3 Bearing Tolerance

3.1Bearing Tolerance

Bearing “tolerances” or dimensional accuracy and running accuracy, are regulated by ISO 492:2002 and JIS B 1514 standards (rolling bearing tolerances) shown in Table 3.1 and 3.2.

The dimensional accuracy governs the tolerances that must be satisfied when mounting a bearing to a shaft or housing, while the running accuracy defines a permissible run-out occurring when rotating a bearing by one revolution. Appendix III shows bearing accuracy for angular contact ball bearings, BS series bearings, and cylindrical roller bearings. Methods for measuring the accuracy of rolling bearings are described in JIS B 1515 and in Table 3.3.

Table 3.1 Bearing types and applicable tolerance

Standard	Applicable standerd	Tolerance Class					Bearing Types
Japanese industrial standard (JIS)	JIS B 1514	Class 0,6X	Class 6	Class 5	Class 4	Class 2	All type
International Organization for Standardization (ISO)	ISO 492	Normal class Class 6X	Class 6	Class 5	Class 4	Class 2	Radial bearings
	ISO 199	Normal Class	Class 6	Class 5	Class 4	—	Thrust ball bearings
	ISO 578	Class 4	—	Class 3	Class 0	Class 00	Tapered roller bearings (Inch series)
	ISO 1224	—	—	Class 5A	Class 4A	—	Precision instrument bearings
Deutsches Institut fur Normung(DIN)	DIN 620	P0	P6	P5	P4	P2	All type
American National Standards Institute (ANSI) American Bearing Manufacturer's Association (ABMA)	ANSI/ABMA Std.20	ABEC-1 RBEC-1	ABEC-3 RBEC-3	ABEC-5 RBEC-5	ABEC-7	ABEC-9	Radial bearings (Except tapered roller bearings)
	ANSI/ABMA Std.19.1	Class K	Class N	Class C	Class B	Class A	Tapered roller bearings (Metric series)
	ANSI/ABMA Std.19	Class 4	Class 2	Class 3	Class 0	Class 00	Tapered roller bearings (Inch series)

1 "ABEC" is applied for ball bearings and "RBEC" for roller bearings.
Notes 1: JIS B 1514, ISO 492 and 199, and DIN 620 have the same specification level.
2: The tolerance and allowance of JIS B 1514 are slightly different from those of ABMA standards.

Table 3.2 Comparison of tolerance classifications of national standards

Bearing type		Applicable standard	Tolerance class				
Angular contact ball bearings		JIS B 1514 (ISO 492)	Class 0	Class 6	Class 5	Class 4	Class 2
Cylindrical roller bearigns			Class 0	Class 6	Class 5	Class 4	Class 2
Needle roller bearings			Class 0	Class 6	Class 5	Class 4	—
Tapered roller bearings	Metric	JIS B 1514	Class 0.6X	Class 6	Class 5	Class 4	—
	Inch	ANSI/ABMA Std.19	Class 4	Class 2	Class 3	Class 0	Class 00
	J series	ANSI/ABMA Std.19.1	Class K	Class N	Class C	Class B	Class A
Double row angular contact thrust ball bearings		TPI standard	—	—	Class 5	Class 4	—

To attain a higher level of running accuracy required of a main spindle of machine tool, a high-precision bearing that satisfies the user's main spindle specifications must be chosen. Usually, a high precision bearing per JIS accuracy class 5, 4 or 2 is selected according to an intended application. In particular, the radial run-out, axial run-out and nonrepetitive run-out of a main spindle bearing greatly affect the running accuracy of the main spindle and therefore have to be strictly controlled. With the recent super high-precision machine tools, the control of N.R.R.O. (Non-Repetitive Run-Out) has increasing importance, and the main spindle on a turning machine or machining center incorporates an N.R.R.O. accuracy controlled bearing.

For cylindrical roller bearings, the accuracies of tapered bores conform with JIS Classes 4 and 2 as shown in Table 3.4. Poor accuracies of the tapered bore lead to misalignment of the inner ring, causing poor performance, premature seizure and flaking. Use of a taper gauge is recommended for higher accuracy of the main spindle. Refer to "8 Handling of Bearings, Clearance adjustment for cylindrical roller bearing" for more information on taper angle.

Table 3.3 Measuring methods for running accuracies

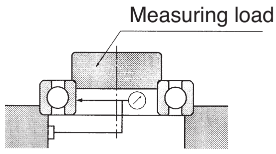
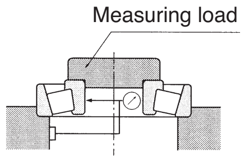
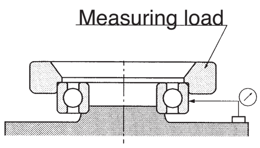
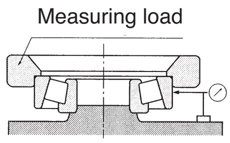
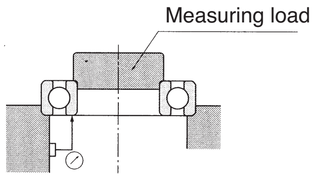
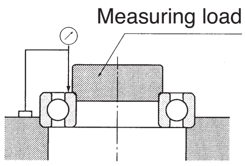
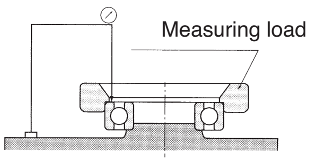
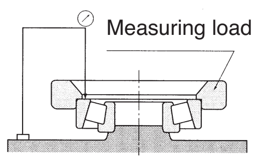
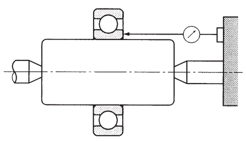
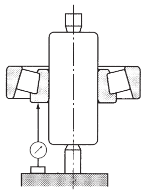
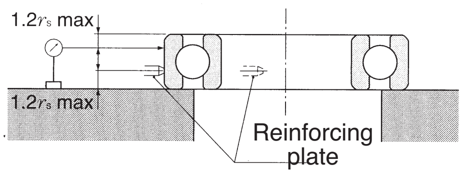
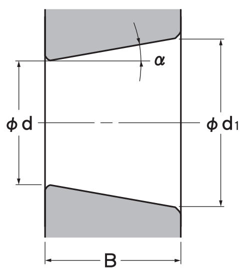
Characteristic tolerance	Measurement method	Explanation
Inner ring radial runout (K_{ia})	 	For inner ring radial runout, record the total indicator reading (TIR)
Outer ring radial runout (K_{ea})	 	For outer ring radial runout, record the total indicator reading (TIR) after one revolution.
Inner ring axial runout (S_{ia})	 	For inner ring axial runout, record the total indicator reading (TIR) after rotating the inner ring one revolution.
Outer ring axial runout (S_{ea})	 	For outer ring axial runout, record the total indicator reading (TIR) after rotating the inner ring one revolution.
Inner ring side runout with bore (S_d)	 	For inner ring side runout with bore, record the total indicator reading (TIR) after rotating the inner ring one revolution with a tapered mandrel.
Outer ring outside (S_D)		For outer ring outside surface inclination, record the total indicator reading (TIR) after aligning the ring with the reinforcing plate and rotating it one revolution.

Table 3.4 Tolerance of taper-bored bearings

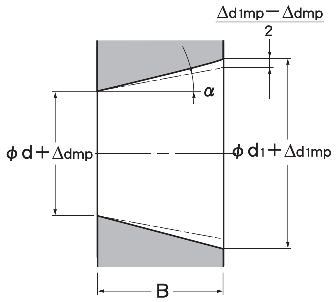
Unit: μm

d mm		Δd_{mp}				$\Delta d_{1mp}-\Delta d_{mp}$ (approx.)				V_{dp}	
		Class 4		Class 2		Class 4		Class 2		Class 4	Class 2
over	incl.	high	low	high	low	high	low	high	low	max	
18	30	+10	0	+ 6	0	+ 4	0	+3	0	2.5	1.5
30	50	+12	0	+ 7	0	+ 5	0	+3.5	0	2.5	1.5
50	80	+15	0	+ 8	0	+ 6	0	+4	0	3	2
80	120	+20	0	+10	0	+ 7	0	+5	0	4	2.5
120	180	+25	0	+12	0	+ 8	0	+6	0	5	3.5
180	250	+29	0	+14	0	+ 9	0	+7	0	7	4.5
250	315	+32	0	–	–	+10	0	–	–	8	–
315	400	+36	0	–	–	+12	0	–	–	9	–
400	500	+40	0	–	–	+14	0	–	–	10	–

Note: **NTN** specification



Theoretical tapered bore



Tapered bore having single plane mean bore diameter deviation

Tolerance of 1/12 taper angle $4^\circ 46' 18.8''\ ^{+24''}_{0}$

$\alpha = 2^\circ 23' 9.4''$

$d_1 = d + \frac{1}{12} B$

V_{dp} : Single radial plane bore diameter variation

Δd_{mp} : Single plane mean bore diameter deviation (at theoretical small end on tapered bore)

Δd_{1mp} : Single plane mean bore diameter deviation (at theoretical large end on tapered bore)

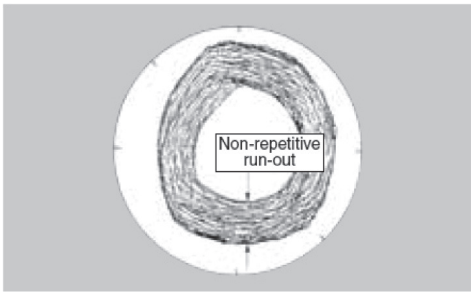
B : Nominal inner ring width

3.2 N.R.R.O. (Non-Repetitive Run-Out) of bearing

Accuracies of rolling bearings are defined by applicable ISO standards and a JIS standard, wherein the accuracies are discussed under the descriptions according to the methods for measuring running accuracies in Table 3.3. In fact, however, a rolling bearing for machine tool is used in a continuous revolving motion that involves more than one revolution. As a result, the actual run-out accuracy with a rolling bearing includes elements that are not synchronous with the revolution of the bearing , causing the trajectory of plotting with running accuracies to vary with each revolution shown in Fig.3.1.

The run-out of an element not in synchronization with the revolutions of bearing may be caused by form accuracy of raceways, dimension tolerance of rolling elements, and N.R.R.O. accuracy of cage under high speed condition etc. Improvement in spindle form accuracy could lead to higher precision workpiece and better tolerance and surface roughness of mold tooling.

Fig.3.1 Illustration of non-repetitive run-out

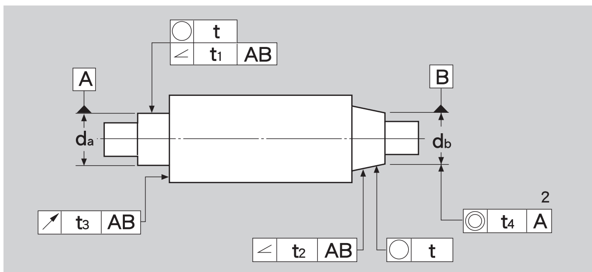


3.3 Accuracies of Shaft and Housing

Depending on the fit of a bearing to a shaft and a housing, the bearing internal clearance can vary. For this reason, an adequate bearing fit has to be attained so that the bearing can perform as designed. Table 3.5 and 3.6 show the accuracies of shaft and housing. Table 3.7 lists the fundamental tolerance IT mentioned in Table 3.5 and 3.6.

Also, the axial tightening torque on a bearing needs to be considered. To avoid deformation of bearing raceway surface owing to axial tightening of the bearing, it is necessary to carefully determine the dimensions of components associated with a tightening force the magnitude of tightening force and the number of tightening bolts.

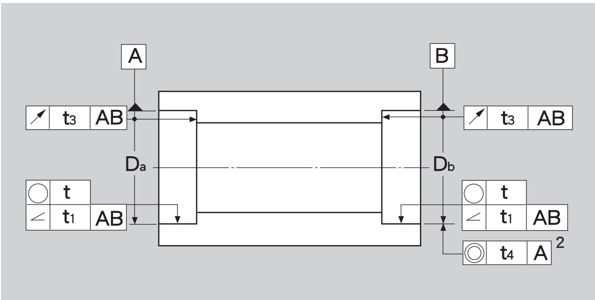
Table 3.5 Form accuracy of spindle



Accuracy	Symbol	Tolerance[3]	Fundamental permissible tolerance IT		
			P5	P4	P2
Deviation from circular form	○	t	$\frac{IT3}{2}$	$\frac{IT2}{2}$	$\frac{IT0}{2}$ [4]
Angularity	∠	t_1	$\frac{IT3}{2}$	$\frac{IT2}{2}$	$\frac{IT0}{2}$ [4]
	∠	t_2	—	$\frac{IT3}{2}$	$\frac{IT2}{2}$
Run out	↗	t_3	IT3	IT3	IT2
Eccentricity	◎	t_4	IT5	IT4	IT3

1 The form tolerance, symbol, and reference face of spindle are in accordance with ISO R1101.
2 The length of the bearing fit surface is often too small to measure concentricity. Therefore, this criterion applies only when the fit surface has a width sufficient as a reference face.
3 When determining a tolerance for permissible form accuracy, the reference dimensions used are shaft diameters d_a and d_b.
For example, when using a JIS class 5 bearing for a dia. 50 mm shaft, the tolerance of roundness is t = IT3/2 = 4/2=2 μm.
4 IT0 is preferred if the diameter tolerance of the bearing fit surface is IT3.

Table 3.6 Form accuracy of housing



Accuracy	Symbol	Tolerance[3]	Fundamental permissible tolerance IT		
			P5	P4	P2
Deviation from circular form	○	t	$\frac{IT3}{2}$	$\frac{IT2}{2}$	$\frac{IT1}{2}$
Angularity	∠	t_1	$\frac{IT3}{2}$	$\frac{IT2}{2}$	$\frac{IT1}{2}$
Run out	↗	t_3	IT3	IT3	IT2
Eccentricity	◎	t_4	IT5	IT4	IT3

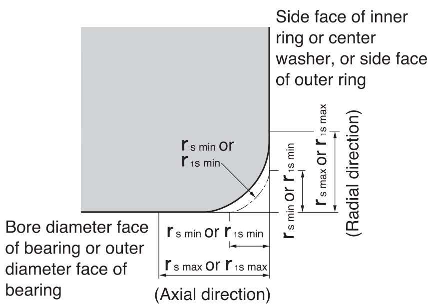
1 The form tolerance, symbol and reference face of the housing are in accordance with ISO R1101.
2 The length of the bearing fit surface is often too small to measure concentricity. Therefore, this criterion applies only when the fit surface has a width sufficient as a reference face.
3 Housing bore diameters D_a and D_b are the reference dimensions used when the tolerance for permissible form accuracy are determined.
For example, when a JIS class 5 bearing is used for a housing with a 50 mm inside bore, the tolerance of roundness is t = IT3/2 = 5/2 = 2.5 μm.

Table 3.7 Fundamental tolerance IT

Classification of nominal dimension mm		Fundamental tolerance IT value μm				
over	incl.	IT0	IT1	IT2	IT3	IT4
6	10	0.6	1	1.5	2.5	4
10	18	0.8	1.2	2	3	5
18	30	1	1.5	2.5	4	6
30	50	1	1.5	2.5	4	7
50	80	1.2	2	3	5	8
80	120	1.5	2.5	4	6	10
120	180	2	3.5	5	8	12
180	250	3	4.5	7	10	14
250	315	4	6	8	12	16
315	400	5	7	9	13	18
400	500	6	8	10	15	20

In designing a bearing and housing, it is very important to provide a sufficient shoulder height for the bearing and housing so as to maintain bearing and housing accuracies and to avoid interference with the bearing related corner radius. The chamfer dimensions are shown in Table 3.8 and the recommended shoulder height and corner radii on the shaft and housing are listed in Table 3.9.

Table 3.8 Allowable critical-value of bearing chamfer Radial bearings



Unit : mm

r_s min[1] or r_{1s} min	Nominal bore diameter d		$r_{s\,max}$ or $r_{1s\,max}$	
	over	incl.	Radial direction	Axial direction
0.05	-	-	0.1	0.2
0.08	-	-	0.16	0.3
0.1	-	-	0.2	0.4
0.15	-	-	0.3	0.6
0.2	-	-	0.5	0.8
0.3	-	40	0.6	1
	40	-	0.8	1
0.6	-	40	1	2
	40	-	1.3	2
1	-	50	1.5	3
	50	-	1.9	3
1.1	-	120	2	3.5
	120	-	2.5	4
1.5	-	120	2.3	4
	120	-	3	5
2	-	80	3	4.5
	80	220	3.5	5
	220	-	3.8	6

Table 3.9 Fillet radius and abutment heigh

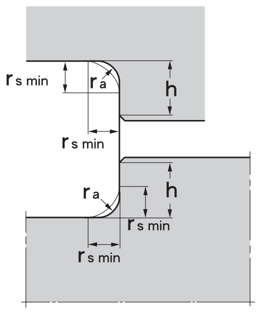
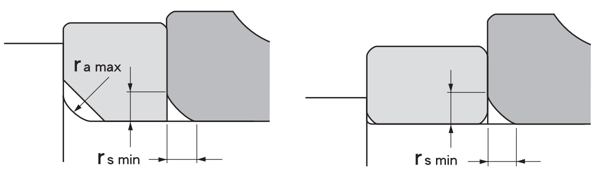


Fig. 3.2 Bearing mounting with spacer



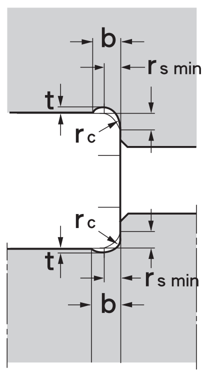
(a) (b)

Unit : mm

r_s min	r_{as} max	h (min)
		Normal use[1]
0.05	0.05	0.3
0.08	0.08	0.3
0.1	0.1	0.4
0.15	0.15	0.6
0.2	0.2	0.8
0.3	0.3	1.25
0.6	0.6	2.25
1	1	2.75
1.1	1	3.5
1.5	1.5	4.25
2	2	5
2.1	2	6
2.5	2	6
3	2.5	7
4	3	9
5	4	11
6	5	14
7.5	6	18
9.5	8	22
12	10	27
15	12	32
19	15	42

1 If bearing supports large axial load, the height of the shoulder must exceed the value given here.
Note: *ras max* maximum allowable fillet radius.

Table 3.10 Relief dimensions for grounding



r_s min	Relief dimensions		
	b	*t*	r_c
1	2	0.2	1.3
1.1	2.4	0.3	1.5
1.5	3.2	0.4	2
2	4	0.5	2.5
2.1	4	0.5	2.5
2.5	4	0.5	2.5
3	4.7	0.5	3
4	5.9	0.5	4
5	7.4	0.6	5
6	8.6	0.6	6
7.5	10	0.6	7

3.4 Accuracies of Shaft and Housing

If the dmN value is in the range of dmN≦750×10³ (dmN value is defined in Section 9.2), the fit values shown in Tables 3.11 and 3.12 are recommended to ensure high accuracies of precision bearings.

If the dmN value is in the range of dmN＞750×10³, it is necessary to consider expansion of inner ring caused by centrifugal force. It also influences preload in bearings. In this case, more detailed analysis is needed from some simulation tools such as TH-BBAN software for determining bearing fit and possibly increasing interference fit to compensate the centrifugal effect.

Fits given in Table 3.13 are recommended for high speed thrust angular contact ball bearings. To maintain high accuracy, provision of interference between the shaft and the bore of inner ring is essential. The fit of the housing and bearing should be same as that for cylindrical roller bearings, since an angular contact ball bearing is normally used together with a cylindrical roller bearing. For a cylindrical roller bearing with taper bore, when fitting a tapered bore bearing onto a shaft, carefully and thoroughly adjust the fit of the tapered bore to the shaft to maintain high precision of the bearing. Table 3.14 is listed for recommendation for housing fit.

For ball screw support bearings(BS series type) recommended fit of shaft and housing are h5 and H6 respectively. The tolerances of shoulder squareness is within 4 μm for diameter less than 80 mm.

Table 3.11 Shaft fit for angular contact ball bearings

Unit: μm

Nominal bore diameter *d* mm		Fit of inner ring with shaft
Over	Incl.	
2.5	10	0～2T
10	18	0～2T
18	30	0～2T
30	50	0～3T
50	80	1T～4T
80	120	1T～5T
120	180	2T～7T
180	250	2T～8T

Notes:
1. The mean value should be the target value.
2. If the dmn value of the high-speed machine is in the range of dmN＞750×10³, it is necessary to increase the amount of interference. In this case, contact TPI Engineering for technical assistance.

T: Tight (Interference) FitTable

Table 3.12 Housing fit for angular contact ball bearings

Unit: μm

Nominal outside diameter *D* mm		Fit of outer ring with housing	
over	incl.	Bearing on fixed side	Bearing on free side
10	50	2L～5L	6L～10L
50	80	3L～7L	6L～10L
80	120	4L～9L	8L～13L
120	150	5L～11L	10L～18L
150	180	6L～13L	11L～17L
180	250	7L～15L	13L～20L
250	315	8L～17L	15L～23L

Notes:
1. The mean value should be the target value.
2. If the dmn value is in the range of dmn＞100×10⁴, spacer width and bearing arrangement, it is necessary to increase the amount of interference.
   In this case, contact TPI for technical assistance.

L: Loose fit

Table 3.13 Shaft fit for high speed thrust angular contact ball bearings

Unit: μm

Nominal bore diameter *d* mm		Fit of inner ring to shaft
Over	Incl.	
2.5	10	0～2T
10	18	0～2T
18	30	0～2.5T
30	50	0～3T
50	80	0～3.5T
80	120	0～4T
120	180	0～5T
180	250	0～6T

Note
1: Target the median value.
2: For high-speed applications where dmn value exceeds 0.75 ×10⁶, the fit should be increased.For such an arrangement, consult TPI.

T: Tight (Interference) fit

Table 3.14 Housing fit for cylindrical roller bearings

Unit: μm

Nominal bore diameter *D* mm		Fit between outer ring and housing
over	incl.	
30	50	0～3T
50	80	0～4T
80	120	0～4T
120	150	0～5T
150	180	0～5T
180	250	0～6T
250	315	0～7T
315	400	0～8T
400	500	0～9T

Note
1: Target the median value.

T: Tight (Interference) fit