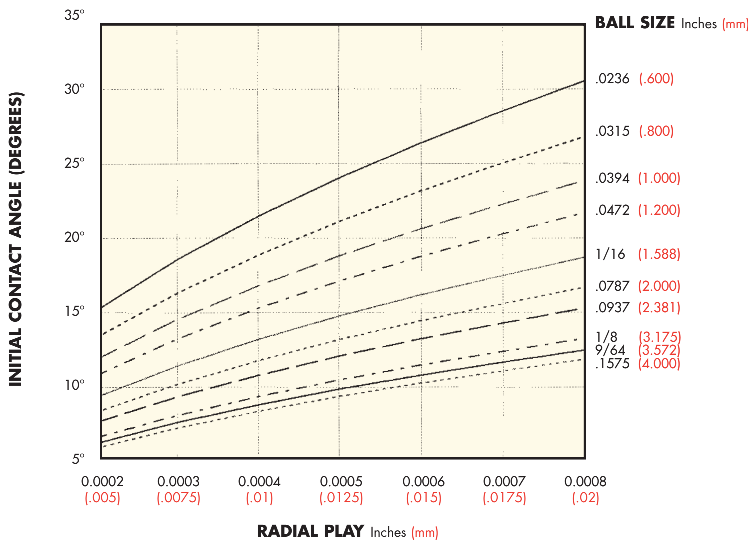
O-Type Preload
Stiffer

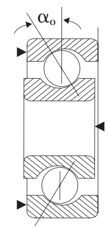


X-Type Preload
Less Stiff

Note that in the examples above, preload is achieved by pressing the inner races together (or outer races apart) to give O-type preload or by pressing the outer races together (or inner races apart) to give X-type preload. The O and X refer to the shape formed by the contact angle lines in the diagrams.

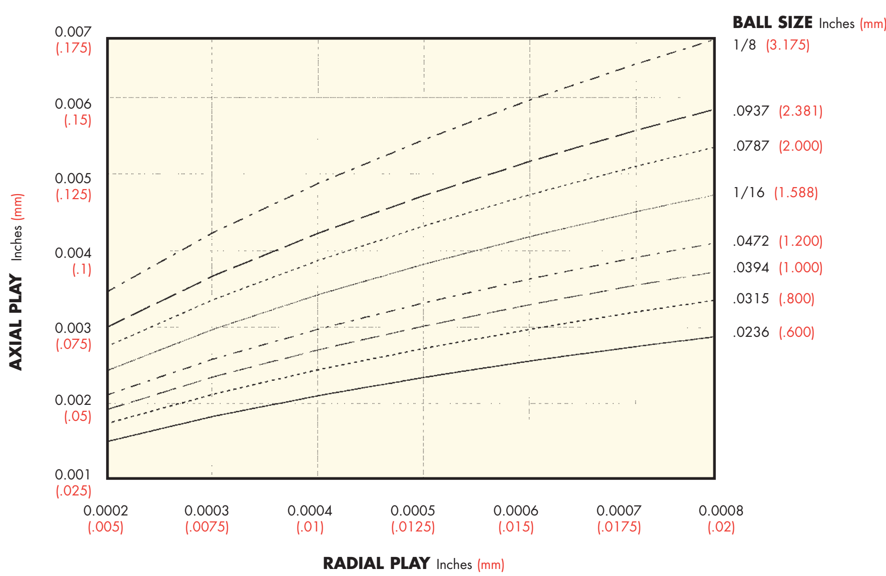
Once the preload has been applied, the balls will sit at the ball contact angle. This angle will increase as more preload is applied, and the starting value of this angle (the initial contact angle) will be larger for larger radial play values.

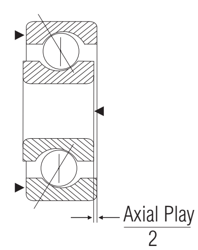




Initial Contact Angle

The axial displacement of the raceways relative to each other under load is the *axial play*. It is typically 8-10 times the radial play for a given bearing and so must be acccounted for in any design.

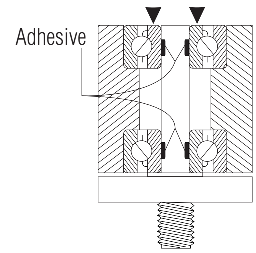




Methods of Preloading

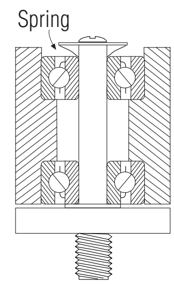
Deadweight:

A fixed weight is set against the bearing ring while adhesive cures to retain the bearings.



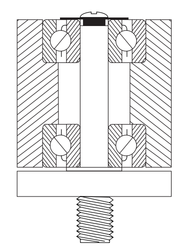
Spring:

A spring (often Belleville type) is used to press the races together or apart. Note that this assembly will have minimal stiffness, controlled by the spring rate rather than the raceway/ball elasticity.



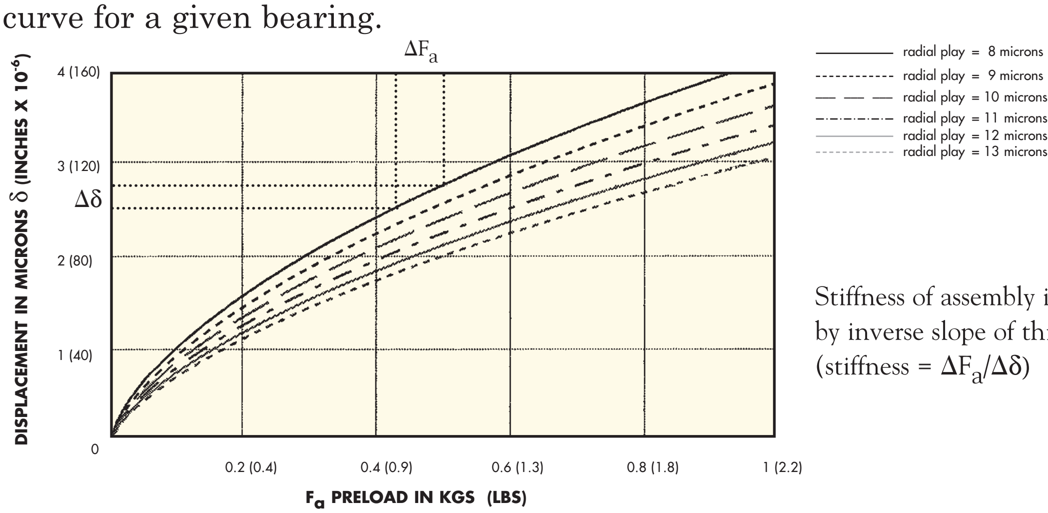
Solid clamping:

Component parts are machined to precise matched dimensions to remove play when the races are solidly clamped together (Duplex pairs). This method is expensive and not really suited to high volume mass-production.



Stiffness and Resonance

A calculation can be made to determine the displacement vs. preload curve for a given bearing.



Stiffness of assembly is given by inverse slope of this curve (stiffness = $\Delta F_a/\Delta\delta$)

This shows the amount of additional axial displacement of a bearing raceway as the preload force is increased. The axial stiffness is the inverse of the slope of this curve. It can be seen that higher radial play values lead to higher stiffness. This makes sense since a looser bearing will allow the ball to move higher in the raceway under axial load (higher contact angle), providing more resistance to axial movement.

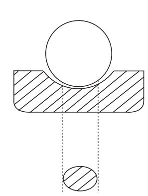
The above curve is important in calculating the amount of preload to apply to a bearing assembly. For miniature bearings, typical preloads are in the range of 0.5 to 2 lbs, less for very small bearings. This region of the curve is where the bearing has more compliance and the loads are such that lifetime/wear is not affected. At much higher preloads, approaching the static load rating of the bearing, damage and much reduced lifetime will occur.

<u>Note on handling preloaded bearing assemblies:</u> The displacement vs. preload curve is also relevant in understanding how to handle miniature bearing assemblies. At higher preloads, a change in displacement of 1-2 microns (<0.0001 inch) will produce an increase in force of many pounds. What this means is that preloaded assemblies are quite susceptible to shock loads and must be handled accordingly. Many engineers are surprised to find that a small pivot assembly will become brinelled (raceway damage) when dropped from a height of only a few inches onto a lab bench.

The *radial stiffness*, resistance to radial loads on the bearing, varies in the opposite manner to axial stiffness since lower radial play (lower contact angle of the ball) provides more resistance to radial movement.

Stiffness of a bearing assembly is of interest in designing for higher resonance frequency or for higher moment resistance. It should be noted that axial and radial stiffness move oppositely relative to changes in radial play. The only way to increase both axial and radial stiffness at the same time is to increase the amount of preload applied.

Torque



The contact area of the ball to the raceway is called the contact ellipse. In general, a larger contact ellipse will give higher torque. As the radial play increases and the ball moves higher in the raceway (bigger contact angle), the contact ellipse becomes smaller for a given applied axial load.

This leads to some simple rules in designing for lower torque.

Factor	**Torque effect**
Ball size	Smaller gives lower torque
Number of balls	Fewer gives lower torque
Radial play	Higher gives lower torque
Applied load	Higher gives higher torque

Of course, there are other factors, such as choice of lubricant and retainer type that also effect torque, but the above are the rules for bearing geometry considerations.

The chart below can be used as a simple guide to expected average torque levels for individual bearings with oil lubricant, however, the user must be cautioned that real-life torque values will vary considerably according to the application.

AVERAGE BEARING TORQUE (GM-CM)

DYNAROLL BEARING SIZE (Inch Series)	RETAINER TYPE	BALL SIZE Inch (mm)	# BALLS	THRUST LOAD (gm)	MAX. AVG. TORQUE (gm-cm), OIL LUBE @ INDICATED THRUST — RADIAL PLAY Inches (mm)		
					MC2 .0001-.0003 .002-.008	MC3 .0002 -.0004 .005-.010	MC5 .0005 -.0008 .013-.020
09, 0, 1,1-4, 1-5 144, 155, 156, 168	Crown (W)	≤ 1/16	≤ 13	75	.18	.15	.14
2-5	Ribbon (J)	1/16	6	75	.18	.15	.14
2-6, 2, 166	Ribbon (J)	1/16	≤ 8	75	.2	.16	.15
188	Ribbon (J)	2	8	400	.63	.54	.49
3	Ribbon (J)	3/32	7	400	.65	.55	.5
4	Ribbon (J)	3/32	8	400	.7	.6	.55

Conclusion

This article is supposed to be a general introduction to bearing geometry issues in miniature single-row deep-groove radial ball bearings. More detailed information, including formulae used and a deeper discussion of bearing issues is available from www.dynaroll.com