

## Radial Play (Internal Clearance) in Ball Bearings

At first glance, ball bearings are relatively simple mechanisms. However, an analysis of their internal geometries reveals that they are quite complex. For example, the ball to raceway conformity, the radial play, and the number of balls all impact the ability a ball bearing to support loads under a variety of conditions. Typically, ball and other rolling element bearings are designed and assembled with a slight amount of internal looseness between the rolling elements (balls), and the raceways. This looseness results in both **radial play** and **axial play** in the bearing.

It should be noted that due to the nature of their design and construction, the internal geometry of needle, roller, and tapered roller bearings is quite different than that found in ball bearings. For example, tapered roller bearings are somewhat unique in that the clearance within the bearing is adjusted at the time of assembly. Radial play and running clearance or of primary importance an all rolling element bearings. In this Technical Information Sheet (TIS), the discussion of contact angle, deflection, end play, and preload applies primarily to ball bearings.

### Definition of Radial Play in a Ball Bearing

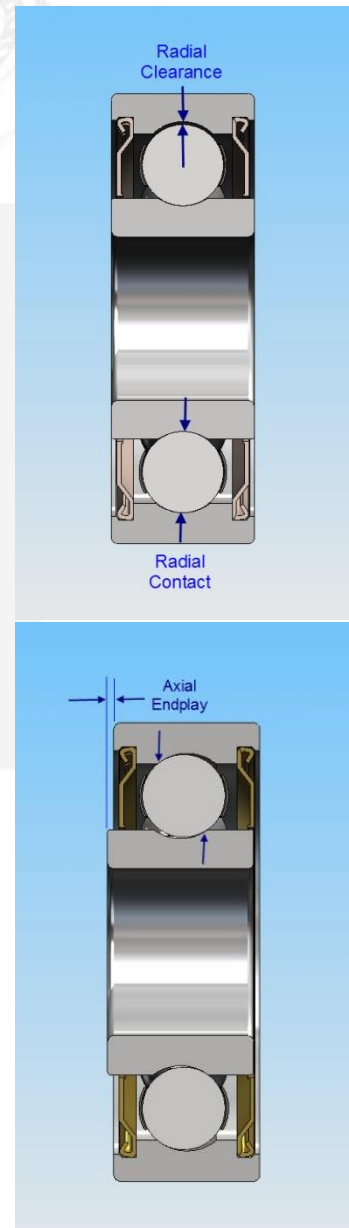
**Radial play**, or internal clearance, is the internal radial looseness in a bearing and is the measured value of the total radial movement of the outer ring with respect to the inner ring in a plane perpendicular to the bearing axis. Ball bearings are assembled to radial play values depending upon a desired range. The radial play is determined by the actual raceway diameters and ball diameter.

Radial play can be verified on assembled bearings using specially designed gages. When measuring the radial play, the bearing is subjected to a standard gage load to ensure full contact between all the bearing components. With regard to miniature and thin section bearings under such a load, the measured value is larger than the stated value for radial play. This is due to elastic deformation. Compensation factors are used in these cases.

### Definition of Axial Play in a Ball Bearing

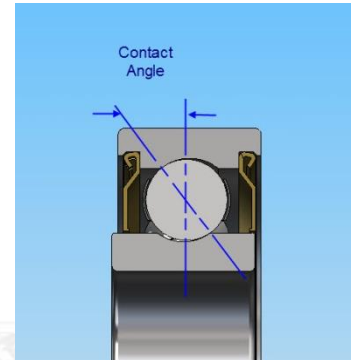
**Axial, or end play**, is the maximum relative axial movement of the inner ring with respect to the outer ring. The end play is directly related to the radial play of the ball bearing. In most part numbering systems axial play is not normally specified.

There is often confusion with “looseness” and precision level. Radial play is specified independently of ABEC tolerance classes for rings. With ball bearings, in most cases, the internal looseness should be removed in the assembly process by applying an axial preload across the pair of bearings. This can be accomplished with shims, springs, take up nuts, and/or other assembly techniques. Axial preload is also an important design parameter that affects both performance and life. Preload is explained in further detail in a separate Technical Information Sheet (TIS).



## Contact Angle in a Ball Bearing

When ball bearings are axially preloaded a **contact angle** is established. The contact angle is the angle between a plane perpendicular to the bearing axis and a line joining the two contact points between the ball and the inner and outer raceways. The initial contact angle is the contact angle when the bearing is subjected to the minimal axial force or load necessary to remove the looseness resulting from the radial play. Additional applied axial loads will increase the contact angle further. The greater the value of radial play in the bearing, the greater the resulting contact angle will be.



In most bearing applications, radial play, from a functional point of view, is more critical than axial play. As a result, it has become the standard purchasing specification.

### General Design Considerations:

The selection of the radial play value in a specific bearing application is an important design consideration. As described previously, radial play directly affects the contact angle and axial, or end, play of the bearing. In addition, in operation it is an important factor that has a significant influence on other factors such as noise, vibration, heat, stress, deflection, load distribution and fatigue life.

**Fitting:** A looser or greater value of radial play should be selected when the bearing is mounted using interference fits. The radial clearance in the bearing is reduced after mounting due to deformation of the inner or outer rings. With miniature bearings having very thin cross section rings, the radial play is reduced by approximately 80% of the actual amount of interference. The radial play after mounting is the primary design consideration. Therefore, a tolerance study of the mating components should be completed and compensation for the interference at maximum material condition must be made. For maximum life, a positive clearance after mounting is desired.

**Loading:** When a ball bearing is subjected to thrust loading, a higher contact angle will result in reduced ball to raceway stresses. Greater values of radial play result in higher values of contact angle. Under these conditions, this will provide longer bearing life, lower torque, and less axial deflection. In a pure thrust situation, a 15° increase in contact angle can result in over a 70% reduction in contact stress (ball-to-raceway).

When a ball bearing is subjected to pure radial loads (or radial load with low axial load), lower radial play is normally recommended. This distributes the load over a greater number of balls. However, particularly with miniature bearings, bearings with low radial play should not be subjected to interference fits. This can result in negative clearance and drastically reduce life.

**Misalignment and Positioning:** Higher values of radial play allow for greater misalignment and should be selected in cases where there is a high degree of shaft deflection. It should be noted, although a ball bearing has the ability to compensate (around 1° or less), misalignment greatly reduces bearing life. However, in cases with light loads, the impact of minor misalignment may be tolerable.

Tighter values of radial play will of course control and restrict radial movement.

When axial positioning must be controlled or end play of “zero” is desired, it is recommended that the end play be removed by applying axial preload via shims, washers, or other assembly methods. Duplex



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bearings should be considered as well. It is not advisable to use low values of radial play to control end play.

**Temperature:** When a high temperature gradient exists between the inner and outer rings a looser radial play is recommended.

**Speed:** As mentioned previously, high values of radial play result in high values of contact angle. When a bearing is rotating, the set of balls (or ball complement) is rotating about the pitch circle of the bearing, each ball is rotating about its own axis, and gyratory moments are acting upon the balls. The magnitude of the gyratory moment is related to the contact angle. As rotational speed increases, the gyratory forces acting on the balls increases and there is sliding action between the balls and the raceways. This slippage results in lubricant film failure, increased heat, and potential premature failure. The balance between the benefits of contact angle reducing stress must be weighed against the potential for lubricant failure due to ball slippage.

### Specifying Radial Play:

It is not practical, or perhaps even possible, to produce a group of bearings that all have the exact same amount of radial play. This is because all of the features of the bearing components (inner ring raceway, outer ring raceway, and balls) that effect radial play, have manufacturing tolerances associated with them. Manufacturers measure and sort the bearing rings and balls so that they can be "matched" during the assembly process to achieve a specific range of radial play for a group (or manufacturing lot) of bearings.

There are several ways to specify radial play. Radial play specifications are usually manufacturer dependent. Complete part number descriptions are detailed in a separate Technical Information Sheet (TIS). AST specifies radial play as follows:

For metric design ball bearings (miniature and instrument) with a bore diameter of less than 10 mm.

Clearance Symbol		MC1 (Extra Tight)	MC2 (Tight)	MC3 (Normal)	MC4 (Normal +)	MC5 (Loose)	MC6 (Extra Loose)
Actual Clearance in uM	min	0	3	5	8	13	20
	max	5	8	10	13	20	28
Actual Clearance in inches	min	0	0.0001	0.0002	0.0003	0.0005	0.0008
	max	0.0002	0.0003	0.0004	0.0005	0.0008	0.0011

For inch design ball bearings (miniature and instrument) with a bore diameter of less than 10 mm.

AST CODE	Actual Radial Play Range in Inches	Classification
K13 or P13	.0001 to .0003	Tight
K25 or P25	.0002 to .0005	Normal
K58 or P58	.0005 to .0008	Loose
K811 or P811	.0008 to .0011	Extra Loose



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For deep groove ball bearings with a bore diameter of 10 mm or greater the following tables are used.

## Clearance for Radial Deep Groove Ball Bearings in Micrometers

Bore Diameter (d) in mm		Bore Diameter (d) in inches		C2 (less than standard clearance)		C0 (standard clearance)		C3 (greater than standard clearance)		C4 (greater than C3 clearance)		C5 (greater than C4 clearance)	
OVER	INCL.	OVER	INCL.	min.	max	min.	max.	min.	max.	min.	max.	min.	max.
2.5	6	0.0984	0.2362	0	7	2	13	8	23	-	-	-	-
6	10	0.2362	0.3937	0	7	2	13	8	23	14	29	20	37
10	18	0.3937	0.7087	0	9	3	18	11	25	18	33	25	45
18	24	0.7087	0.9449	0	10	5	20	13	28	20	36	28	48
24	30	0.9449	1.1811	1	11	5	20	13	28	23	41	30	53
30	40	1.1811	1.5748	1	11	6	20	15	33	28	46	40	64
40	50	1.5748	1.9685	1	11	6	23	18	36	30	51	45	73
50	65	1.9685	2.5591	1	15	8	28	23	43	38	61	55	90
65	80	2.5591	3.1496	1	15	10	30	25	51	46	71	65	105
80	100	3.1496	3.9370	1	18	12	36	30	58	53	84	75	120
100	120	3.9370	4.7244	2	20	15	41	36	66	61	97	90	140
120	140	4.7244	5.5118	2	23	18	48	41	81	71	114	105	160

Values are in micrometers

## Clearance for Radial Deep Groove Ball Bearings in Inches (.0001")

Bore Diameter (d) in mm		Bore Diameter (d) in inches		C2 (less than standard clearance)		C0 (standard clearance)		C3 (greater than standard clearance)		C4 (greater than C3 clearance)		C5 (greater than C4 clearance)	
OVER	INCL.	OVER	INCL.	min.	max	min.	max.	min.	max.	min.	max.	min.	max.
2.5	6	0.0984	0.2362	0	3	1	5	3	9	-	-	-	-
6	10	0.2362	0.3937	0	3	1	5	3	9	6	11	8	15
10	18	0.3937	0.7087	0	3.5	1	7	4.5	10	7	13	10	18
18	24	0.7087	0.9449	0	4	2	8	5	11	8	14	11	19
24	30	0.9449	1.1811	0.5	4.5	2	8	5	11	9	16	12	21
30	40	1.1811	1.5748	0.5	4.5	2.5	8	6	13	11	18	16	25
40	50	1.5748	1.9685	0.5	4.5	2.5	9	7	14	12	20	18	29
50	65	1.9685	2.5591	0.5	6	3	11	9	17	15	24	22	35
65	80	2.5591	3.1496	0.5	6	4	12	10	20	18	28	26	41
80	100	3.1496	3.9370	0.5	7	4.5	14	12	23	21	33	30	47
100	120	3.9370	4.7244	1	8	6	16	14	26	24	38	35	55
120	140	4.7244	5.5118	1	9	7	19	16	32	28	45	41	63

Values are in .0001 inches

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