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Engineering Section

Rolling Bearings – Types and Features

Design and Classification

Rolling bearings use balls or other rolling elements, located between bearing rings, to minimize friction. The rolling elements are separated and held in position by "cages" or other retaining devices.

The construction of six of the most common rolling element bearings are illustrated here for identification of nomenclature. Specific dimensions and details for these bearings are given in the dimensional tables in the preceeding sections of this catalog.

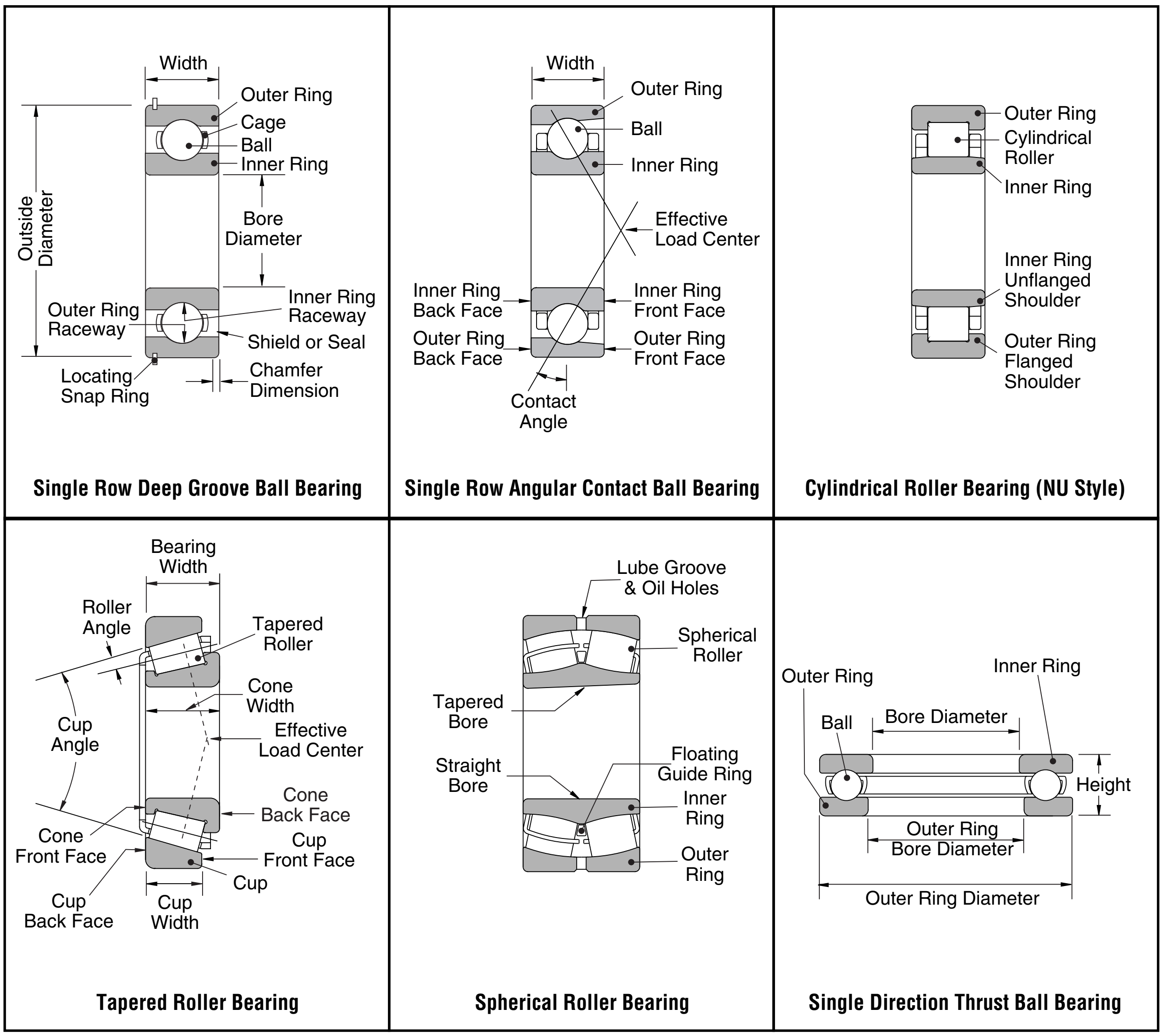


Figure 10.1 — Nomenclature for Bearing Components and Reference Dimensions.

In comparison to plain or sleeve type bearings, rolling bearings offer several advantages:

- Starting torque is minimal and the difference between starting torque and running torque is small.
- Rolling bearings can be designed to take both radial and axial loads simultaneously or independently.
- Rolling bearings can be preloaded to produce a negative clearance. This gives the bearing greater rigidity to constrain the radial and axial movement of a shaft relative to its housing.

Depending on the shape of their rolling elements, bearings fall into two main classes--ball bearings and roller bearings. Roller bearings are further classified by the specific shape of their rollers and by other individual features.

Bearings are also classified by function. For example, they can be classified as "radial," "thrust" or both, depending on the direction of the applied load and may be further classified as cylindrical, tapered, spherical or duplex depending on their configuration.

Description and Features

Typical bearing configurations are described below:

Deep Groove Ball Bearings are the most common type of rolling element bearing. They have a single row of balls held in place by a cage, usually made of steel, that rotates between two rings with polished raceways. The design of the bearing allows for radial and axial loading while operating at high speeds. These bearings often come with shields or seals to protect the inside of the bearing from contamination in the application.

Double Row Ball Bearings have two rows of balls between two bearing rings. This is a back-to-back mounting of two single-row angular contact ball bearings, but their inner and outer rings are each integrated into one. This design allows for heavier axial loads in either direction and a significant radial load capacity. Some of these bearings are also available with shields and seals.

Self-Aligning Ball Bearings have an inner ring with two raceways. The outer ring has one spherical raceway and its center coincides with that of the bearing. Because of this, the axis of the inner ring, the balls and the cage can deflect around the bearing center. As a result, minor angular misalignment of the shaft, in relation to the bearing housing, can be accommodated. This type of bearing, with tapered bore, is often mounted using an adapter sleeve.

Cylindrical Roller Bearings have large radial load capacities. The rolling elements remain in linear contact with the bearing raceway and are precisely crowned to relieve the edge loading caused by shaft misalignment.

A cylindrical roller bearing in which either the inner or outer ring has no rib, may be used as free-end or floating bearing because its rings are free to move, in an axial direction, relative to each other. If either the inner or outer ring has two ribs and the other ring has one rib, the bearing is capable of taking a certain amount of axial load in one direction. Double row cylindrical roller bearings have high radial rigidity and are used primarily for precision machine tools.

Tapered Roller Bearings can take both radial and axial loads in one direction. They use conical rolling elements which are guided by ribs on the bearing's inner ring. The bearing rollers are precisely crowned near each end to relieve edge loading.

Since an axial force is generated in these bearings when a radial load is applied, they are often mounted in pairs, face to face, like single row angular contact ball bearings. When this is the case, the proper internal clearance can be obtained by adjusting the axial distance between the inner rings or outer rings of the two opposed bearings. Since they are separable, the inner and outer rings can be mounted independently.

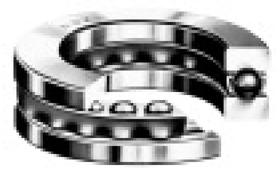
Tapered roller bearings are divided into three types--normal, medium angle and steep angle--depending on the degree of contact angle. Double row tapered roller bearings are also available.

Spherical Roller Bearings are capable of handling both radial and axial loads in either direction and have excellent radial load carrying capacity. The line of contact between the barrel-shaped rollers and the outer ring raceway is a circular arc centered on the bearing axis. The outer ring raceway is spherical, making it self-aligning. There are two inner raceways and two rows of rollers.

Spherical roller bearings with tapered bores can be mounted directly on tapered shafts or on cylindrical shafts by using an adapter or withdrawal sleeve. Spherical roller bearings are available with pressed-steel, machined bronze or molded cages.

Duplex Bearing Set is a pair of radial bearings combined in various arrangements. It is often a combination of angular contact ball bearings or of tapered roller bearings. It may be a combination placed face to face (type DF) or back to back (type DB) or in tandem (type DT). Types DF and DB are capable of taking radial loads and axial loads in either direction. They may be modified to accommodate a variety of preloading requirements. Type DT is used when the application requires large axial loads in one direction.

Single Direction and Double Direction Thrust Ball Bearings are composed of washer-like bearing rings with raceway grooves for the balls. The ring attached to the shaft is called the inner ring or tight washer and the ring attached to the housing is called the outer ring or loose washer. In double direction thrust ball bearings there are three rings, with the center one fixed to the shaft.



Single direction thrust ball bearings can support axial loads in one direction; double direction, in two. There are also thrust ball bearings with an aligning seat washer beneath the outer ring to compensate for shaft misalignment or mounting errors.

Spherical Roller Thrust Bearings have a spherical raceway in the outer ring with the rollers obliquely arranged in a single row. Since the raceway in the outer ring is spherical, these bearings are self-aligning.

Spherical roller thrust bearings have a very high axial load capacity and are capable of taking moderate radial loads when an axial load is imposed. These bearings are suited for lower speeds and require oil for lubrication. They are assembled with pressed-steel cages or machined brass cages.

Bearing Selection

The original equipment manufacturer (OEM) will select a bearing for their equipment based on the loading requirements of, and the space available for, the bearing. The bearing style and size provide the foundation for the bearing selection based on the load carrying capacity in relation to the loads to be carried.

Selection Based on Basic Load Rating

The most common way to determine bearing life is by using the load ratings of the bearing and the loads required by the application. The common measurement is "L_{10}" life, defined as the number of revolutions before metal fatigue first appears on 10% of a large group of like bearings. This is referred to as basic rating life or fatigue life. The equations for calculating L_{10} life are:

For ball bearings: $L_{10} = \left(\frac{C}{P}\right)^3$ **For roller bearings:** $L_{10} = \left(\frac{C}{P}\right)^{10/3}$

Where L_{10}: Rating fatigue life (1 million Revs)

P: Bearing Equivalent Load (lbf, N, kgf), see below for calculation of **P**

C: Basic Load Rating (from catalog tables)

For radial bearings, **C=Cr** For thrust bearings, **C=Ca**

If the bearings run at a constant speed, it is convenient to determine L_{10} life in terms of hours. This equation is expressed as

For ball bearings: $L_{10h} = \frac{1,000,000}{60n}\left(\frac{C}{P}\right)^3$ **For roller bearings:** $L_{10h} = \frac{1,000,000}{60n}\left(\frac{C}{P}\right)^{10/3}$

Where L_{10h}: Rating fatigue life in hours **n**: Rotational speed, RPM

Equivalent Bearing Loads (P)

To determine the value of **P**, you must first determine the effects of the radial and axial loads applied. Once this hypothetical load is determined, it is assumed to be constant in magnitude and direction. The general formula for the calculation of **P** is: P = X Fr + Y Fa

Where **P**: Bearing equivalent load (lbf, N, kgf)

X: the Radial factor

Fr: the Actual constant radial load

Y: the Axial factor

Fa: the Actual constant axial load

The values for **X** and **Y** can be determined using the tables 10.2-10.4. First, determine the type of bearing being considered. Then, calculate the ratio of the axial load to the radial load and compare this to the bearings "**e**" value in the table.* The "**e**" value is determined by multiplying the axial load applied to the bearing by the bearing coefficient factor, f_0, which is obtained from the bearing tables. Divide the result by the static radial load rating. Locate the result in the first column and read across to find the "**e**" value. (In the case of angular contact bearings, the "i" value must be used. If a duplex pair in a DB or DF configuration is used, the "i" value is 2.) In effect, if the axial load is small compared to the radial load, then only the radial load is considered. If not, then a combination of the two is used. After determining the equivalent bearing load, **P**, the L_{10} formula given above can be used to determine the L_{10} life with 90% reliability for a given bearing's basic load rating. Also, for a required L_{10} life, a basic load rating requirement can be found for bearing selection.

Table 10.2 — Equivalent Load Factors for Ball Bearings

Dynamic Equivalent Load $P=XFr+YFa$

$\frac{f_o F_a}{C_{or}}$	e	$\frac{F_a}{F_r} \le e$		$\frac{F_a}{F_r} > e$	
		X	Y	X	Y
0.172	0.19	1	0	0.56	2.30
0.345	0.22	1	0	0.56	1.99
0.689	0.26	1	0	0.56	1.71
1.03	0.28	1	0	0.56	1.55
1.38	0.30	1	0	0.56	1.45
2.07	0.34	1	0	0.56	1.31
3.45	0.38	1	0	0.56	1.15
5.17	0.42	1	0	0.56	1.04
6.89	0.44	1	0	0.56	1.00

Static Equivalent Load

$\frac{F_a}{F_r} > 0.8,\ P_o = 0.6F_r + 0.5F_a$ $\frac{F_a}{F_r} \le 0.8,\ P_o = F_r$

Table 10.3 — Equivalent Load Factors for Angular Contact Ball Bearings

Dynamic Equivalent Load $P=XFr+YFa$

Contact Angle	$\frac{i f_o F_a}{C_{or}}$*	e	Single, DT				DB or DF			
			$F_d/F_r \le e$		$F_d/F_r > e$		$F_d/F_r \le e$		$F_d/F_r > e$	
			X	Y	X	Y	X	Y	X	Y
15°	0.178	0.38	1	0	0.44	1.47	1	1.65	0.72	2.39
	0.357	0.40	1	0	0.44	1.40	1	1.57	0.72	2.28
	0.714	0.43	1	0	0.44	1.30	1	1.46	0.72	2.11
	1.07	0.46	1	0	0.44	1.23	1	1.38	0.72	2.00
	1.43	0.47	1	0	0.44	1.19	1	1.34	0.72	1.93
	2.14	0.50	1	0	0.44	1.12	1	1.26	0.72	1.82
	3.57	0.55	1	0	0.44	1.02	1	1.14	0.72	1.66
	5.35	0.56	1	0	0.44	1.00	1	1.12	0.72	1.63
25°	--	0.68	1	0	0.41	0.87	1	0.92	0.67	1.41
30°	--	0.80	1	0	0.39	0.76	1	0.78	0.63	1.24
40°	--	1.14	1	0	0.35	0.57	1	0.55	0.57	0.93

*For *i*, use 2 for DB, DF and 1 for DT.

Static Equivalent Load $P_o=X_oF_r+Y_oF_a$

Contact Angle	Single, DT		DB or DF	
	X_0	Y_0	X_0	Y_0
15°	0.5	0.46	1	0.92
25°	0.5	0.38	1	0.76
30°	0.5	0.33	1	0.66
40°	0.5	0.26	1	0.52

Single or DT mounting When $F_r>0.5F_r+Y_oF_a$ use $P_o=F_r$

Table 10.4 — Load Conversion Factors for Other Bearings

CYLINDRICAL ROLLER SPHERICAL ROLLER TAPERED ROLLER SELF-ALIGNING BALL	PLEASE CONSULT NSK ENGINEERING FOR VALUES, OR REFER TO NSK CATALOG E1101a

Correction of Basic Load Rating Due to Temperature

The operating temperature will significantly affect the fatigue life by altering the hardness of the bearing. Consequently, the basic load rating, which depends on the physical properties of the bearing material, will decrease with higher temperatures. Thus, the basic load rating must be corrected for higher temperatures using the equation: Ct = ft*C

Where C_t: Basic load rating after temperature correction

f_t: Temperature factor (see following table)

C: Basic load rating from tables, before application of temperature correction.

Table 10.5 — Temperature Factor (f_t)

	Bearing Temperature (°C)			
	≤150	175°	200°	250°
Temperature Factor f_t	1.00	.95	.90	.75

Adjustments to Fatigue Life Rating

Each style of bearing has many characteristics that make that bearing better suited for an application than another bearing. For example, some common applications require a bearing that can handle misalignment, loads in both directions, high speeds, etc…, or a combination of two or more. These operating conditions will alter the bearing life and are accounted for by using correction factors for temperature, reliability, bearing material, and other operating conditions. For the complete list of adjustment factors and their values, please contact NSK engineering or refer to NSK catalog E1101a.

The formula for adjusting life based on reliability, material, and operating conditions is:

$$L_{na}=a_1*a_2*a_3*L_{10}$$

Where L_{na}: Adjusted life rating.

L_{10}: Life rating, adjusted for fatigue life for 90% reliability. This may not satisfy all applications. For higher reliability requirements, L10 must be adjusted.

a_1: Life correction factor for reliability. This is determined from the reliability required of the bearing for its application (see table below).

a_2: Life correction factor for bearing material.

a_3: Life correction factor for operating conditions

Values of a_2 and a_3 are difficult to determine, however, for most applications, a_2* a_3=1 can be assumed. If you have concerns about lubrication viscosity, temperature, contamination, misalignment, or other operating abnormalities, please consult NSK Engineering.

Table 10.6 — Reliability Factor (a_1).

	Reliability					
	90%	95%	96%	97%	98%	99%
a_1	1.00	.62	.53	.44	.33	.21

Static Load Rating

Some applications are stationary with loads for long periods, rotate at very low speeds, are subjected to slow oscillations, or are exposed to shock loads. In these events, the static load rating **(C_{or} or C_{oa})** must be used in the life calculations. Please contact NSK engineering for more details.

Selection Based on Dimensions

For single row bearings having the same width series, diameter series, and bore size, all styles have the same bore, O.D., and width. For example, 6203, NJ203, and 7203 all have a 17mm bore, a 42mm O.D., and 12mm width. Therefore, selection can be made based on the requirements of the application such as, speeds, misalignment capabilities, bearing value, etc..., provided that the life requirement is met by the bearing style.

Bearing Identification

Bearing Number Formulation

Bearings are identified by numbers and letters which designate bearing type, boundary dimensions, tolerance class, internal clearance and other specifications. The numbers used for standard bearings conform to ISO 15, Designation of Rolling Bearings. Boundary dimensions for the most commonly used bearings are based on the ISO Boundary Dimensions Tables.

In order to establish certain standards in addition to those specified in ISO, NSK also uses various symbols of its own.

Table 10.7 — Bearing Series Numbers	Bearing Series	Bearing Type	Dimension Series	
			Width† Series	Diameter Series
Single Row Deep Groove Ball Bearing	68	6	(1)	8
	69	6	(1)	9
	60	6	(1)	0
	62	6	(0)	2
	63	6	(0)	3
	64	6	(0)	4
Single Row Angular Contact Ball Bearing	70	7	(1)	0
	72	7	(0)	2
	73	7	(0)	3
	74	7	(0)	4
Self-Aligning Ball Bearing	12	1	(0)	2
	13	1	(0)	3
	22	2	(2)	2
	23	2	(2)	3
Single Row Cylindrical Roller Bearing	NU10	NU	1	0
	NU2	NU	(0)	2
	NU22	NU	2	2
	NU3	NU	(0)	3
	NU23	NU	2	3
	NU4	NU	(0)	4
	NJ2	NJ	(0)	2
	NJ22	NJ	2	2
	NJ3	NJ	(0)	3
	NJ23	NJ	2	3
	NJ4	NJ	(0)	4
	N2	N	(0)	2
	N3	N	(0)	3
	N4	N	(0)	4
	NF2	NF	(0)	2
	NF3	NF	(0)	3
	NF4	NF	(0)	4
Double Row Cylindrical Roller Bearing	NNU49	NNU	4	9
	NN30	NN	2	0
Metric Tapered Roller Bearing	320	3	2	0
	302	3	0	2
	322	3	2	2
	303	3	0	3
	323	3	2	3
Spherical Roller Bearing	230	2	3	0
	231	2	3	1
	222	2	2	2
	232	2	3	2
	213††	2	0	3
	223	2	2	3
Thrust Ball Bearing with Flat Seat	511	5	1	1
	512	5	1	2
	513	5	1	3
	514	5	1	4
	522	5	2	2
	523	5	2	3
	524	5	2	4
Spherical Roller Thrust Bearing	292	2	9	2
	293	2	9	3
	294	2	9	4

† The width series numbers shown in parentheses are usually omitted.
†† 213 is customary usage since this series would be 203 according to standard practice

Bearing Number Formulation (Continued)

Bearing series numbers indicate bearing types and dimension series. They constitute the basic number structure for bearing designations. These are shown in Table 10.7 on page 306. Supplementary symbols and meanings of typical numbers and symbols are shown in Table 10.8 on page 308.

Typical examples of bearing designations are illustrated below:

6 3 08 ZZ C3

- C3: Radial clearance (C3)
- ZZ: Shields on Both Sides
- 08: Bearing Bore (40mm)
- 3: Diameter Series 3
- 6: Single Row Deep Groove Ball Bearing

1 2 06 K + H206

- H206: Adapter with 25mm Bore
- K: Tapered Bore (1:12 Taper)
- 06: Bearing Bore (30mm)
- 2: Diameter Series 2
- 1: Self-Aligning Ball Bearing

NU 3 18 M ()

- (): Radial Clearance (Blank is CN)
- M: Machined Brass Cage
- 18: Bearing Bore (90mm)
- 3: Diameter Series 3
- NU: Cylindrical Roller Bearing (NU Type)

NN 3 0 17 K CC1 P4

- P4: Tolerance to ISO Class 4
- CC1: Radial Clearance for Matched Cylindrical Roller Bearings
- K: Tapered Bore (1:12 Taper)
- 17: Bearing Bore (85mm)
- 0: Diameter Series 0
- 3: Width Series 3
- NN: Cylindrical Roller Bearing (NN Type)

7 2 20 A DB C3

- C3: Axial Clearance (C3)
- DB: Back-to-Back Arrangement
- A: Contact Angle (30°)
- 20: Bearing Bore (100mm)
- 2: Diameter Series 2
- 7: Single Row Angular Contact Ball Bearing

HR 3 0 2 07 J

- J: Small Diameter of Outer Ring Raceway and Contact Angle Conform to ISO Standard
- 07: Bearing Bore (35mm)
- 2: Diameter Series 2
- 0: Width Series 0
- 3: Tapered Roller Bearing
- HR: High Capacity Bearing

2 4 0 /1000 M K30 E4 C3

- C3: Radial Clearance (C3)
- E4: Outer Ring with Oil Groove and Oil Holes
- K30: Tapered Bore (1:30 Taper)
- M: Machined Brass Cage
- /1000: Bearing Bore (1,000mm)
- 0: Diameter Series 0
- 4: Width Series 4
- 2: Spherical Roller Bearing

5 1 2 15

- 15: Bearing Bore (75mm)
- 2: Diameter Series 2
- 1: Height Series 1
- 5: Thrust Ball Bearing

Table 10.8 — Formulation of Bearing Numbers

Basic Bearing
Bearing Series
Bore
Contact Angle
Internal Design
Material
Cage
External Seals, Shields

Bearing Series

68 69 60 ⋮	Single Row Deep Groove Ball Bearings
70 72 73 ⋮	Single Row Angular Contact Ball Bearings
12 13 22 ⋮	Self-Aligning Ball Bearings
NJ 2 N 3 NN 30 ⋮	Cylindrical Roller Bearings
320 322 323 ⋮	Tapered Roller Bearings
230 222 223 ⋮	Spherical Roller Bearings
511 512 513 ⋮	Thrust Ball Bearings with Flat Seats
292 293 294 ⋮	Spherical Roller Thrust Bearings

Bore

1 thru 9	Bore in mm
00	10mm
01	12mm
02	15mm
03	17mm
/22	22mm
/28	28mm
/32	32mm
04 thru 96	Multiply by 5 for Bore in mm (ex. 04=20mm)
/500 thru /2500	Bore in mm

Contact Angle Angular Contact Ball Bearings

A	30°
B	40°
C	15°

Contact Angle Tapered Roller Bearings

(none)	Contact Angle Less than 17°
C	Contact Angle Approx. 20°
D	Contact Angle Approx 28°

Internal Design

A	Modified Internal Design
J	Small Diameter of Outer Ring Raceway and Contact Angle of Tapered Roller Bearings Conform to ISO
	(For High Capacity Bearings)
CA	Spherical Roller Bearings with Machined Cages
CD	Spherical Roller Bearings with Pressed Cages
E	Cylindrical Roller Bearings
H	Spherical Radial and Thrust Roller Bearings
HR (*prefix*)	Tapered Roller Bearings

Material

g	Case-Hardened Steel Used in Outer Rings, Inner Rings and Rolling Elements
h	Stainless Steel Used in Outer Rings, Inner Rings and Rolling Elements

Cage

M	Machined Brass Cages
W	Pressed Steel Cages
T	Phenolic Resin/ Polyamide Cages
V	Bearings without Cages (Cageless Ball and Roller Bearings)
H	(Spherical Bearings) Polyamide Cages

External Seals, Shields

Z	Shield on One Side Only
ZZ	Z Shields on Both Sides
DU	Contact Rubber Seal on One Side Only
DDU	DU Seals on Both Sides
V	Non-Contact Rubber Seal on One Side Only
VV	V Seals on Both Sides

Table 10.8 — Formulation of Bearing Numbers (continued) – Supplementary Symbols

Supplementary Features
Features
Arrangement
Radial Internal Clearance
Tolerance Class
Special Specifications
Spacer or Sleeve
Lubrication

Features Design of Outer and Inner Ring

K	Tapered Bore (Taper 1:12)
K30	Tapered Bore (Taper 1:30)
E4	Lubrication Grooves and Holes in Outer Ring
N	Snap Ring Groove in Outer Ring
NR	Snap Ring Groove with Snap Ring in Outer Ring

Arrangement

DB	Back to Back Duplex Arrangement
DF	Face to Face Duplex Arrangement
DT	Tandem Duplex Arrangement
SU	Single Universal – Bearings with front and back face standout adjusted to be equal
DU	Duplex Universal (SU sold as pair)

Radial Internal Clearance

C2	For All Radial Ball Bearings	Clearance Less Than Normal
CO		Normal Clearance
C3		Clearance Greater Than Normal
C4		Clearance Greater Than C3
CC1	For Matched Cylindrical Roller Bearings	Clearance Less Than C
CC2		Clearance Less Than Normal
CC		Normal Clearance
CC3		Clearance Greater Than Normal
CC4		Clearance Greater Than CC3
CC5		Clearance Greater Than CC4
MC2	For Extra Small Ball Bearings and Miniature Bearings	Clearance Less Than MC3
MC3		Normal Clearance
MC4		Clearance Greater Than MC3
MC5		Clearance Greater Than MC4

Tolerance Class

(None)	ISO Class 0 (ABEC 1)
P6	ISO Class 6 (ABEC 3)
P5	ISO Class 5 (ABEC 5)
P4	ISO Class 4 (ABEC 7)

Special Specifications

X28	Inner and Outer Rings Heat Stabilized for Maximum Working Temperature of 200°C
S11	Spherical Bearings Heat Stabilized to 200°C
P55	High Running Accuracy of Inner and Outer Rings

Spacer or Sleeve

+K	Bearings with Outer Ring Spacer
+L	Bearings with Inner Ring Spacer
+KL	Bearings with Both Outer and Inner Ring Spacers
+H	Adapter Designation
+AH	Withdrawal Sleeve Designation
HJ	Angle Ring Designation

Lubrication

AKC	Exxon Andok C
AV2	Shell Alvania No. 2
B32	Exxon Beacon 325
SRI	Chevron SRI-2
SDR	Shell Dolium R

Snap Ring and Groove Dimensions

Table 10.9 — Snap Ring and Groove Dimensions (Dimension Series 0,2,3 & 4)

Units: inch

BEARING BORE d (mm)				SNAP RING GROOVE POSITION, a		GROOVE WIDTH, b	SNAP RING THICKNESS, f	SNAP RING O.D., D_2	HOUSING BORE, Dx
DIMENSION SERIES									
0	2	3	4	0	2,3,4	med.	med.	max.	min.
10	–	–	–	0.0500	–	0.0402	0.0311	1.1299	1.1575
12	–	–	–	0.0500	–	0.0402	0.0311	1.2087	1.2362
–	10	9	8	–	0.0780	0.0591	0.0421	1.3661	1.3976
15	12	–	9	0.0780	0.0780	0.0591	0.0421	1.4449	1.4764
17	15	10		0.0780	0.0780	0.0591	0.0421	1.5630	1.5945
–	–	12	10	–	0.0780	0.0591	0.0421	1.6260	1.6535
–	17	–	–	–	0.0780	0.0591	0.0421	1.7559	1.7913
20	–	15	12	0.0780	0.0780	0.0591	0.0421	1.8228	1.8504
22	–	–	–	0.0780	–	0.0591	0.0421	1.9016	1.9291
25	20	17		0.0780	0.0939	0.0591	0.0421	2.0748	2.1063
–	22	–	–	–	0.0939	0.0591	0.0421	2.1929	2.2244
28	25	20	15	0.0780	0.0939	0.0591	0.0421	2.2795	2.3031
30	–	–	–	0.0780	–	0.0591	0.0421	2.3898	2.4213
–	–	22	–	–	0.0939	0.0591	0.0421	2.4291	2.4606
32	28	–	–	0.0780	0.0939	0.0591	0.0421	2.5079	2.5394
35	30	25	17	0.0780	0.1250	0.0807	0.0650	2.6654	2.6969
–	32	–	–	–	0.1250	0.0807	0.0650	2.7835	2.8150
40	–	28	–	0.0941	0.1250	0.0807	0.0650	2.9370	2.9921
–	35	30	20	–	0.1250	0.0807	0.0650	3.0945	3.1496
45		32		0.0941	0.1250	0.0807	0.0650	3.2126	3.2677
50	40	35	25	0.0941	0.1250	0.0807	0.0650	3.4094	3.4646
–	45	–	–	–	0.1250	0.0807	0.0650	3.6063	3.6614
55	50	40	30	0.1130	0.1250	0.1122	0.0949	3.7992	3.8583
60	–	–	–	0.1130	–	0.1122	0.0949	4.0000	4.0551
65	55	45	35	0.1130	0.1250	0.1122	0.0949	4.1929	4.2520
70	60	50	40	0.1130	0.1250	0.1122	0.0949	4.5906	4.6457
75	–	–	–	0.1130	–	0.1122	0.0949	4.7874	4.8425
–	65	55	45	–	0.1559	0.1280	0.1091	5.1063	5.1772
80	70	–	–	0.1130	0.1559	0.1280	0.1091	5.3031	5.3740
85	75	60	50	0.1130	0.1559	0.1280	0.1091	5.5000	5.5709
90	80	65	55	0.1409	0.1880	0.1280	0.1091	5.8937	5.9843
95	–	–	–	0.1409	–	0.1280	0.1091	6.0906	6.1811
100	85	70	60	0.1409	0.1880	0.1280	0.1091	6.2874	6.3780
105	90	75	65	0.1409	0.1880	0.1280	0.1091	6.6811	6.7717
110	95	80		0.1409	0.2191	0.1437	0.1437	7.2008	7.2835
120	100	85	70	0.1409	0.2191	0.1437	0.1437	7.5945	7.6772
–	105	90	75	–	0.2191	0.1437	0.1437	7.9882	8.0709
130	110	95	80	0.2191	0.2191	0.1437	0.1437	8.3819	8.4646

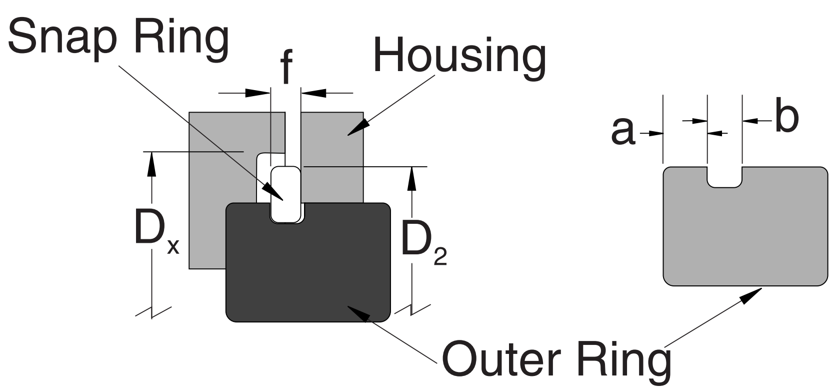
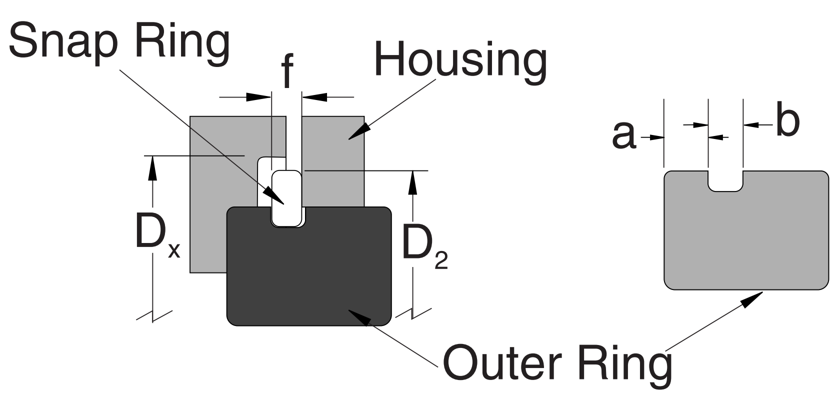


Table 10.10 — Snap Ring and Groove Dimensions (Series 6800 & 6900)

Units: inch

BEARING BORE d (mm) / DIMENSION SERIES		SNAP RING GROOVE POSITION, a		GROOVE WIDTH, b	SNAP RING THICKNESS, f	SNAP RING O.D., D_2	HOUSING BORE, Dx
8	9	8	9	med.	med.	max.	min.
–	10	–	1.0677	0.0222	0.0256	0.9764	1.0039
–	12	–	1.0677	0.0222	0.0256	1.0551	1.0827
–	15	–	1.3226	0.0423	0.0315	1.2126	1.2402
–	17	–	1.3226	0.0423	0.0315	1.2913	1.3189
20	–	0.0482	–	0.0423	0.0315	1.3701	1.3976
22	–	0.0482	–	0.0423	0.0315	1.4488	1.4764
25	20	0.0482	1.7305	0.0423	0.0315	1.5669	1.5945
–	22	–	1.7305	0.0423	0.0315	1.6457	1.6732
28	–	0.0482	–	0.0423	0.0315	1.6850	1.7126
30	25	0.0482	1.7305	0.0423	0.0315	1.7638	1.7913
32	–	0.0482	–	0.0423	0.0315	1.8425	1.8701
–	28	–	1.7305	0.0423	0.0315	1.8819	1.9094
35	30	0.0482	1.7305	0.0423	0.0315	1.9606	1.9882
40	32	0.0482	1.7305	0.0423	0.0315	2.1575	2.1850
–	35	–	1.7305	0.0423	0.0315	2.2756	2.3031
45	–	0.0482	–	0.0423	0.0315	2.3937	2.4213
–	40	–	1.7305	0.0423	0.0315	2.5512	2.5787
50	–	0.0482	–	0.0423	0.0315	2.6693	2.6969
–	45	–	1.7305	0.0571	0.0421	2.7874	2.8346
55	50	0.0640	1.7305	0.0571	0.0421	2.9449	2.9921
60	–	0.0640	–	0.0571	0.0421	3.2559	3.3071
–	55	–	2.1374	0.0571	0.0421	3.3228	3.3858
65	60	0.0640	2.1374	0.0571	0.0421	3.5197	3.5827
70	65	0.0640	2.1374	0.0571	0.0421	3.7165	3.7795
75	–	0.0640	–	0.0571	0.0421	3.9134	3.9764
80	70	0.0640	2.5453	0.0571	0.0421	4.1102	4.1732
–	75	–	2.5453	0.0571	0.0421	4.3583	4.4094
85	80	0.0787	2.5453	0.0571	0.0421	4.5551	4.6063
90	–	0.0787	–	0.0571	0.0421	4.7520	4.8031
95	85	0.0787	3.3610	0.0571	0.0421	4.9488	5.0000
100	90	0.0787	3.3610	0.0571	0.0421	5.1457	5.1969
105	95	0.0787	3.3610	0.0571	0.0421	5.3425	5.3937
110	100	0.0945	3.3610	0.0807	0.0650	5.7362	5.7874
–	105	–	3.3610	0.0807	0.0650	5.9331	5.9843
120	110	0.0945	3.3610	0.0807	0.0650	6.1299	6.1811
130	120	0.1260	3.3610	0.0807	0.0650	6.7520	6.8110
140	–	0.1260	–	0.0807	0.0650	7.1457	7.2047
–	130	–	3.3610	0.0807	0.0650	7.3425	7.4016
150	140	0.1260	3.3610	0.0807	0.0650	7.7362	7.7953
160	–	0.1260	–	0.0807	0.0650	8.1299	8.1890



Bearing Tolerances

BEARING TOLERANCE STANDARDS

The dimensional and running accuracies of rolling bearings are standardized by ISO with regard to the following items:

- Tolerances for bore diameter, outer diameter, individual ring width, and overall width.
- Tolerances for absolution dimensions of inscribed circle diameter and circumscribed circle diameter.
- Tolerances for chamfer dimension.
- Tolerances for width variations
- Tolerances for taper angle and taper bore diameters
- Tolerances for radial runout of inner ring and outer rings.
- Tolerances for axial runout of inner and outer rings.
- Tolerances for side or face runout of inner ring.
- Tolerances for side or face runout of outer ring.

In grading bearing tolerances, ISO "normal class" represents the standard. ISO classes 6, 5, 4, and 2 represent four higher grades. In general, DIN, JIS, and ABMA tolerance classes conform to these ISO standards. Tolerance classes applicable to each bearing type are shown in the subsequent tables.

Table 10.11 — Bearing Types and Tolerance Classes

Bearing Types		Applicable Tolerance Classes					Applicable Tables	Applicable Pages
Angular Contact Ball Bearings		Class N	Class 6	Class 5	Class 4	Class 2	9-12 to 9-16	236 to 239
Self-Aligning Ball Bearings		Class N	Class 6 equivalent	Class 5 equivalent	–	–		
Cylindrical Roller Bearings		Class N	Class 6	Class 5	Class 4	Class 2		
Spherical Roller Bearings		Class N	Class 6 equivalent	Class 5 equivalent	–	–		
Tapered Roller Bearings	Metric Design	Class N Class 6X	–	Class 5	Class 4	–	9-17 to 9-21	240 to 242
	Inch Design	ABMA Class 4	ABMA Class 2	ABMA Class3	ABMA Class 0	ABMA Class 00	9-22 to 9-24	244 to 244
Thrust Ball Bearings		Class N	Class 6	Class 5	Class 4	–	9-25 to 9-27	246 to 247
Spherical Roller Thrust Bearings		Class N	–	–	–	–	9-28 to 9-29	248 to 248
Equivalend Standards (ref.)	JIS[1]	Class 0	Class 6	Class 5	Class 4	Class 2	–	–
	DIN[2]	0	P6	P5	P4	P2	–	–
	ABMA[3] Ball Bearings	ABEC 1	ABEC 3	ABEC 5 (Class 5P)	ABEC 7 (Class 7P)	ABEC9 (Class 9P)	9-12 to 9-16	236 to 239
	ABMA[3] Roller Bearings	RBEC 1	RBEC 3	RBEC 5			–	–
	ABMA[3] Tapered Roller Bearings	Class 4	Class 2	Class 3	Class 0	Class 00	9-22 to 9-24	244 to 244

1) JIS: Japanese Industrial Standards, 2) DIN: Deutch Industrie Norm, 3) ABMA: American Bearing Manufacturers Association

Bearing Tolerance Nomenclature

Rough definitions of the items listed above for running accuracy and their measuring methos are shown below. They are described in detail in ISO 5593 (Rolling Bearings-Vocabulary), JIS B 1515 (Measuring Methods for Rolling Bearings), and elsewhere.

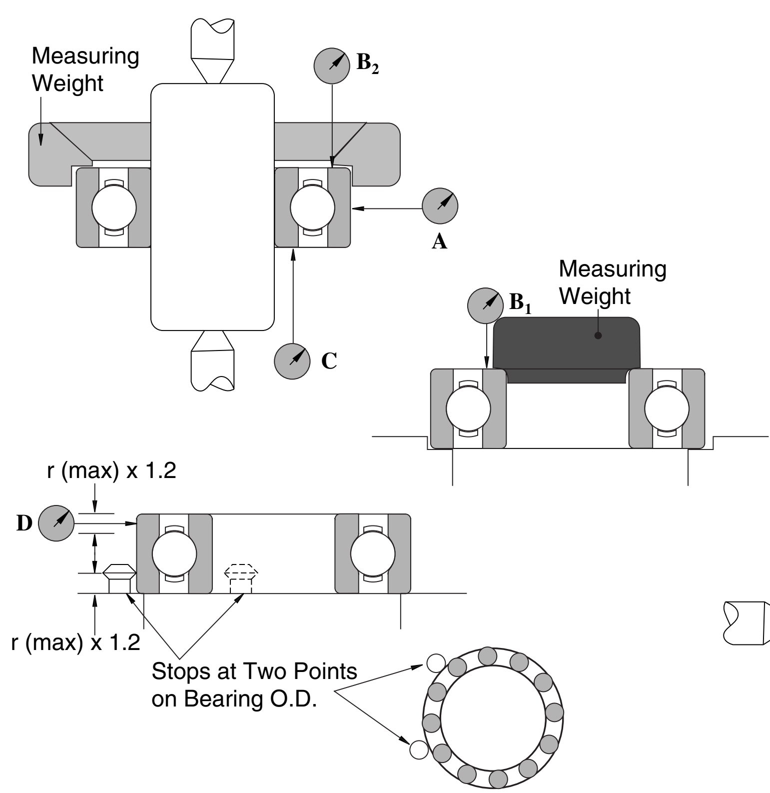
Symbols for Boundary Dimensions and Running Accuracy

d	Bearing bore diameter, nominal	Δ_{Ts}	Deviation of the actual bearing width
Δ_{ds}	Deviation of single bore diameter	D	Bearing outside diameter, nominal
Δ_{dmp}	Single plane mean bore diameter deviation	Δ_{Ds}	Deviation of a single outside diameter
V_{dp}	Bore diameter variation in a single radial plane	Δ_{Dmp}	Single plane mean outside diameter deviation
V_{dmp}	Mean bore diameter variation	V_{Dp}	Outside diameter variation in a single radial plane
B	Inner ring width, nominal	V_{Dmp}	Mean outside diameter variation
Δ_{Bs}	Deviation of a single inner ring width	C	Outer ring width, nominal
V_{Bs}	Inner ring width variation	Δ_{Cs}	Deviation of a single outer ring width
K_{ia}	Radial runout of assembled bearing inner ring	V_{Cs}	Outer ring width variation
S_d	Inner ring reference face (backface, where applicable) runout with bore	K_{ea}	Radial runout of assembled bearing outer ring
S_{ia}	Assembled bearing inner ring face (backface) runout with raceway	S_D	Variation of bearing outside surface generatrix inclination with outer ring reference face (backface)
S_i, S_e	Raceway to backface thickness variation of thrust bearing	S_{ea}	Assembled bearing outer ring (backface) runout with raceway
T	Bearing width, nominal		

Measuring Methods for Running Accuracy (summarized)

Running Accuracy	Inner Ring	Outer Ring	Dial Gage
K_{ia}	Rotating	Stationary	A
K_{ea}	Stationary	Rotating	A
S_{ia}	Rotating	Stationary	B1
S_{ea}	Stationary	Rotating	B2
S_d	Rotating	Stationary	C
S_D	–	Rotating	D
S_i, S_e	Only the shaft or housing or central washer is to be rotated.		E

Illustrations



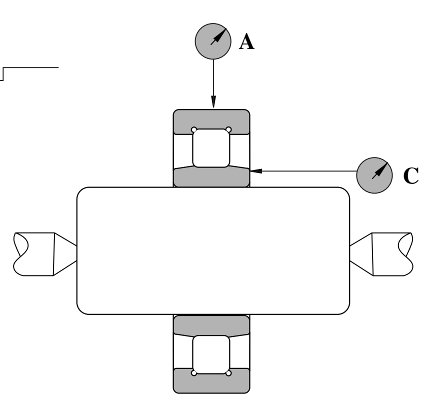


Table 10.12 — Tolerances for Inner Ring Bore of Radial Bearings (excluding Tapered Roller Bearings)

Units: inch

Nominal Bore Diameter *d* (mm)		Δdmp(1)										ds(1)			
		Class N		Class 6		Class 5		Class 4		Class 2		Class 4 Diameter Series 0, 1, 2, 3, 4		Class 2	
over	incl	high	low	high	low	high	low	high	low	high	low	high	low	high	low
0.6[2])	2.5	0	-.0003	0	-.0003	0	-.0002	0	-.0002	0	-.0001	0	-.0002	0	-.0001
2.5	10	0	-.0003	0	-.0003	0	-.0002	0	-.0002	0	-.0001	0	-.0002	0	-.0001
10	18	0	-.0003	0	-.0003	0	-.0002	0	-.0002	0	-.0001	0	-.0002	0	-.0001
18	30	0	-.0004	0	-.0003	0	-.0002	0	-.0002	0	-.0001	0	-.0002	0	-.0001
30	50	0	-.0005	0	-.0004	0	-.0003	0	-.0002	0	-.0001	0	-.0002	0	-.0001
50	80	0	-.0006	0	-.0005	0	-.0004	0	-.0003	0	-.0002	0	-.0003	0	-.0002
80	120	0	-.0008	0	-.0006	0	-.0004	0	-.0003	0	-.0002	0	-.0003	0	-.0002
120	150	0	-.0010	0	-.0007	0	-.0005	0	-.0004	0	-.0003	0	-.0004	0	-.0003
150	180	0	-.0010	0	-.0007	0	-.0005	0	-.0004	0	-.0003	0	-.0004	0	-.0003
180	250	0	-.0012	0	-.0009	0	-.0006	0	-.0005	0	-.0003	0	-.0005	0	-.0003
250	315	0	-.0014	0	-.0010	0	-.0007	–	–	–	–	–	–	–	–
315	400	0	-.0016	0	-.0012	0	-.0009	–	–	–	–	–	–	–	–
400	500	0	-.0018	0	-.0014	–	–	–	–	–	–	–	–	–	–
500	630	0	-.0020	0	-.0016	–	–	–	–	–	–	–	–	–	–
630	800	0	-.0030	–	–	–	–	–	–	–	–	–	–	–	–
800	1000	0	-.0039	–	–	–	–	–	–	–	–	–	–	–	–
1000	1250	0	-.0049	–	–	–	–	–	–	–	–	–	–	–	–
1250	1600	0	-.0063	–	–	–	–	–	–	–	–	–	–	–	–
1600	2000	0	-.0079	–	–	–	–	–	–	–	–	–	–	–	–

Note: 1) Applicable to bearings with cylindrical bores.
2) 0.6 mm is included in this group.

Table 10.13 — Tolerances for Outer Ring O.D. of Radial Bearings (excluding Tapered Roller Bearings)

Units: inch

Nominal Outside Diameter D (mm)		ΔDmp										ΔDs			
		Class N		Class 6		Class 5		Class 4		Class 2		Class 4 Diameter Series 0, 1, 2, 3, 4		Class 2	
over	incl	high	low	high	low	high	low	high	low	high	low	high	low	high	low
2.5[1])	6	0	-.0003	0	-.0003	0	-.0002	0	-.0002	0	-.0001	0	-.0002	0	-.0001
6	18	0	-.0003	0	-.0003	0	-.0002	0	-.0002	0	-.0001	0	-.0002	0	-.0001
18	30	0	-.0004	0	-.0003	0	-.0002	0	-.0002	0	-.0002	0	-.0002	0	-.0002
30	50	0	-.0004	0	-.0004	0	-.0003	0	-.0002	0	-.0002	0	-.0002	0	-.0002
50	80	0	-.0005	0	-.0004	0	-.0004	0	-.0003	0	-.0002	0	-.0003	0	-.0002
80	120	0	-.0006	0	-.0005	0	-.0004	0	-.0003	0	-.0002	0	-.0003	0	-.0002
120	150	0	-.0007	0	-.0006	0	-.0004	0	-.0004	0	-.0002	0	-.0004	0	-.0002
150	180	0	-.0010	0	-.0007	0	-.0005	0	-.0004	0	-.0003	0	-.0004	0	-.0003
180	250	0	-.0012	0	-.0008	0	-.0006	0	-.0004	0	-.0003	0	-.0004	0	-.0003
250	315	0	-.0014	0	-.0010	0	-.0007	0	-.0005	0	-.0003	0	-.0005	0	-.0003
315	400	0	-.0016	0	-.0011	0	-.0008	0	-.0006	0	-.0004	0	-.0006	0	-.0004
400	500	0	-.0018	0	-.0013	0	-.0009	–	–	–	–	–	–	–	–
500	630	0	-.0020	0	-.0015	0	-.0011	–	–	–	–	–	–	–	–
630	800	0	-.0030	0	-.0018	0	-.0014	–	–	–	–	–	–	–	–
800	1000	0	-.0039	0	-.0024	–	–	–	–	–	–	–	–	–	–
1000	1250	0	-.0049	–	–	–	–	–	–	–	–	–	–	–	–
1250	1600	0	-.0063	–	–	–	–	–	–	–	–	–	–	–	–
1600	2000	0	-.0079	–	–	–	–	–	–	–	–	–	–	–	–
2000	2500	0	-.0098	–	–	–	–	–	–	–	–	–	–	–	–

Note: 1) 2.5 mm is included within this group.

Remarks:
1) The outside diameter low tolerances specified in this table do not apply within a distance of 1.2 times the chamfer dimension r (max) from the ring face.
2) The cylindrical bore diameter "no-go" side" tolerance limit (high) specified in this table does not necessarily apply within a distance of 1.2 times the chamfer dimesion r (max) from the ring face.
3) ABMA Std 20-1987 was amended: ABEC1 ° RBEC1, ABEC3 ° RBEC3, ABEC5 ° RBEC5, ABEC7, and ABEC9 are equivalent to Classes N, 6,5,4, and 2 respectively.

Table 10.12 —Tolerances for Inner Ring Bore of Radial Bearings (excluding Tapered Roller Bearings) (continued)

Units: inch

V_{dp} (1)											V_{dmp} (1)				
Class N			Class 6			Class 5		Class 4		Class	Class				
Diameter Series			Diameter Series			Dia. Series		Dia. Series							
7,8,9	0,1	2,3,4	7,8,9	0,1	2,3,4	7,8,9	0,1,2,3,4	7,8,9	0,1,2,3,4	2	N	6	5	4	2
max	max	max	max	max	max	max	max	max	max	max	max	max	max	max	max
+.0004	+.0003	+.0002	+.0004	+.0003	+.0002	+.0002	+.0002	+.0002	+.0001	+.0001	+.0002	+.0002	+.0001	+.0001	+.0001
+.0004	+.0003	+.0002	+.0004	+.0003	+.0002	+.0002	+.0002	+.0002	+.0001	+.0001	+.0002	+.0002	+.0001	+.0001	+.0001
+.0004	+.0003	+.0002	+.0004	+.0003	+.0002	+.0002	+.0002	+.0002	+.0001	+.0001	+.0002	+.0002	+.0001	+.0001	+.0001
+.0005	+.0004	+.0003	+.0004	+.0003	+.0002	+.0002	+.0002	+.0002	+.0002	+.0001	+.0003	+.0002	+.0001	+.0001	+.0001
+.0006	+.0005	+.0004	+.0005	+.0004	+.0003	+.0003	+.0002	+.0002	+.0002	+.0001	+.0004	+.0003	+.0002	+.0001	+.0001
+.0007	+.0007	+.0004	+.0006	+.0006	+.0004	+.0004	+.0003	+.0003	+.0002	+.0002	+.0004	+.0004	+.0002	+.0001	+.0001
+.0010	+.0010	+.0006	+.0007	+.0007	+.0004	+.0004	+.0003	+.0003	+.0002	+.0002	+.0006	+.0004	+.0002	+.0002	+.0001
+.0012	+.0012	+.0007	+.0009	+.0009	+.0006	+.0005	+.0004	+.0004	+.0003	+.0003	+.0007	+.0006	+.0003	+.0002	+.0001
+.0012	+.0012	+.0007	+.0009	+.0009	+.0006	+.0005	+.0004	+.0004	+.0003	+.0003	+.0007	+.0006	+.0003	+.0002	+.0001
+.0015	+.0015	+.0009	+.0011	+.0011	+.0007	+.0006	+.0005	+.0005	+.0004	+.0003	+.0009	+.0007	+.0003	+.0002	+.0002
+.0017	+.0017	+.0010	+.0012	+.0012	+.0007	+.0007	+.0006	–	–	–	+.0010	+.0007	+.0004	–	–
+.0020	+.0020	+.0012	+.0015	+.0015	+.0009	+.0009	+.0007	–	–	–	+.0012	+.0009	+.0005	–	–
+.0022	+.0022	+.0013	+.0017	+.0017	+.0010	–	–	–	–	–	+.0013	+.0010	–	–	–
+.0025	+.0025	+.0015	+.0020	+.0020	+.0012	–	–	–	–	–	+.0015	+.0012	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–

Note: 1) Applicable to bearings with cylindrical bores.

Table 10.13 —Tolerances for Outer Ring O.D. of Radial Bearings (excluding Tapered Roller Bearings) (continued)

Units: inch

V_{Dp} (1)													V_{Dmp} (1)				
Class N				Class 6				Class 5		Class 4		Class 2					
Open Type			Shielded Sealed	Open Type			Shielded Sealed	Open Type		Open Type		Open Type					
Diameter Series				Diameter Series				Dia. Series		Dia. Series			Class				
7,8,9	0,1	2,3,4	2,3,4	7,8,9	0,1	2,3,4	0,1,2,3,4	7,8,9	0,1,2,3,4	7,8,9	0,1,2,3,4		N	6	5	4	2
max	max	max	max	max	max	max	max	max	max	max	max	max	max	max	max	max	max
+.0004	+.0003	+.0002	+.0004	+.0004	+.0003	+.0002	+.0004	+.0002	+.0002	+.0002	+.0001	+.0001	+.0002	+.0002	+.0001	+.0001	+.0001
+.0005	+.0004	+.0003	+.0005	+.0004	+.0003	+.0002	+.0004	+.0002	+.0002	+.0002	+.0002	+.0002	+.0003	+.0002	+.0001	+.0001	+.0001
+.0006	+.0004	+.0003	+.0006	+.0004	+.0004	+.0003	+.0005	+.0003	+.0002	+.0002	+.0002	+.0002	+.0003	+.0003	+.0002	+.0001	+.0001
+.0006	+.0005	+.0004	+.0008	+.0006	+.0004	+.0003	+.0006	+.0003	+.0003	+.0003	+.0002	+.0002	+.0004	+.0003	+.0002	+.0001	+.0001
+.0007	+.0007	+.0004	+.0010	+.0006	+.0006	+.0004	+.0008	+.0004	+.0003	+.0003	+.0002	+.0002	+.0004	+.0004	+.0002	+.0002	+.0001
+.0009	+.0009	+.0006	+.0012	+.0007	+.0007	+.0004	+.0010	+.0004	+.0003	+.0004	+.0003	+.0002	+.0006	+.0004	+.0002	+.0002	+.0001
+.0012	+.0012	+.0007	+.0015	+.0009	+.0009	+.0006	+.0012	+.0005	+.0004	+.0004	+.0003	+.0003	+.0007	+.0006	+.0003	+.0002	+.0001
+.0015	+.0015	+.0009	–	+.0010	+.0010	+.0006	–	+.0006	+.0004	+.0004	+.0003	+.0003	+.0009	+.0006	+.0003	+.0002	+.0002
+.0017	+.0017	+.0010	–	+.0012	+.0012	+.0007	–	+.0007	+.0006	+.0005	+.0004	+.0003	+.0010	+.0007	+.0004	+.0003	+.0002
+.0020	+.0020	+.0012	–	+.0014	+.0014	+.0008	–	+.0008	+.0006	+.0006	+.0004	+.0004	+.0012	+.0008	+.0004	+.0003	+.0002
+.0022	+.0022	+.0013	–	+.0016	+.0016	+.0010	–	+.0009	+.0007	–	–	–	+.0013	+.0010	+.0005	–	–
+.0025	+.0025	+.0015	–	+.0019	+.0019	+.0011	–	+.0011	+.0008	–	–	–	+.0015	+.0011	+.0006	–	–
+.0037	+.0037	+.0022	–	+.0022	+.0022	+.0013	–	+.0014	+.0010	–	–	–	+.0022	+.0013	+.0007	–	–
+.0049	+.0049	+.0030	–	+.0030	+.0030	+.0018	–	–	–	–	–	–	+.0030	+.0018	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–

Note: 1) Applicable only when a locating snap ring is not used

Table 10.14 — Tolerances for Inner and Outer Ring Widths of Radial Bearings (excluding Tapered Roller Bearings)

Units: inch

Nominal Bore Diameter *d* (mm)		ΔB_s(or C_s)(1)										V_{Bs}(or V_{Cs})(1)				
		Single Bearing						Combined Bearings(2)				Inner Ring (or Outer Ring)2)		Inner Ring		
		Class N Class 6		Class 5 Class 4		Class 2		Class N Class 6		Class 5 Class 4		Class		Class		
												N	6	5	4	2
over	incl	high	low	high	low	high	low	high	low	high	low	max	max	max	max	max
0.6[3]	2.5	0	-.0016	0	-.0016	0	-.0016	–	–	0	-.0098	+.0005	+.0005	+.0002	+.0001	+.0001
2.5	10	0	-.0047	0	-.0047	0	-.0047	0	-.0098	0	-.0098	+.0006	+.0006	+.0002	+.0001	+.0001
10	18	0	-.0047	0	-.0047	0	-.0047	0	-.0098	0	-.0098	+.0008	+.0008	+.0002	+.0001	+.0001
18	30	0	-.0047	0	-.0047	0	-.0047	0	-.0098	0	-.0098	+.0008	+.0008	+.0002	+.0001	+.0001
30	50	0	-.0047	0	-.0047	0	-.0047	0	-.0098	0	-.0098	+.0008	+.0008	+.0002	+.0001	+.0001
50	80	0	-.0059	0	-.0059	0	-.0059	0	-.0150	0	-.0098	+.0010	+.0010	+.0002	+.0002	+.0001
80	120	0	-.0079	0	-.0079	0	-.0079	0	-.0150	0	-.0150	+.0010	+.0010	+.0003	+.0002	+.0001
120	150	0	-.0098	0	-.0098	0	-.0098	0	-.0197	0	-.0150	+.0012	+.0012	+.0003	+.0002	+.0001
150	180	0	-.0098	0	-.0098	0	-.0118	0	-.0197	0	-.0150	+.0012	+.0012	+.0003	+.0002	+.0002
180	250	0	-.0118	0	-.0118	0	-.0138	0	-.0197	0	-.0197	+.0012	+.0012	+.0004	+.0002	+.0002
250	315	0	-.0138	0	-.0138	–	–	0	-.0197	0	-.0197	+.0014	+.0014	+.0005	–	–
315	400	0	-.0157	0	-.0157	–	–	0	-.0248	0	-.0248	+.0016	+.0016	+.0006	–	–
400	500	0	-.0177	–	–	–	–	–	–	–	–	+.0020	+.0018	–	–	–
500	630	0	-.0197	–	–	–	–	–	–	–	–	+.0024	+.0020	–	–	–
630	800	0	-.0295	–	–	–	–	–	–	–	–	+.0028	–	–	–	–
800	1000	0	-.0394	–	–	–	–	–	–	–	–	+.0031	–	–	–	–
1000	1250	0	-.0492	–	–	–	–	–	–	–	–	+.0039	–	–	–	–
1250	1600	0	-.0630	–	–	–	–	–	–	–	–	+.0047	–	–	–	–
1600	2000	0	-.0787	–	–	–	–	–	–	–	–	+.0055	–	–	–	–

Note: 1) Tolerance for width deviation and tolerance limits for the width variation of the outer ring should be the same.
2) Applicable to individual rings manufactured for combined bearings.
3) 0.6 mm is included in this group.

Table 10.15 — Tolerances for Inner Ring Runout of Radial Bearings (excluding Tapered Roller Bearings)

Units: inch

Nominal Bore Diameter *d* (mm)		K_{ia}					S_d			S_{ia} 1)		
		Class N	Class 6	Class 5	Class 4	Class 2	Class 5	Class 4	Class 2	Class 5	Class 4	Class 2
over	incl	max	max	max	max	max	max	max	max	max	max	max
0.6[2]	2.5	+.0004	+.0002	+.0002	+.0001	+.0001	+.0003	+.0001	+.0001	+.0003	+.0001	+.0001
2.5	10	+.0004	+.0002	+.0002	+.0001	+.0001	+.0003	+.0001	+.0001	+.0003	+.0001	+.0001
10	18	+.0004	+.0003	+.0002	+.0001	+.0001	+.0003	+.0001	+.0001	+.0003	+.0001	+.0001
18	30	+.0005	+.0003	+.0002	+.0001	+.0001	+.0003	+.0002	+.0001	+.0003	+.0002	+.0001
30	50	+.0006	+.0004	+.0002	+.0002	+.0001	+.0003	+.0002	+.0001	+.0003	+.0002	+.0001
50	80	+.0008	+.0004	+.0002	+.0002	+.0001	+.0003	+.0002	+.0001	+.0003	+.0002	+.0001
80	120	+.0010	+.0005	+.0002	+.0002	+.0001	+.0004	+.0002	+.0001	+.0004	+.0002	+.0001
120	150	+.0012	+.0007	+.0003	+.0002	+.0001	+.0004	+.0002	+.0001	+.0004	+.0003	+.0001
150	180	+.0012	+.0007	+.0003	+.0002	+.0002	+.0004	+.0002	+.0002	+.0004	+.0003	+.0002
180	250	+.0016	+.0008	+.0004	+.0003	+.0002	+.0004	+.0003	+.0002	+.0005	+.0003	+.0002
250	315	+.0020	+.0010	+.0005	–	–	+.0005	–	–	+.0006	–	–
315	400	+.0024	+.0012	+.0006	–	–	+.0006	–	–	+.0008	–	–
400	500	+.0026	+.0014	–	–	–	–	–	–	–	–	–
500	630	+.0028	+.0016	–	–	–	–	–	–	–	–	–
630	800	+.0031	–	–	–	–	–	–	–	–	–	–
800	1000	+.0035	–	–	–	–	–	–	–	–	–	–
1000	1250	+.0039	–	–	–	–	–	–	–	–	–	–
1250	1600	+.0047	–	–	–	–	–	–	–	–	–	–
1600	2000	+.0055	–	–	–	–	–	–	–	–	–	–

Note: 1) Applicable to ball bearings only.
2) 0.6mm is included in this group

Table 10.16 — Tolerances for Outer Ring Runout of Radial Bearings (excluding Tapered Roller Bearings)

Units: inch

Nominal Outside Diameter D (mm)		K_{ea}					S_D			S_{ea}(1)			V_{Cs}(2)		
		Class					Class			Class			Class		
		N	6	5	4	2	5	4	2	5	4	2	5	4	2
over	incl	max	max	max	max	max	max	max	max	max	max	max	max	max	max
2.5[3)]	6	+.0006	+.0003	+.0002	+.0001	+.0001	+.0003	+.0002	+.0001	+.0003	+.0002	+.0001	+.0002	+.0001	+.0001
6	18	+.0006	+.0003	+.0002	+.0001	+.0001	+.0003	+.0002	+.0001	+.0003	+.0002	+.0001	+.0002	+.0001	+.0001
18	30	+.0006	+.0004	+.0002	+.0002	+.0001	+.0003	+.0002	+.0001	+.0003	+.0002	+.0001	+.0002	+.0001	+.0001
30	50	+.0008	+.0004	+.0003	+.0002	+.0001	+.0003	+.0002	+.0001	+.0003	+.0002	+.0001	+.0002	+.0001	+.0001
50	80	+.0010	+.0005	+.0003	+.0002	+.0002	+.0003	+.0002	+.0001	+.0004	+.0002	+.0002	+.0002	+.0001	+.0001
80	120	+.0014	+.0007	+.0004	+.0002	+.0002	+.0004	+.0002	+.0001	+.0004	+.0002	+.0002	+.0003	+.0002	+.0001
120	150	+.0016	+.0008	+.0004	+.0003	+.0002	+.0004	+.0002	+.0001	+.0005	+.0003	+.0002	+.0003	+.0002	+.0001
150	180	+.0018	+.0009	+.0005	+.0003	+.0002	+.0004	+.0002	+.0001	+.0006	+.0003	+.0002	+.0003	+.0002	+.0001
180	250	+.0020	+.0010	+.0006	+.0004	+.0003	+.0004	+.0003	+.0002	+.0006	+.0004	+.0003	+.0004	+.0003	+.0002
250	315	+.0024	+.0012	+.0007	+.0004	+.0003	+.0005	+.0003	+.0002	+.0007	+.0004	+.0003	+.0004	+.0003	+.0002
315	400	+.0028	+.0014	+.0008	+.0005	+.0003	+.0005	+.0004	+.0003	+.0008	+.0005	+.0003	+.0005	+.0003	+.0003
400	500	+.0031	+.0016	+.0009	–	–	+.0006	–	–	+.0009	–	–	+.0006	–	–
500	630	+.0039	+.0020	+.0010	–	–	+.0007	–	–	+.0010	–	–	+.0007	–	–
630	800	+.0047	+.0024	+.0012	–	–	+.0008	–	–	+.0012	–	–	+.0008	–	–
800	1000	+.0055	+.0030	–	–	–	–	–	–	–	–	–	–	–	–
1000	1250	+.0063	–	–	–	–	–	–	–	–	–	–	–	–	–
1250	1600	+.0075	–	–	–	–	–	–	–	–	–	–	–	–	–
1600	2000	+.0087	–	–	–	–	–	–	–	–	–	–	–	–	–
2000	2500	+.0098	–	–	–	–	–	–	–	–	–	–	–	–	–

Note: 1) Tolerance for width deviation and tolerance limits for the width variation of the outer ring should be the same bearing.
2) Applicable to individual rings manufactured for combined bearings.
3) 2.5mm is included within this group

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Table 10.17 — Tolerances for Inner Ring Bore Diameter of Metric Tapered Roller Bearings

Units: inch

Nominal Bore Diameter *d* (mm)		Δ*d*mp						Δ*d*s		V*d*p				V*d*mp			
		Class N Class 6X		Class 6 Class 5		Class 4		Class 4		Class				Class			
										N,6X	6	5	4	N,6X	6	5	4
over	incl	high	low	high	low	high	low	high	low	max	max	max	max	max	max	max	max
10	18	0	-.0003	0	-.0003	0	-.0002	0	-.0002	+.0003	+.0003	+.0002	+.0002	+.0002	+.0002	+.0002	+.0002
18	30	0	-.0004	0	-.0003	0	-.0002	0	-.0002	+.0004	+.0003	+.0002	+.0002	+.0003	+.0002	+.0002	+.0002
30	50	0	-.0005	0	-.0004	0	-.0003	0	-.0003	+.0005	+.0004	+.0003	+.0002	+.0004	+.0003	+.0002	+.0002
50	80	0	-.0006	0	-.0005	0	-.0004	0	-.0004	+.0006	+.0005	+.0004	+.0003	+.0004	+.0004	+.0002	+.0002
80	120	0	-.0008	0	-.0006	0	-.0004	0	-.0004	+.0008	+.0006	+.0004	+.0003	+.0006	+.0004	+.0003	+.0002
120	180	0	-.0010	0	-.0007	0	-.0005	0	-.0005	+.0010	+.0007	+.0006	+.0004	+.0007	+.0006	+.0004	+.0003
180	250	0	-.0012	0	-.0009	0	-.0006	0	-.0006	+.0012	+.0009	+.0007	+.0004	+.0009	+.0006	+.0004	+.0003
250	315	0	-.0014	0	-.0010	0	-.0007	0	-.0007	+.0014	–	–	–	+.0010	–	–	–
315	400	0	-.0016	0	-.0012	0	-.0009	0	-.0009	+.0016	–	–	–	+.0012	–	–	–
400	500	0	-.0018	0	-.0014	0	-.0011	0	-.0011	–	–	–	–	–	–	–	–
500	630	0	-.0020	0	-.0016	–	–	–	–	–	–	–	–	–	–	–	–
630	800	0	-.0030	0	-.0024	–	–	–	–	–	–	–	–	–	–	–	–

Remarks: 1. The outside diameter "no-go side" tolerances (high) specified in this table do not necessarily apply within a distance of 1.2 times the chamfer dimension r (max) from the ring face.
2. Some of these tolerances conform to the NSK standard, and not ISO standards.

Table 10.18 — Tolerances for Outer Ring Diameter of Metric Tapered Roller Bearings

Units: inch

Nominal Outside Diameter *D* (mm)		Δ*d*mp						Δ*d*s		V*d*p				V*d*mp			
		Class N Class 6X		Class 6 Class 5		Class 4		Class 4		Class				Class			
										N,6X	6	5	4	N,6X	6	5	4
over	incl	high	low	high	low	high	low	high	low	max	max	max	max	max	max	max	max
18	30	0	-.0004	0	-.0003	0	-.0002	0	-.0002	+.0004	+.0003	+.0002	+.0002	+.0003	+.0002	+.0002	+.0002
30	50	0	-.0004	0	-.0004	0	-.0003	0	-.0003	+.0004	+.0004	+.0003	+.0002	+.0003	+.0003	+.0002	+.0002
50	80	0	-.0005	0	-.0004	0	-.0004	0	-.0004	+.0005	+.0004	+.0003	+.0003	+.0004	+.0003	+.0002	+.0002
80	120	0	-.0006	0	-.0005	0	-.0004	0	-.0004	+.0006	+.0005	+.0004	+.0003	+.0004	+.0004	+.0003	+.0002
120	150	0	-.0007	0	-.0006	0	-.0004	0	-.0004	+.0007	+.0006	+.0004	+.0003	+.0006	+.0004	+.0003	+.0002
150	180	0	-.0010	0	-.0007	0	-.0005	0	-.0005	+.0010	+.0007	+.0006	+.0004	+.0007	+.0006	+.0004	+.0003
180	250	0	-.0012	0	-.0008	0	-.0006	0	-.0006	+.0012	+.0008	+.0006	+.0004	+.0009	+.0006	+.0004	+.0003
250	315	0	-.0014	0	-.0010	0	-.0007	0	-.0007	+.0014	+.0010	+.0007	+.0006	+.0010	+.0007	+.0005	+.0004
315	400	0	-.0016	0	-.0011	0	-.0008	0	-.0008	+.0016	+.0011	+.0009	+.0006	+.0012	+.0008	+.0006	+.0004
400	500	0	-.0018	0	-.0013	0	-.0009	0	-.0009	+.0018	–	–	–	+.0013	–	–	–
500	630	0	-.0020	0	-.0015	–	-.0011	–	-.0011	+.0020	–	–	–	+.0015	–	–	–
630	800	0	-.0030	0	-.0018	–	–	–	–	–	–	–	–	–	–	–	–
800	1000	0	-.0039	0	-.0024	–	–	–	–	–	–	–	–	–	–	–	–

Remarks: 1. The outside diameter "no-go side" tolerances (high) specified in this table do not necessarily apply within a distance of 1.2 times the chamfer dimension r (max) from the ring face.
2. Some of these tolerances conform to the NSK standard, and not ISO standards.

Table 10.19 — Tolerances for Inner Ring Running Accuracy of Metric Tapered Bearings

Units: inch

Nominal Bore Diameter d (mm)		K_{ia}				S_d		S_{ia}
		Class N Class 6X	Class 6	Class 5	Class 4	Class 5	Class 4	Class 4
over	incl	max	max	max	max	max	max	max
10	18	+.0006	+.0003	+.0001	+.0001	+.0003	+.0001	+.0001
18	30	+.0007	+.0003	+.0002	+.0001	+.0003	+.0002	+.0002
30	50	+.0008	+.0004	+.0002	+.0002	+.0003	+.0002	+.0002
50	80	+.0010	+.0004	+.0002	+.0002	+.0003	+.0002	+.0002
80	120	+.0012	+.0005	+.0002	+.0002	+.0004	+.0002	+.0002
120	180	+.0014	+.0007	+.0003	+.0002	+.0004	+.0002	+.0003
180	250	+.0020	+.0008	+.0004	+.0003	+.0004	+.0003	+.0003
250	315	+.0024	+.0010	+.0005	+.0004	+.0005	+.0003	+.0004
315	400	+.0028	+.0012	+.0006	+.0005	+.0006	+.0004	+.0006
400	500	+.0028	+.0014	+.0007	+.0006	+.0007	+.0005	+.0007
500	630	+.0033	+.0016	+.0008	--	+.0009	--	--
630	800	+.0039	+.0018	+.0009	--	+.0011	--	--

Table 10.20 — Tolerances for Outer Ring Running Accuracy of Metric Tapered Bearings

Units: inch

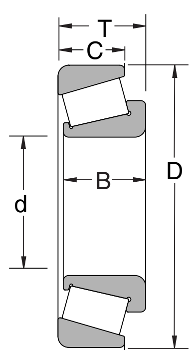
Nominal Outside Diameter *D* (mm)		K_{ea}				S_D		S_{ea}
		Class N Class 6X	Class 6	Class 5	Class 4	Class 5	Class 4	Class 4
over	incl	max	max	max	max	max	max	max
18	30	+.0007	+.0004	+.0002	+.0002	+.0003	+.0002	+.0002
30	50	+.0008	+.0004	+.0003	+.0002	+.0003	+.0002	+.0002
50	80	+.0010	+.0005	+.0003	+.0002	+.0003	+.0002	+.0002
80	120	+.0014	+.0007	+.0004	+.0002	+.0004	+.0002	+.0002
120	150	+.0016	+.0008	+.0004	+.0003	+.0004	+.0002	+.0003
150	180	+.0018	+.0009	+.0005	+.0003	+.0004	+.0002	+.0003
180	250	+.0020	+.0010	+.0006	+.0004	+.0004	+.0003	+.0004
250	315	+.0024	+.0012	+.0007	+.0004	+.0005	+.0003	+.0004
315	400	+.0028	+.0014	+.0008	+.0005	+.0005	+.0004	+.0005
400	500	+.0031	+.0016	+.0009	+.0006	+.0006	+.0004	+.0006
500	630	+.0039	+.0020	+.0010	+.0007	+.0007	+.0005	+.0007
630	800	+.0047	+.0024	+.0012	--	+.0008	--	--
800	1000	+.0047	+.0030	+.0014	--	+.0009	--	--

Table 10.21 — Tolerances for Cone Width, Cup Width, and Combined Cone/Cup Width of Metric Tapered Roller Bearings

Units: inch

Nominal Bore Diameter *d* (mm)		ΔB_s						ΔC_s						ΔT_s					
		Class N Class 6		Class 6X		Class 5 Class 4		Class N Class 6		Class 6X		Class 5 Class 4		Class N Class 6		Class 6X		Class 5 Class 4	
over	incl	high	low	high	low	high	low	high	low	high	low	high	low	high	low	high	low	high	low
10	18	0	-.0047	0	-.0020	0	-.0079	0	-.0047	0	-.0039	0	-.0079	-.0079	0	+.0039	0	+.0079	-.0079
18	30	0	-.0047	0	-.0020	0	-.0079	0	-.0047	0	-.0039	0	-.0079	-.0079	0	+.0039	0	+.0079	-.0079
30	50	0	-.0047	0	-.0020	0	-.0094	0	-.0047	0	-.0039	0	-.0094	-.0079	0	+.0039	0	+.0079	-.0079
50	80	0	-.0059	0	-.0020	0	-.0118	0	-.0059	0	-.0039	0	-.0118	-.0079	0	+.0039	0	+.0079	-.0079
80	120	0	-.0079	0	-.0020	0	-.0157	0	-.0079	0	-.0039	0	-.0157	+.0079	-.0079	+.0039	0	+.0079	-.0079
120	180	0	-.0098	0	-.0020	0	-.0197	0	-.0098	0	-.0039	0	-.0197	+.0138	-.0098	+.0059	0	+.0138	-.0098
180	250	0	-.0118	0	-.0020	0	-.0197	0	-.0118	0	-.0039	0	-.0197	+.0138	-.0098	+.0059	0	+.0209	-.0098
250	315	0	-.0138	0	-.0020	0	-.0276	0	-.0138	0	-.0039	0	-.0276	+.0138	-.0098	+.0079	0	+.0209	-.0098
315	400	0	-.0157	0	-.0020	0	-.0315	0	-.0157	0	-.0039	0	-.0315	+.0157	-.0157	+.0079	0	+.0157	-.0157
400	500	0	-.0177	–	–	0	-.0315	0	-.0177	–	–	0	-.0315	+.0157	-.0157	–	–	+.0157	-.0157
500	630	0	-.0197	–	–	0	-.0315	0	-.0197	–	–	0	-.0315	+.0197	-.0197	–	–	+.0197	-.0197
630	800	0	-.0295	–	–	0	-.0315	0	-.0295	–	–	0	-.0315	+.0236	-.0236	–	–	+.0236	-.0236

Remarks: 1. The effective width of a cone with rollers T1 is defined as the overall bearing width of a cone with rollers combined with a master cup.
2. The effective width of a cup T2 is defined as the overall bearing width of a cup combined with a master cone with rollers.

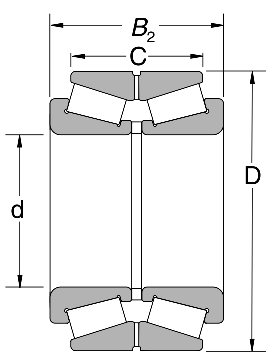


Single Row

Table 10.21 — Tolerances for Cone Width, Cup Width, and Combined Cone/Cup Width(continued)

Units: inch

Nominal Bore Diameter *d* (mm)		Effective Cone Width (with Rollers) Deviation ΔT_{1s}				Effective Cup Width Deviation ΔT_{2s}				Overall Combined Bearing Width Deviation			
										ΔB_{2s}		ΔB_{4s}, ΔC_{4s}	
		Class N		Class 6X		Class N		Class 6X		All classes of double-row bearings		All classes of four-row bearings	
over	incl	high	low	high	low	high	low	high	low	high	low	high	low
10	18	+.0039	0	+.0020	0	+.0039	0	+.0020	0	+.0079	-.0079	–	–
18	30	+.0039	0	+.0020	0	+.0039	0	+.0020	0	+.0079	-.0079	–	–
30	50	+.0039	0	+.0020	0	+.0039	0	+.0020	0	+.0079	-.0079	–	–
50	80	+.0039	0	+.0020	0	+.0039	0	+.0020	0	+.0118	-.0118	+.0118	-.0118
80	120	+.0039	-.0039	+.0020	0	+.0039	-.0039	+.0020	0	+.0118	-.0118	+.0157	-.0157
120	180	+.0059	-.0059	+.0020	0	+.0079	-.0039	+.0039	0	+.0157	-.0157	+.0197	-.0197
180	250	+.0059	-.0059	+.0020	0	+.0079	-.0039	+.0039	0	+.0177	-.0177	+.0236	-.0236
250	315	+.0059	-.0059	+.0039	0	+.0079	-.0039	+.0039	0	+.0217	-.0217	+.0276	-.0276
315	400	+.0079	-.0079	+.0039	0	+.0079	-.0079	+.0039	0	+.0236	-.0236	+.0315	-.0315
400	500	–	–	–	–	–	–	–	–	+.0276	-.0276	+.0354	-.0354
500	630	–	–	–	–	–	–	–	–	+.0315	-.0315	+.0394	-.0394
630	800	–	–	–	–	–	–	–	–	+.0472	-.0472	+.0591	-.0591



KBE Type

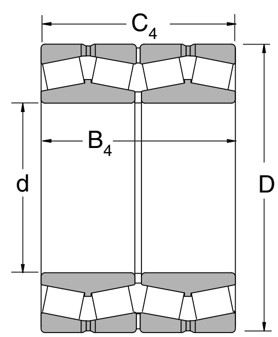


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Table 10.22 —Tolerances for Outer Ring Outside Diameter and Radial Runout of Inch Tapered Roller Bearings

more

Units: inch

Nominal Outside Diameter *D* (in)		ΔDs					
		Class 4,2		Class 3,0		Class 00	
over	incl.	high	low	high	low	high	low
	10.5000	+.0010	0	+.0005	0	+.0003	0
10.5000	12.0000	+.0010	0	+.0005	0	–	–
12.0000	24.0000	+.0020	0	+.0010	0	–	–
24.0000	36.0000	+.0030	0	+.0015	0	–	–
36.0000	48.0000	+.0040	0	+.0020	0	–	–
48.0000		+.0050	0	+.0030	0	–	–

Table 10.23 — Tolerances for Overall Width and Combined Width of Inch Tapered Roller Bearings

more

Units: inch

Nominal Bore Diameter *d* (in)		ΔTs									
		Class 4		Class 2		Class 3,0				Class 0 Class 00	
						D ≤508.000mm		D>508.000mm			
over	incl.	high	low	high	low	high	low	high	low	high	low
	4.0000	+.0080	–	+.0080	–	+.0080	-.0080	+.0080	-.0080	+.0080	-.0080
4.0000	12.0000	+.0140	-.0100	+.0080	–	+.0080	-.0080	+.0080	-.0080	+.0080	-.0080
12.0000	24.0000	+.0150	-.0150	+.0150	-.0150	+.0080	-.0080	+.0150	-.0150	–	–
24.0000		+.0150	-.0150	–	–	+.0150	-.0150	+.0150	-.0150	–	–

Table 10.24 — Tolerances for Inner Ring Bore of Inch Design Tapered Roller Bearings

Units: inch

Nominal Bore Diameter *d* (in)		Δd_s					
		Class 4,2		Class 3,0		Class 00	
over	incl.	high	low	high	low	high	low
	3.0000	+.0005	0	+.0005	0	+.0003	0
3.0000	10.5000	+.0010	0	+.0005	0	+.0003	0
10.5000	12.0000	+.0010	0	+.0005	0	–	–
12.0000	24.0000	+.0020	0	+.0010	0	–	–
24.0000	36.0000	+.0030	0	+.0015	0	–	–
36.0000	48.0000	+.0040	0	+.0020	0	–	–
48.0000		+.0050	0	+.0030	0	–	–

Table 10.22 —Tolerances for Outer Ring Outside Diameter and Radial Runout of Inch Tapered Roller Bearings (continued)

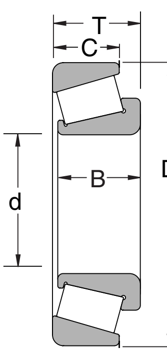
Units: inch

K_{ia}, K_{ea}				
Class 4	Class 2	Class 3	Class 0	Class 00
max	max	max	max	max
.0020	.0015	.0003	.0002	.0001
.0020	.0015	.0003	.0002	–
.0020	.0015	.0003	–	–
.0030	.0020	.0020	–	–
.0030	–	.0030	–	–
.0030	–	.0030	–	–

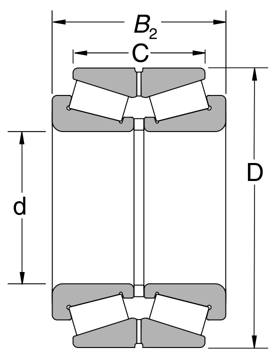
Table 10.23 —Tolerances for Overall Width and Combined Width of Inch Tapered Roller Bearings (continued)

Units: inch

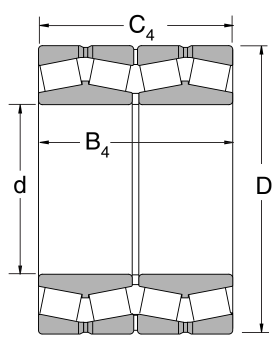
Double-Row Bearings (KBE Type) ΔB_{2s}										Four-Row Bearings (KV Type) ΔB_{4s}, ΔC_{4s}	
Class 4		Class 2		Class 3,0				Class 0,00		Class 4,3,0	
				D ≤508.000mm		>508.000mm					
high	low	high	low	high	low	high	low	high	low	high	low
+.0160	0	+.0160	0	+.0160	-.0160	+.0160	-.0160	+.0160	-.0160	+.0600	-.0600
+.0280	-.0200	+.0160	-.0080	+.0160	-.0160	+.0160	-.0160	+.0160	-.0160	+.0600	-.0600
+.0300	-.0300	+.0300	-.0300	+.0160	-.0160	+.0308	-.0308	–	–	+.0600	-.0600
+.0300	-.0300	–	–	+.0300	-.0300	+.0308	-.0308	–	–	+.0600	-.0600



Single Row



KBE Type



KV Type

Table 10.25 —Tolerances for Shaft Washer Bore Diameter and Running Accuracy of Thrust Ball Bearings

Units: inch

Nominal Bore Diameter d or d_2 (mm)		Δd_{mp} or Δd_{2mp}				V_{dp} or V_{d2p}		S_i or S_e 1)			
		Class N,6,5		Class 4			Class 4	Class N	Class 6	Class 5	Class4
over	incl	high	low	high	low	max	max	max	max	max	max
	18	0	-.0003	0	-.0003	.0002	.0002	.0004	.0002	.0001	.0001
18	30	0	-.0004	0	-.0003	.0003	.0002	.0004	.0002	.0001	.0001
30	50	0	-.0005	0	-.0004	.0004	.0003	.0004	.0002	.0001	.0001
50	80	0	-.0006	0	-.0005	.0004	.0004	.0004	.0003	.0002	.0001
80	120	0	-.0008	0	-.0006	.0006	.0004	.0006	.0003	.0002	.0001
120	180	0	-.0010	0	-.0007	.0007	.0006	.0006	.0004	.0002	.0002
180	250	0	-.0012	0	-.0009	.0009	.0007	.0008	.0004	.0002	.0002
250	315	0	-.0014	0	-.0010	.0010	.0007	.0010	.0005	.0003	.0002
315	400	0	-.0016	0	-.0012	.0012	.0009	.0012	.0006	.0003	.0002
400	500	0	-.0018	0	-.0014	.0013	.0010	.0012	.0007	.0004	.0002
500	630	0	-.0020	0	-.0016	.0015	.0012	.0014	.0008	.0004	.0003
630	800	0	-.0030	0	-.0020	–	–	.0016	.0010	.0005	.0003
800	1000	0	-.0039	–	–	–	–	.0018	.0012	.0006	–
1000	1250	0	-.0049	–	–	–	–	.0020	.0014	.0007	–

Note: 1) For double-direction bearings, the thickness variation doesn't depend on the bore diameter $\mathbf{d_2}$, but on **d** for single-direction bearings with the same D in the same diameter series.

Remarks: The thickness variation of housing washers, $\mathbf{S_e}$, applies only to flat-seat thrust bearings

Table 10.26 —Tolerances for Outside Diameter of Housing Washers and Aligning Seat Washers of Thrust Ball Bearings

Units: inch

Nominal Outside Diameter of Bearing or Aligning Seat Washer D or D_3 (mm)		ΔDmp						V_{Dp}		Aligning Seat Washer Outside Diameter Deviation ΔD_{3s}	
		Flat Seat Type				Aligning Seat Washer Type		Class N,6,5	Class 4		
		Class N,6,5		Class 4		Class N,6				Class N,6	
over	incl	high	low	high	low	high	low	max	max	high	low
10	18	0	-.0004	0	-.0003	0	-.0007	+.0003	+.0002	0	-.0010
18	30	0	-.0005	0	-.0003	0	-.0008	+.0004	+.0002	0	-.0012
30	50	0	-.0006	0	-.0004	0	-.0009	+.0005	+.0003	0	-.0014
50	80	0	-.0007	0	-.0004	0	-.0011	+.0006	+.0003	0	-.0018
80	120	0	-.0009	0	-.0005	0	-.0013	+.0007	+.0004	0	-.0024
120	180	0	-.0010	0	-.0006	0	-.0015	+.0007	+.0004	0	-.0030
180	250	0	-.0012	0	-.0008	0	-.0018	+.0009	+.0006	0	-.0035
250	315	0	-.0014	0	-.0010	0	-.0021	+.0010	+.0007	0	-.0041
315	400	0	-.0016	0	-.0011	0	-.0024	+.0012	+.0008	0	-.0047
400	500	0	-.0018	0	-.0013	0	-.0027	+.0013	+.0010	0	-.0053
500	630	0	-.0020	0	-.0015	0	-.0030	+.0015	+.0011	0	-.0071
630	800	0	-.0030	0	-.0018	0	-.0044	+.0022	+.0013	0	-.0089
800	1000	0	-.0039	–	–	–	–	+.0030	–	–	–
1000	1250	0	-.0049	–	–	–	–	–	–	–	–
1250	1600	0	-.0063	–	–	–	–	–	–	–	–

Table 10.27 —Tolerances for Thrust Ball Bearing Height and Central Washer Height

Units: inch

Nominal Bore Diameter d (mm)		Flat Seat Type				Aligning Seat Washer Type				With Aligning Seat Washer				Height Deviation of Central Washer ΔB_s	
		ΔT_s or ΔT_{2s}		ΔT_{1s}		ΔT_{3s} or ΔT_{5s}		ΔT_{5s}		ΔT_{4s} or ΔT_{8s}		ΔT_{1s}			
		Class N,6,5,4		Class N,6,5,4		Class N,6		Class N,6		Class N,6		Class N,6		Class N,6,5,4	
over	incl	high	low	high	low	high	low	high	low	high	low	high	low	high	low
	30	+0	-.0030	+.0020	-.0059	+0	-.0030	+.0020	-.0059	+.0020	-.0030	+.0059	-.0059	+0	-.0020
30	50	+0	-.0039	+.0030	-.0079	+0	-.0039	+.0030	-.0079	+.0020	-.0039	+.0069	-.0079	+0	-.0030
50	80	+0	-.0049	+.0039	-.0098	+0	-.0049	+.0039	-.0098	+.0030	-.0049	+.0098	-.0098	+0	-.0039
80	120	+0	-.0059	+.0049	-.0118	+0	-.0059	+.0049	-.0118	+.0030	-.0059	+.0108	-.0118	+0	-.0049
120	180	+0	-.0069	+.0059	-.0138	+0	-.0069	+.0059	-.0138	+.0039	-.0069	+.0138	-.0138	+0	-.0059
180	250	+0	-.0079	+.0069	-.0157	+0	-.0079	+.0069	-.0157	+.0039	-.0079	+.0148	-.0157	+0	-.0069
250	315	+0	-.0089	+.0079	-.0177	+0	-.0089	+.0079	-.0177	+.0049	-.0089	+.0177	-.0177	+0	-.0079
315	400	+0	-.0118	+.0098	-.0236	+0	-.0118	+.0098	-.0236	+.0059	-.0108	+.0217	-.0217	+0	-.0098

Note: 1) For double-direction bearings, the thickness variation doesn't depend on the bore diameter d_2, but on **d** for single-direction bearings with the same **D** in the same diameter series.

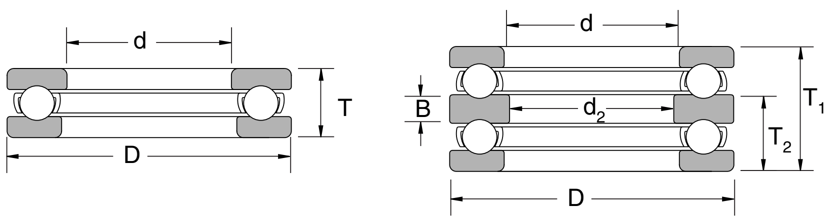


Table 10.28 —Tolerances for Bore Diameters of Inner Rings and Height (Class N) of Spherical Thrust Roller Bearings

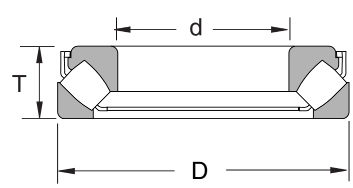
Units: inch

Nominal Bore Diameter d (mm)		Δd_{mp}		V_{dp}	Reference		
					S_d	ΔT_s	
over	incl	high	low	max	max	high	low
50	80	0	-.0006	.0004	.0010	+.0059	-.0059
80	120	0	-.0008	.0006	.0010	+.0079	-.0079
120	180	0	-.0010	.0007	.0012	+.0098	-.0098
180	250	0	-.0012	.0009	.0012	+.0118	-.0118
250	315	0	-.0014	.0010	.0014	+.0138	-.0138
315	400	0	-.0016	.0012	.0016	+.0157	-.0157
400	500	0	-.0018	.0013	.0018	+.0177	-.0177

Table 10.29 —Tolerances for Outer Ring Diameter (Class N) of Spherical Thrust Roller Bearings

Units: inch

Nominal Outside Diameter D (mm)		ΔD_{mp}	
over	incl	high	low
120	180	0	-.0010
180	250	0	-.0012
250	315	0	-.0014
315	400	0	-.0016
400	500	0	-.0018
500	630	0	-.0020
630	800	0	-.0030
800	1000	0	-.0039



Bearing Fits & Internal Clearance

Fit--Why It's Important

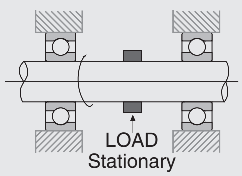
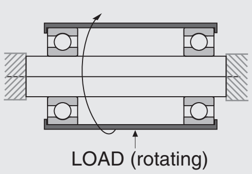
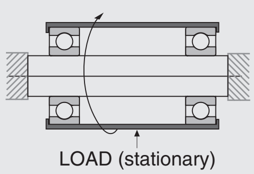
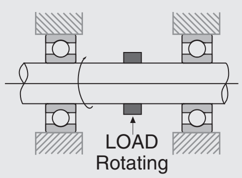
When a bearing's inner ring is fitted to the shaft with only slight interference, slipping or "creep" may occur. Creep may also occur between the outer ring and housing.

When creep occurs the fitted surfaces become abraded which causes excessive wear and may cause considerable damage to the shaft or housing. In addition, abrasive metal particles resulting from creep may enter the interior of the bearing and cause abnormal heating and vibration.

It is important to prevent creep by having sufficient interference to firmly secure the bearing ring to either the shaft or housing.

In specific applications, fits can be made without interference. For example, it is usually not necessary to provide fit interference for rings subjected only to stationary loads. In other applications, loose fits may be used to accommodate certain operating conditions or to facilitate bearing mounting and dismounting. In these cases, lubrication or other methods need to be considered to prevent damage to the fitting surfaces due to creep.

Table 10.30 —Loading Conditions and Fit

Load Applicaiton	Bearing Operation		Loading Conditions	Fit	
	Inner Ring	Outer Ring		Inner Ring and Shaft	Outer Ring and Housing
	Rotating	Stationary	Rotating Inner Ring Load Stationary Outer Ring Load	Tight Fit	Loose Fit
	Stationary	Rotating			
	Stationary	Rotating	Rotating Outer Ring Load Stationary Inner Ring Load	Loose Fit	Tight Fit
	Rotating	Stationary			
Direction of Load Indeterminate	Rotating or Stationary	Rotating or Stationary	-	Tight Fit	Tight Fit

How To Select Proper Fit

Load Conditions and Fit

Proper fit may be selected from Table 10.30 on page 327 based on the load and operating conditions.

Magnitude of Load and Interference

Under load, a slight amount of deflection or deformation of the bearing rings will occur. This reduces the interference fit. For this reason, heavier loaded bearings require a heavier initial interference fit. The required interference can be calculated using the following equations:

$$\Delta d_f = 0.08\sqrt{\frac{d}{B}F_r}\ \text{x}10^{-3}$$

light and normal loads

$$\Delta d_e \geq 0.02\frac{F_r}{B}\ \text{x}10^{-3}$$

when $F_r > .20\ C_{or}$

Where Δd_f: Interference decrease of inner ring (mm)
Δd_e: Effective interference (mm)
d: Bearing bore diameter (mm)
B: Inner ring width (mm)
F_r: Radial load applied to bearing (N)

Interference Variation Due to Temperature Difference Between Bearing and Shaft or Housing

Interference decreases when bearing temperature increases during operation. If the temperature difference between the interior of the bearing and the surrounding parts of the housing is ΔT(°C), then the temperature difference between the fitted surfaces of the shaft and the inner ring is estimated to be about (0.1~0.15)T. Decrease of inner ring interference due to this difference may be calculated from the following equation: $\Delta d_T = (0.10 \sim 0.15)\Delta T \bullet \alpha \bullet d = 0.0015\Delta T \bullet d\text{x}10^{-3}$

Where Δd_T = Decrease of interference of inner ring due to temperature increase (mm)
ΔT = Temperature difference between bearing and surrounding parts
α = Coefficient of linear expansion of bearing steel (12.5 x 10-6(1/°C))
d = bore diameter

Table 10.31 — Fits of Radial Bearings with Solid Steel Shafts

Load Conditions		Examples	Shaft Diameter (mm): Ball Bearings	Shaft Diameter (mm): Cylindrical or Tapered Roller Brgs.	Shaft Diameter (mm): Spherical Roller Bearings	Tolerance of Shaft
Radial Bearings with Cylindrical Bores						
Rotating Outer Ring Load	Easy axial displacement of inner ring on shaft desirable	Wheels on Stationary axles	All Shaft Diameters			g6
	Easy axial displacement of inner ring on shaft unnecesary	Tension Pulleys, Rope Sheaves				h6
Rotating Inner Ring Load or Direction of Load Indeterminate	Light Load ($<0.06C_r$[1])	Electrical Appliances, Pumps, Blowers, Transport Vehicles, Precision Machinery, Machine Tools	<18	–	–	js5
			18 to 100	<40	–	js6 (j6)
			100 to 200	40 to 140	–	K6
			–	140 to 200	–	m6
	Normal Loads (0.06 to 0.13 C_r[1])	General Bearing Applications, Medium and Large Motors, Turbines, Pumps, Engine Main Bearings, Gears, Woodworking Machines	<18	–	–	js5~6(j5~6)
			18 to 100	<40	<40	k5 or 6
			100 to 140	40 to 100	40 to 65	m5 or 6
			140 to 200	100 to 140	65 to 100	m6
			200 to 280	140 to 200	100 to 140	n6
			–	200 to 400	140 to 280	p6
			–	–	280 to 500	r6
			–	–	>500	r7
	Heavy Loads ($>0.13C_r$[1])	Railway Axle boxes, Industrial Vehicles, Traction Motors, Construction Equipment, Crushers	–	50 to 140	50 to 100	n6
			–	140 to 200	100 to 140	p6
			–	over 200	140 to 200	r6
			–	–	200 to 500	r7
Axial Loads Only		–	All Shaft Diameters			js6 (j6)
Radial Bearings with Tapered Bores and Sleeves (Contact NSK Engineering)						

Note:1. C_r represents the basic load rating of the bearing

Table 10.32 — Fits of Thrust Bearings with Solid Steel Shafts

For more information, see page 356

Load Conditions		Examples	Shaft Diameter (mm)	Tolerance of Shaft
Central Axial Load Only		Main Shafts of Lathes	All Shaft Diameters	h6 or js6 (j6)
Combined Radial and Axial Loads (Spherical Thrust Roller Bearings)	Stationary Inner Ring Load	Cone Crushers	All Shaft Diameters	js6(j6)
	Rotating Inner Ring Load or Direction of Load Indeterminate	Paper Pulp Refiners, Plastic Extruders	<200	k6
			200 to 400	m6
			Over 400	n6

Table 10.33 — Fits of Radial Bearings with Housings

For more information, see page 358

Load Conditions			Examples	Tolerances for Housing Bores
Solid Housings	Rotating Outer Ring Load	Heavy Loads on Bearing in Thin-Walled Housing or Heavy Shock Loads	Automotive Wheel Hubs (Roller Bearings) Crane Traveling Wheels	P7
		Normal or Heavy Loads	Automotive Wheel Hubs (Ball Bearings) Vibrating Screens	N7
		Light or Variable Loads	Conveyor Roller, Rope Sheaves, Tension Pulleys	M7
	Direction of Load Indeterminate	Heavy Shock Loads	Traction Motors	M7
		Normal or Heavy Loads	Pumps, Crankshaft Main Bearings, Medium and Large Motors	K7
Solid or Split Housings		Normal or Light Loads		JS7 (J7)
	Rotating Inner Ring Load	Loads of All Kinds	General Bearing Applications, Railway Axleboxes	H7
		Normal and Light Loads	Plummer Blocks	H8
		High Temperature Rise of Inner Ring Through Shaft	Paper Dryers	G7
		Accurate Running Desirable Under Normal and Light Loads	Grinding Spindle Rear Ball Bearings, High Speed Centrifugal Compressor Free Bearings	JS6(J6)
Solid Housings	Direction of Load Indeterminate		Grinding Spindle Front Ball Bearings, High Speed Centrifugal Compressor Fixed Bearings	K6
	Rotating Inner Ring Load	Accurate Running at High Rigidity Desirable under Variable Loads	Cylindrical Roller Bearings for Machine Tool Main Spindle	M6 or N6
		Minimum noise is required	Electrical Home Appliances	H6

Table 10.34 — Fits of Thrust Bearings with Housings

For more information, see page 358

Load Conditions			Remarks	Tolerances for Housing Bores
Axial Loads Only		Thrust Ball Bearings	General Purpose Application	Clearance over 0.25mm
			When Precision is Required	H8
		Spherical Thrust Roller Bearings	When Radial Loads are Sustained by Other Bearings	Outer ring has radial clearance
Combined Radial and Axial Loads	Stationary Outer Ring Loads	Spherical Thrust Roller Bearings	–	H7 orJS7(J7)
	Rotating Outer Ring Loads or Direction of Load Indeterminate		Normal Loads	K7
			Relatively Heavy Radial Loads	M7

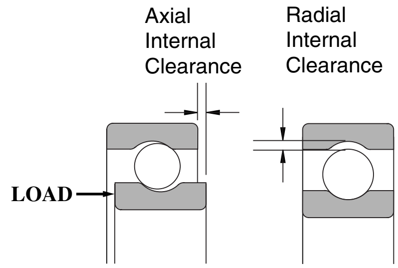
Introduction
Ball Bearings
Cylindrical Roller Bearings
Spherical Roller Bearings
Tapered Roller Bearings
Thrust Bearings
Split Pillow Blocks
Super Precision Bearings
Linear Motion
Rolling Mill Bearings
Engineering Section

Bearing Internal Clearance

Internal Clearances and Standards

Bearing internal clearance is the total clearance between the rings and rolling elements. Internal clearance influences fatigue life, vibration, noise, and operating temperature. Therefore, selection of the proper clearance is critical.

Radial and axial clearances are defined as the total amount that one ring can be displaced relative to the other in either the radial or axial direction as shown in this drawing.



To obtain accurate measurements for ball bearings, internal clearance is usually measured by applying a specified measuring load to the bearings. The clearance measured is always slightly larger than the actual bearing internal clearance due to the elastic deformation caused by the measuring load.

Actual internal clearance is obtained by correcting the measured clearance by the amount of elastic deformation. In the case of roller bearings this elastic deformation is negligible.

Bearing internal clearances listed throughout this catalog have been corrected to provide actual internal clearances.

Radial Internal Clearance

Radial Internal Clearances for several types of ball bearings and roller bearings are presented in the following tables:

Table 10.35 — Radial Internal Clearance in Single Row Deep Groove Ball Bearings Under No Load

Units: inch

Nominal Bore Diameter d (mm)		Radial Internal Clearance							
		C2		C0		C3		C4	
over	incl	low	high	low	high	low	high	low	high
(10mm Only)*		+.0000	+.0003	+.0001	+.0005	+.0003	+.0009	+.0006	+.0011
10	18	+.0000	+.0004	+.0001	+.0007	+.0004	+.0010	+.0007	+.0013
18	24	+.0000	+.0004	+.0002	+.0008	+.0005	+.0011	+.0008	+.0014
24	30	+.0000	+.0004	+.0002	+.0008	+.0005	+.0011	+.0009	+.0016
30	40	+.0000	+.0004	+.0002	+.0008	+.0006	+.0013	+.0011	+.0018
40	50	+.0000	+.0004	+.0002	+.0009	+.0007	+.0014	+.0012	+.0020
50	65	+.0000	+.0006	+.0003	+.0011	+.0009	+.0017	+.0015	+.0024
65	80	+.0000	+.0006	+.0004	+.0012	+.0010	+.0020	+.0018	+.0028
80	100	+.0000	+.0007	+.0005	+.0014	+.0012	+.0023	+.0021	+.0033
100	120	+.0001	+.0008	+.0006	+.0016	+.0014	+.0026	+.0024	+.0038
120	140	+.0001	+.0009	+.0007	+.0019	+.0016	+.0032	+.0028	+.0045
140	160	+.0001	+.0009	+.0007	+.0021	+.0018	+.0036	+.0032	+.0051
160	180	+.0001	+.0010	+.0008	+.0024	+.0021	+.0040	+.0036	+.0058
180	200	+.0001	+.0012	+.0010	+.0028	+.0025	+.0046	+.0042	+.0064
200	225	–	+.0013	+.0010	+.0315	+.0029	+.0053	+.0049	+.0074
225	250	–	+.0014	+.0012	+.0035	+.0033	+.0059	+.0057	+.0084
250	280	–	+.0016	+.0014	+.0037	+.0035	+.0063	+.0061	+.0092
280	315	–	+.0020	+.0020	+.0043	+.0043	+.0071	+.0075	+.0104
315	355	–	+.0022	+.0022	+.0049	+.0049	+.0079	+.0085	+.0116
355	400	–	+.0026	+.0026	+.0055	+.0055	+.0089	+.0096	+.0134

*For bore sizes smaller than 10mm, refer to Table 10.36

Table 10.36 — Radial Internal Clearances in Extra Small & Miniature Ball Bearings Under No Load

Units: inch

Clearance Symbols (Among these NSK Standard Clearances, MC5 is the most widely used)											
MC1		MC2		MC3		MC4		MC5		MC6	
low	high	low	high	low	high	low	high	low	high	low	high
+0	+.0002	+.0001	+.0003	+.0002	+.0004	+.0003	+.0005	+.0005	+.0008	+.0008	+.0011

Table 10.37 — Radial Internal Clearances in Cylindrical Roller Bearings with Cylindrical Bores

Units: μm

Nominal Bore Dia. d(mm)		Clearances in Interchangeable Bearings with Cylindrical Bores										Clearances in Matched Bearings with Cylindrical Bores											
		C2		CO		C3		C4		C5		CC1		CC2		CC(1)		CC3		CC4		CC5	
over	incl	min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max
0	10	.0000	.0010	.0008	.0018	.0014	.0024	.0020	.0030	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10	24	.0000	.0010	.0008	.0018	.0014	.0024	.0020	.0030	.0026	.0035	.0002	.0006	.0004	.0008	.0008	.0012	.0014	.0018	.0018	.0022	.0026	.0030
24	30	.0000	.0010	.0008	.0018	.0014	.0024	.0020	.0030	.0028	.0037	.0002	.0006	.0004	.0010	.0010	.0014	.0016	.0020	.0020	.0024	.0028	.0031
30	40	.0002	.0012	.0010	.0020	.0018	.0028	.0024	.0033	.0031	.0041	.0002	.0006	.0005	.0010	.0010	.0016	.0018	.0022	.0022	.0028	.0031	.0037
40	50	.0002	.0014	.0012	.0024	.0020	.0031	.0028	.0039	.0037	.0049	.0002	.0007	.0006	.0012	.0012	.0018	.0020	.0026	.0026	.0031	.0037	.0043
50	65	.0004	.0016	.0016	.0028	.0024	.0035	.0031	.0043	.0039	.0055	.0002	.0008	.0006	.0014	.0014	.0020	.0022	.0030	.0030	.0035	.0043	.0051
65	80	.0004	.0018	.0016	.0030	.0026	.0039	.0035	.0049	.0051	.0065	.0004	.0010	.0008	.0016	.0016	.0024	.0028	.0035	.0035	.0043	.0051	.0059
80	100	.0006	.0020	.0020	.0033	.0030	.0043	.0041	.0055	.0061	.0075	.0004	.0012	.0010	.0018	.0018	.0028	.0031	.0041	.0041	.0049	.0061	.0071
100	120	.0006	.0022	.0020	.0035	.0033	.0049	.0049	.0065	.0071	.0087	.0004	.0012	.0010	.0020	.0020	.0031	.0037	.0047	.0047	.0057	.0071	.0081
120	140	.0006	.0024	.0024	.0041	.0039	.0057	.0057	.0075	.0079	.0096	.0004	.0014	.0012	.0024	.0024	.0035	.0041	.0053	.0053	.0063	.0079	.0091
140	160	.0008	.0028	.0028	.0047	.0045	.0065	.0065	.0085	.0089	.0108	.0004	.0014	.0014	.0026	.0026	.0039	.0045	.0059	.0059	.0071	.0089	.0102
160	180	.0010	.0030	.0030	.0049	.0047	.0067	.0067	.0087	.0098	.0118	.0004	.0016	.0014	.0030	.0030	.0043	.0049	.0065	.0065	.0079	.0098	.0112
180	200	.0014	.0035	.0035	.0057	.0055	.0077	.0077	.0098	.0108	.0130	.0006	.0018	.0016	.0031	.0031	.0047	.0055	.0071	.0071	.0087	.0108	.0124
200	225	.0018	.0041	.0041	.0065	.0063	.0087	.0087	.0110	.0120	.0144	.0006	.0020	.0018	.0035	.0035	.0053	.0061	.0079	.0079	.0094	.0120	.0138
225	250	.0018	.0043	.0043	.0069	.0067	.0093	.0093	.0118	.0130	.0156	.0006	.0020	.0020	.0039	.0039	.0059	.0067	.0085	.0085	.0104	.0130	.0150
250	280	.0022	.0049	.0049	.0077	.0075	.0102	.0102	.0130	.0146	.0173	.0008	.0022	.0022	.0043	.0043	.0065	.0073	.0094	.0094	.0116	.0146	.0165
280	315	.0022	.0051	.0051	.0081	.0079	.0108	.0108	.0138	.0161	.0191	.0008	.0024	.0024	.0047	.0047	.0071	.0081	.0104	.0104	.0128	.0161	.0185
315	355	.0026	.0057	.0057	.0089	.0089	.0120	.0120	.0152	.0179	.0211	.0008	.0026	.0026	.0053	.0053	.0079	.0089	.0116	.0116	.0142	.0179	.0205
355	400	.0039	.0075	.0075	.0110	.0110	.0146	.0146	.0181	.0201	.0236	.0010	.0030	.0030	.0059	.0059	.0089	.0100	.0130	.0130	.0159	.0201	.0230
400	450	.0043	.0083	.0083	.0122	.0122	.0161	.0161	.0201	.0222	.0262	.0010	.0033	.0033	.0067	.0067	.0100	.0112	.0146	.0146	.0179	.0222	.0256
450	500	.0043	.0087	.0087	.0130	.0130	.0173	.0173	.0217	.0246	.0289	.0010	.0037	.0037	.0075	.0075	.0112	.0124	.0161	.0161	.0199	.0246	.0283

Note: (1) CC is the symbol for normal clearance for matched cylindrical roller bearings and solid-type needle roller bearings.

Table 10.38 — Radial Internal Clearances in Cylindrical Roller Bearings with Tapered Bores

Units: μm

Nominal Bore Dia. d(mm)		Clearances in Matched Bearings with Tapered Bores													
		CC9(1)		CC1		CC2		CC(2)		CC3		CC4		CC5	
over	incl	min	max	min	max	min	max	min	max	min	max	min	max	min	max
10	24	.0002	.0004	.0004	.0008	.0008	.0012	.0014	.0018	.0018	.0022	.0022	.0026	.0030	.0033
24	30	.0002	.0004	.0004	.0010	.0010	.0014	.0016	.0020	.0020	.0024	.0024	.0028	.0031	.0037
30	40	.0002	.0005	.0005	.0010	.0010	.0016	.0018	.0022	.0022	.0028	.0028	.0031	.0037	.0043
40	50	.0002	.0006	.0006	.0012	.0012	.0018	.0020	.0026	.0026	.0031	.0031	.0037	.0043	.0049
50	65	.0002	.0006	.0006	.0014	.0014	.0020	.0022	.0030	.0030	.0035	.0035	.0043	.0051	.0059
65	80	.0004	.0008	.0008	.0016	.0016	.0024	.0028	.0035	.0035	.0043	.0043	.0051	.0059	.0067
80	100	.0004	.0010	.0010	.0018	.0018	.0028	.0031	.0041	.0041	.0049	.0049	.0059	.0071	.0081
100	120	.0004	.0010	.0010	.0020	.0020	.0031	.0037	.0047	.0047	.0057	.0057	.0067	.0081	.0091
120	140	.0006	.0012	.0012	.0024	.0024	.0035	.0041	.0053	.0053	.0063	.0063	.0075	.0091	.0102
140	160	.0006	.0014	.0014	.0026	.0026	.0039	.0045	.0059	.0059	.0071	.0071	.0085	.0102	.0116
160	180	.0006	.0014	.0014	.0030	.0030	.0043	.0049	.0065	.0065	.0079	.0079	.0094	.0112	.0126
180	200	.0008	.0016	.0016	.0031	.0031	.0047	.0055	.0071	.0071	.0087	.0087	.0102	.0124	.0140
200	225	.0008	.0018	.0018	.0035	.0035	.0053	.0061	.0079	.0079	.0094	.0094	.0112	.0138	.0156
225	250	.0010	.0020	.0020	.0039	.0039	.0059	.0067	.0085	.0085	.0104	.0104	.0124	.0150	.0169
250	280	.0010	.0022	.0022	.0043	.0043	.0065	.0073	.0094	.0094	.0116	.0116	.0138	.0165	.0187
280	315	.0012	.0024	.0024	.0047	.0047	.0071	.0081	.0104	.0104	.0128	.0128	.0152	.0185	.0209
315	355	.0012	.0026	.0026	.0053	.0053	.0079	.0089	.0116	.0116	.0142	.0142	.0169	.0205	.0230
355	400	.0014	.0030	.0030	.0059	.0059	.0089	.0100	.0130	.0130	.0159	.0159	.0189	.0230	.0260
400	450	.0016	.0033	.0033	.0067	.0067	.0100	.0112	.0146	.0146	.0179	.0179	.0213	.0256	.0289
450	500	.0018	.0037	.0037	.0075	.0075	.0112	.0124	.0161	.0161	.0199	.0199	.0236	.0283	.0321

Notes (1) Clearance CC9 is applicable to cylindrical roller bearings with tapered bores in ISO Tolerance Classes 5 and 4.
(2) CC is the symbol for normal clearance for matched cylindrical roller bearings and solid-type needle roller bearings.

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Table 10.39 — Radial Internal Clearances in Spherical Roller Bearings with Cylindrical Bores

Units: inch

Nominal Bore Diameter d (mm)		Radial Internal Clearance							
		C2		CO		C3		C4	
over	incl	low	high	low	high	low	high	low	high
24	30	+.0006	+.0010	+.0010	+.0016	+.0016	+.0022	+.0022	+.0030
30	40	+.0006	+.0012	+.0012	+.0018	+.0018	+.0024	+.0024	+.0031
40	50	+.0008	+.0014	+.0014	+.0022	+.0022	+.0030	+.0030	+.0039
50	65	+.0008	+.0016	+.0016	+.0026	+.0026	+.0035	+.0035	+.0047
65	80	+.0012	+.0020	+.0020	+.0031	+.0031	+.0043	+.0043	+.0057
80	100	+.0014	+.0024	+.0024	+.0039	+.0039	+.0053	+.0053	+.0071
100	120	+.0016	+.0030	+.0030	+.0047	+.0047	+.0063	+.0063	+.0083
120	140	+.0020	+.0037	+.0037	+.0057	+.0057	+.0075	+.0075	+.0094
140	160	+.0024	+.0043	+.0043	+.0067	+.0067	+.0087	+.0087	+.0110
160	180	+.0026	+.0047	+.0047	+.0071	+.0071	+.0094	+.0094	+.0122
180	200	+.0028	+.0051	+.0051	+.0079	+.0079	+.0102	+.0102	+.0134
200	225	+.0031	+.0055	+.0055	+.0087	+.0087	+.0114	+.0114	+.0150
225	250	+.0035	+.0059	+.0059	+.0094	+.0094	+.0126	+.0126	+.0165
250	280	+.0039	+.0067	+.0067	+.0102	+.0102	+.0138	+.0138	+.0181
280	315	+.0043	+.0075	+.0075	+.0110	+.0110	+.0146	+.0146	+.0197
315	355	+.0047	+.0079	+.0079	+.0122	+.0122	+.0161	+.0161	+.0217
355	400	+.0051	+.0087	+.0087	+.0134	+.0134	+.0177	+.0177	+.0236
400	450	+.0055	+.0094	+.0094	+.0146	+.0146	+.0197	+.0197	+.0260
450	500	+.0055	+.0102	+.0102	+.0161	+.0161	+.0217	+.0217	+.0283
500	560	+.0059	+.0110	+.0110	+.0173	+.0173	+.0236	+.0236	+.0307
560	630	+.0067	+.0122	+.0122	+.0189	+.0189	+.0256	+.0256	+.0335
630	710	+.0075	+.0138	+.0138	+.0209	+.0209	+.0276	+.0276	+.0362
710	800	+.0083	+.0154	+.0154	+.0228	+.0228	+.0303	+.0303	+.0398
800	900	+.0091	+.0169	+.0169	+.0256	+.0256	+.0339	+.0339	+.0441
900	1000	+.0102	+.0189	+.0189	+.0280	+.0280	+.0366	+.0366	+.0480

Table 10.41 — Radial Internal Clearances in Spherical Roller Bearings with Tapered Bores

Units: inch

Nominal Bore Diameter d (mm)		Radial Internal Clearance							
		C2		C0		C3		C4	
over	incl	low	high	low	high	low	high	low	high
24	30	+.0008	+.0012	+.0012	+.0016	+.0016	+.0022	+.0022	+.0030
30	40	+.0010	+.0014	+.0014	+.0020	+.0020	+.0026	+.0026	+.0033
40	50	+.0012	+.0018	+.0018	+.0024	+.0024	+.0031	+.0031	+.0039
50	65	+.0016	+.0022	+.0022	+.0030	+.0030	+.0037	+.0037	+.0047
65	80	+.0020	+.0028	+.0028	+.0037	+.0037	+.0047	+.0047	+.0059
80	100	+.0022	+.0031	+.0031	+.0043	+.0043	+.0055	+.0055	+.0071
100	120	+.0026	+.0039	+.0039	+.0053	+.0053	+.0067	+.0067	+.0087
120	140	+.0031	+.0047	+.0047	+.0063	+.0063	+.0079	+.0079	+.0102
140	160	+.0035	+.0051	+.0051	+.0071	+.0071	+.0091	+.0091	+.0118
160	180	+.0039	+.0055	+.0055	+.0079	+.0079	+.0102	+.0102	+.0134
180	200	+.0043	+.0063	+.0063	+.0087	+.0087	+.0114	+.0114	+.0146
200	225	+.0047	+.0071	+.0071	+.0098	+.0098	+.0126	+.0126	+.0161
225	250	+.0055	+.0079	+.0079	+.0106	+.0106	+.0138	+.0138	+.0177
250	280	+.0059	+.0087	+.0087	+.0118	+.0118	+.0154	+.0154	+.0193
280	315	+.0067	+.0094	+.0094	+.0130	+.0130	+.0169	+.0169	+.0213
315	355	+.0075	+.0106	+.0106	+.0142	+.0142	+.0185	+.0185	+.0232
355	400	+.0083	+.0118	+.0118	+.0157	+.0157	+.0205	+.0205	+.0256
400	450	+.0091	+.0130	+.0130	+.0173	+.0173	+.0224	+.0224	+.0283
450	500	+.0102	+.0146	+.0146	+.0193	+.0193	+.0248	+.0248	+.0311
500	560	+.0114	+.0161	+.0161	+.0213	+.0213	+.0268	+.0268	+.0343
560	630	+.0126	+.0181	+.0181	+.0236	+.0236	+.0299	+.0299	+.0386
630	710	+.0138	+.0201	+.0201	+.0264	+.0264	+.0335	+.0335	+.0429
710	800	+.0154	+.0224	+.0224	+.0295	+.0295	+.0378	+.0378	+.0480
800	900	+.0173	+.0252	+.0252	+.0331	+.0331	+.0421	+.0421	+.0539
900	1000	+.0193	+.0280	+.0280	+.0366	+.0366	+.0469	+.0469	+.0598

Selection of Bearing Internal Clearance

By way of definition, "Normal Operating Conditions" for bearings occur when the bearing load does not exceed the equivalent load (**P**=0.1**C**), the inner ring is tight-fitted to the shaft and operating speed is less than 50% of the limiting speed given in the bearing tables. For the replacement market the standard clearance group, **C3**, is used for “Normal Operating Conditions.” However, there are six standard clearance groups, designated as **C1, C2, CO, C3, C4** and **C5**. **C1** represents minimum clearance and **C5** represents maximum clearance.

Selection of the proper bearing clearance varies with required fits, loads, speeds, and operating temperatures. Each of these will reduce the initial internal clearance a certain amount. Changes that occur in the radial clearance of roller bearings are shown in Figure 10.42.

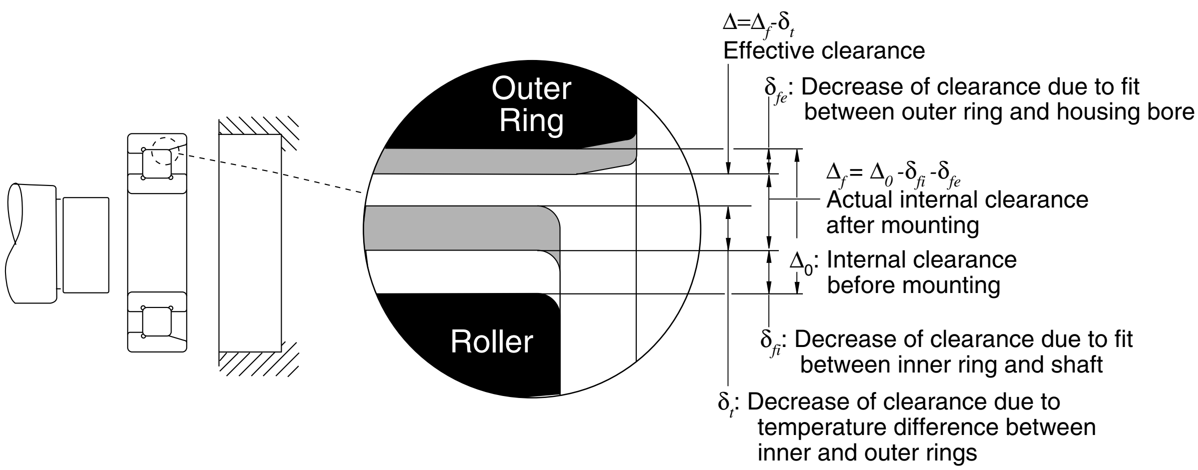

Figure 10.42 — Changes of Radial Internal Clearance of Bearing

Changes in Radial Internal Clearance

Decrease in Radial Clearance Due to Fit

When the inner or outer ring is tight-fitted to the shaft or the housing, a decrease of radial internal clearance is caused by the expansion or contraction of the bearing rings. The decrease varies according to the bearing type, bearing size and shape, and design of the shaft or housing. The amount of decrease normally ranges from 70 to 90% of the interference.

The internal clearance after mounting is obtained by subtracting the interference decrease, Δf, from the initial internal clearance.

Temperature Effects on Radial Internal Clearance

Under normal operation, the radial internal clearance of a bearing will decrease because of the temperature differences between the inner and outer rings. Typically, the temperatures of the inner ring and the rolling elements are higher than that of the outer ring by 8 to 15°F. When the shaft is heated or when the housing is cooled, the difference between the inner and outer rings is even larger.

The amount of decrease due to thermal expansion can be calculated from the following equations:

$$\delta_t = \alpha \Delta_t D_e$$

Where δ_t : Internal clearance decrease (inch) due to temperature

α : Coefficient of linear expansion of bearing steel (12.5 x 10^{-6}) (1/°C)

Δ_t : Temperature difference between inner & outer rings (°C)

D_e : Outer ring raceway diameter (inch)

For Ball Bearings: $D_e = \frac{1}{5}(4D + d)$ **For Roller Bearings:** $D_e = \frac{1}{4}(3D + d)$

Where **D** : Bearing outside diameter (inch)

d : Bearing bore diameter (inch)

Effective Clearance

The effective, or operating, clearance Δ is obtained by subtracting δ_t from the internal clearance after mounting Δf. Theoretically, the longest life of a bearing can be expected when the effective clearance is slightly negative. However, it is difficult to achieve this condition and excessive negative clearance will shorten bearing life. Therefore, a clearance of zero or a slightly positive value is preferable.

Angular contact ball bearings or tapered roller bearings normally require the user to set the internal clearance at mounting. The user should check the proper orientation of these bearings by checking the original bearings or the service manual for the machine. A check should also be made for the recommended set clearance. This can be obtained from the service manual, the machine manufacturer, or the bearing manufacturer.

Preloaded Bearings

Types and Features

Rolling bearings usually retain some internal clearance while in operation. However, in some cases it is desirable to provide a negative clearance. This is called "preloading." Preloading can be used to decrease bearing deflection and provide greater bearing rigidity. However, it may also increase power consumption and reduce bearing life.

A preload is usually given to those types of bearings in which the axial clearance can be adjusted in mounting--for example, angular contact ball bearings and tapered roller bearings. Usually preloaded bearings are mounted face to face or back to back to form a duplex bearing set.

Why Preload?

Typical reasons and aplications for preloading bearings are:

- To maintain bearings in an exact position in both the radial and axial directions and to maintain the running accuracy of the shaft… for example, the main shaft of machine tools and instruments.
- To increase bearing rigidity. This is often needed on the main shaft of machine tools or the pinion shaft of automobile differentials.
- To minimize noise due to axial vibration and resonance… for example, in high speed or high acceleration applications of angular contact ball bearings and thrust ball bearings
- To prevent sliding due to the gyratory movement of rolling elements… for example, in high speed or high acceleration applications of angular contact ball bearings and thrust ball bearings.
- To maintain the rolling elements in their proper position with the bearing rings… for example, on thrust ball bearings and spherical roller thrust bearings mounted on a horizontal shaft.

How to Preload Duplex Bearings

There are two basic methods for preloading duplex bearings--preloading by position and preloading by constant pressure:

Position Preload

Position preload is achieved by positioning two axially opposed bearings while maintaining their relative positions in operation. This is usually done by one of the following methods:

- Installing a duplex bearing set with previously adjusted stand-out dimensions and axial clearance.
- Using a spacer or shim with proper dimensions to obtain the required spacing and preload. See Figure 10.43.
- Using bolts or nuts to allow adjustment of the axial clearance. In this case the starting friction torque should be measured to verify the proper preload.

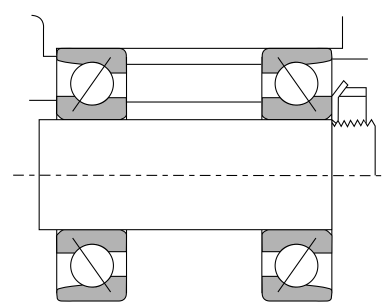

Figure 10.43 — Example of Position Preload

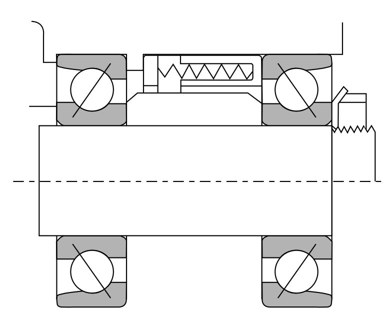

Figure 10.44 — Example of Constant Pressure Preload

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Constant Pressure Preload

Constant pressure preload is achieved by using a coil or leaf spring to impose a constant preload. Even if the relative position of the bearings changes during operation, the magnitude of the preload remains relatively constant. See Figure 10.44

Selecting Preloading Method and the Amount of Preload to Use

Comparison of Preloading Methods

A comparison of rigidity using different preloading methods is shown in the chart below.

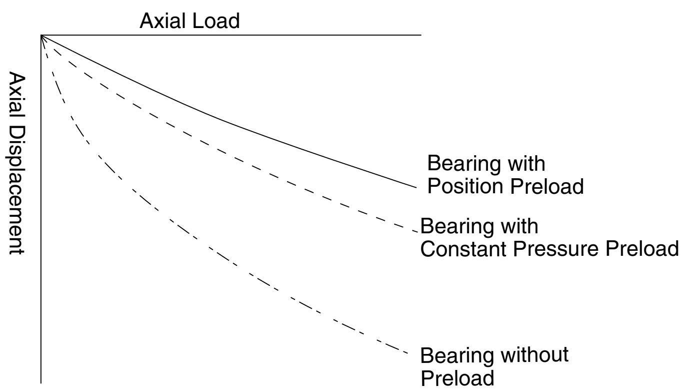


Figure 10.45 — Preload and Rigidity

Position preloading is generally preferred for increasing rigidity. Constant pressure preload is more suitable for high speed applications, prevention of axial vibration, and for use with thrust bearings on horizontal shafts. Position preload and constant pressure preload each offer specific advantages:

- When equal preloads are imposed, the position preload provides greater bearing rigidity. The deflection due to external loads is less for bearings with a position preload.
- In position preloading the level of preload varies depending on such factors as a difference in axial expansion due to a temperature difference between the inner and outer rings and deflection due to load.
- In constant pressure preloading it is possible to minimize any change in the preload because the variation of the spring load with shaft expansion and contraction is negligible.

How Much Preload to Use?

If the preload is larger than necessary, abnormal heat generation, increased frictional torque and reduced fatigue life may occur. The amount of the preload should be determined considering the operating conditions, the purpose of the preload, and the type of bearing to be preloaded.

Preload of Duplex Angular Contact Ball Bearings — The average preloads for duplex angular contact ball bearings (contact angle of 15°) with precision better than P5 class are listed in the tables on the following page. These bearings are used on the main shafts of machine tools.

The recommended fits between the shaft and inner ring, and between the housing and outer ring are listed in Table 10.31 on page 328 thru Table 10.34 on page 329.

For housing fits, the lower limit of the fit range should be selected for fixed-end bearings and the upper limit for free-end bearings.

As a general rule, an extra light or light preload should be selected for spindles of grinders and a medium preload should be selected for the main shafts of high speed lathes and milling machines.

Figure 10.46 — Preload for Duplex Angular Contact Ball Bearings (Series 7000)

Units: Lbf

Bearing Number	Preload			
	Very Light C2	Light C7	Medium C8	Heavy C9
7000C	1.21	6.38	13.26	28.55
7001C	1.33	7.08	14.28	30.80
7002C	1.43	7.76	16.52	35.30
7003C	1.54	8.43	17.65	37.54
7004C	2.86	15.40	30.80	66.09
7005C	3.08	16.52	33.05	73.06
7006C	4.18	22.03	46.31	96.67
7007C	5.51	28.55	61.82	132.64
7008C	6.38	33.05	68.57	142.75
7009C	7.76	42.26	84.30	176.48
7010C	8.54	44.06	92.17	198.96
7011C	11.02	59.57	121.40	265.28
7012C	12.14	61.82	132.64	276.52
7013C	13.26	68.57	142.75	307.99
7014C	16.52	87.68	187.72	386.67
7015C	17.65	92.17	187.72	406.91
7016C	20.91	110.16	231.55	508.07
7017C	22.03	121.40	242.79	528.30
7018C	26.53	142.75	296.75	618.23
7019C	28.55	142.75	307.99	660.94
7020C	28.55	153.99	319.23	685.67

Figure 10.47 — Preload for Duplex Angular Contact Ball Bearings (Series 7200)

Units: Lbf

Bearing Number	Preload			
	X-tra Light C2	Light C7	Medium C8	Heavy C9
7200C	1.21	6.38	13.26	28.55
7201C	1.88	9.89	20.91	44.06
7202C	2.09	11.02	22.03	48.56
7203C	2.65	14.28	28.55	61.82
7204C	3.75	19.90	39.79	85.43
7205C	4.41	24.28	48.56	103.41
7206C	6.61	33.05	70.82	153.99
7207C	8.77	46.31	94.42	198.96
7208C	11.02	57.33	121.40	254.04
7209C	12.14	63.85	132.64	285.51
7210C	13.26	70.82	142.75	307.99
7211C	16.52	87.68	187.72	397.91
7212C	20.91	110.16	231.55	485.59
7213C	24.28	132.64	265.28	573.27
7214C	26.53	142.75	296.75	618.23
7215C	28.55	153.99	319.23	660.94
7216C	33.05	165.24	352.95	753.11
7217C	37.54	198.96	406.91	876.76
7218C	44.06	231.55	485.59	1011.65
7219C	46.31	242.79	508.07	1079.09
7220C	52.83	276.52	573.27	1236.46

Figure 10.49 — Recommended Fits for Precision Class Duplex Angular Contact Ball Bearings with Preload

Nominal Bore Dia. (mm)		Target Shaft Interference (inch)	Nominal Outside Dia. (mm)		Target Housing Clearance (inch)	
Over	Incl.		Over	Incl.		
–	18	0 – 0.0001	–	18	–	–
18	30	0 – 0.0001	18	30	+.0001	+.0002
30	50	0 – 0.0001	30	50	+.0001	+.0002
50	80	0 – 0.0001	50	80	+.0001	+.0003
80	120	0 – 0.0002	80	120	+.0001	+.0004
120	150	–	120	150	+.0002	+.0005
150	180	–	150	180	+.0002	+.0005
180	250	–	180	250	+.0002	+.0006

Preload of Thrust Ball Bearings

When the balls in thrust ball bearings rotate at relatively high speeds, sliding due to the gyratory movement of the balls may occur. The larger of the two values obtained from the equations below should be selected as the minimum axial load in order to prevent such sliding.

$$F_{a,min} = \frac{C_{oa}}{100}\left(\frac{n}{N_{max}}\right)^2$$

Where $F_{a,min}$: Minimum axial load, N
C_{oa}: Basic static load rating, N
n: Rotational speed, rpm
N_{max} : Limiting speed (oil lubrication), rpm

Preload of Spherical Roller Thrust Bearings

When spherical roller thrust bearings are used a preload is necessary to keep the rollers in proper position against the outer ring raceway. The minimum axial load Fa,min necessary to do this is:

$$F_{a,min} = \left(\frac{C_{oa}}{1000}\right)$$

Bearing Lubrication

Lubrication--The Purpose

Lubrication is needed to reduce friction and wear inside the bearing. Proper lubrication and procedures will allow the bearing to reach its expected life.

Primarily, lubrication serves the following purposes:

- Reduces Friction and Wear – Direct metallic contact between the bearing rings, rolling elements and cage is prevented by an oil film which reduces the friction and heat at the contact areas.
- Extends Bearing Life – The rolling fatigue life of bearings depends in a large part on the viscosity and film thickness of the lubricant. A heavy film thickness prolongs the bearing fatigue life.
- Cooling – Circulating oil can be used to carry heat away from the bearing. A circulating system is normally used when excessive heat is generated by the bearing due to high speeds, high loads, or when heat from a source adjacent to the bearing can affect its operation. Oils deteriorate at high temperatures; therefore it is important to keep both the oil and the bearing cool.
- Other Purposes – Proper lubrication also helps to prevent foreign material from entering the bearings, and protects against corrosion or rusting.

Selecting the Correct Lubrication Method

Lubrication can be accomplished by using either oil or grease. The most satisfactory bearing performance will be achieved by selecting the method most suitable for a specific application. This of course will also depend on the conditions under which the bearing will operate.

Oil lubrication is superior in lubricating efficiency, however, grease lubrication allows a simpler structure around the bearings. The following table compares oil and grease lubrication.

Operating Factor	Grease Lubrication	Oil Lubrication
Housing Structure and Sealing Method	Simple	May be complex. Careful maintenance required.
Speed	Limiting speed is 65% to 80% of that of oil lubrication	High limiting speed
Cooling Effect	Poor	Heat transfer is possible using forced oil circulating lubrication
Fluidity	Poor	Good
Full Lubricant Replacement	Sometimes difficult	Easy
Removal of Foreign Matter	Removal of particles from grease is impossible	Easy
External Contamination Due to Leakage	Surroundings seldom contaminated by leakage	Often leaks without proper countermeasures. Not suitable if external contamination must be avoided

Grease Lubrication

Grease Quantity

The quantity of grease to be packed in a housing depends on the housing design, rotational speeds of the bearings, characteristics of the grease selected, and the ambient temperature conditions. These factors are critical to satisfactory performance.

In applications where the operating speed does not exceed one-half the rated limiting speed of the bearing, the bearing should be packed one-half to two-thirds full. If the speed of the bearing exceeds one-half the limiting speed, the quantity of grease should be reduced to one-third to one-half full and periodic regreasing scheduled. When operating conditions are not severe, the original pack of grease should last a long time without replenishment. If the operating conditions become severe, it will be necessary to regrease periodically.

Care should be taken to avoid excessive greasing as this will cause bearings to overheat.

Grease Replenishment

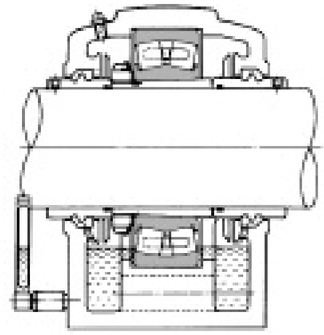
Frequent grease replenishment is required when operating conditions are severe such as in high ambient temperatures or where contaminants can enter bearing housings. Routine regreasing schedules should be established. In cases where extremely severe conditions exist or the bearings are in a remote area, the bearing housing should be designed to make replenishment and replacement as simple as possible. Automatic grease systems are available and should be used.

For normal operating conditions, it may be necessary to regrease the bearing periodically to replace any grease which has leaked from the housing and to eliminate any deteriorated grease.

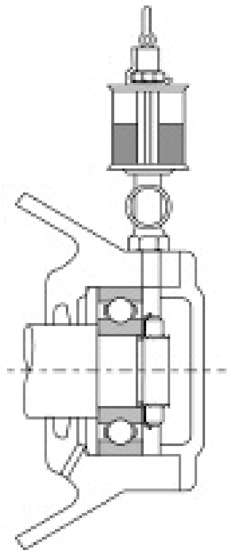
Oil Lubrication

When the operating speed exceeds the grease limiting speed listed for the bearing, oil lubrication should be used. Several methods are available and are described below. The best method to use will depend on operating conditions.

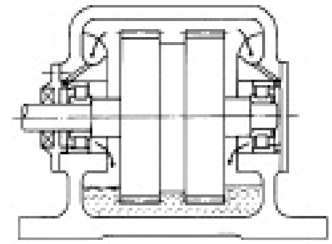
Oil Bath Lubrication is a common method used where bearings are operating below the listed oil limiting speed. The static oil level should be set at the center of the lowest rolling element. An oil sight level gauge should be included in the system so that proper oil level can be quickly monitored.



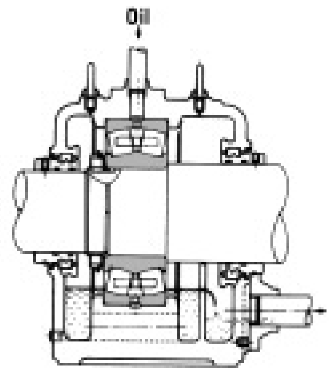
Drip Feed Lubrication is often used for small bearings operated at relatively high speeds. In the illustration, a visible oiler is used. The oil drip rate is controlled by a screw valve located at the top of the oil cup.

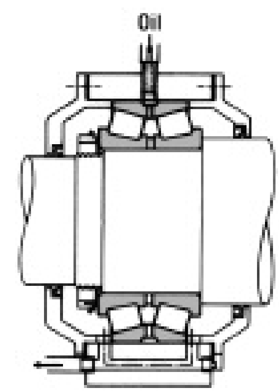


Splash Lubrication – In this lubricating method, oil is splashed onto the bearings by gears or by a simple rotating disc. This method is commonly used in automobile transmissions, differentials and gear boxes. The illustration shows splash lubrication used on a reduction gear.

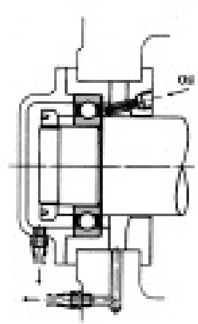


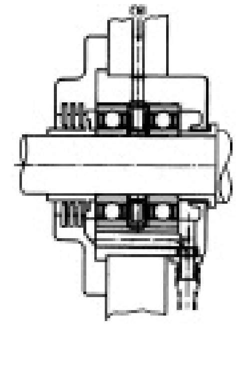
Circulating system lubrication is commonly used for high speed operation and for bearings used at high temperatures. As shown in the illustration, oil from the supply pipe circulates through the bearings and exits to an external reservoir. After cooling in the reservoir it returns to the bearing through a pump and filter. In a circulating system, the oil outlet should be larger in diameter than the supply pipe so that an excessive amount of oil will not remain in the housing.



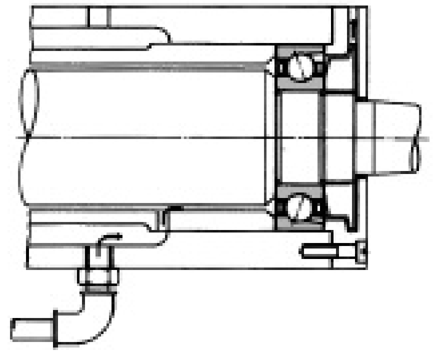


Jet Lubrication is often used for ultra high speed bearings, such as the bearings in jet engines and in machine tool spindles. In this method, lubricating oil is sprayed under pressure from one or more nozzles directly into the rolling elements of the bearing. The illustration shows an example of typical jet lubrication.





Oil Mist Lubrication, – also called oil fog lubrication, uses air to atomize the oil and carry it into the bearing. This method is used in bearings for the ultra high-speed spindles of machine tools, high-speed rotary pumps, and roll necks of rolling mills, as shown in the illustration.



In **Oil/Air Lubrication** systems, a small quantity of oil is periodically injected into an air stream which carries it to the bearing. This system is used when it is necessary to precisely control the quantity of oil entering the bearing to control operating temperature.

Lubricants

Lubricating Grease

Grease is a semi-solid lubricant of a base oil and a thickener. Other ingredients are sometimes added to impart special properties to the base.

The main types and general properties of grease are shown in Table 10.50 on page 343. It should be noted that different brands of the same type of grease may have different properties.

Base Oil – Mineral oil or synthetic oils such as silicon or diester oil, are commonly used as the base oil for grease. The lubricating properties of grease are dependent on the characteristics of its base oil. The viscosity of the base oil is an important consideration when selecting grease. Usually grease made with a low viscosity base oil is more suitable for high speeds and low temperatures while grease made with high viscosity base oils is more suited for high temperatures and heavy loads. The thickener also influences the lubricating properties of grease, therefore selection criteria for grease are not the same as for lubricating oil.

Thickener – Several types of metallic soaps, inorganic compounds such as silica gel and bentonite, and heat resisting organic thickeners such as polyurea and flouric compounds are used as thickeners for grease. The water resistance properties of grease depend on the type of thickener. Sodium soap grease (or compound grease containing sodium soap) emulsifies when exposed to water or high humidity and therefore cannot be used where moisture is prevalent. Lithium soap grease, on the other hand, is recommended where moisture is present because of its resistance to wash off.

For applications where the operating temperature exceeds the limitation of common multi-purpose grease, greases having complex bases or non-soap bases are recommended. The grease used should also have a synthetic oil to withstand rapid deterioration at high temperatures. If the grease used in a high temperature application uses a mineral oil, it should be replenished frequently as deterioration of the oil will be accelerated at high temperatures.

Additives – Grease often contains a variety of additives such as antioxidants, corrosion inhibitors, and extreme pressure additives to give it special properties. Extreme pressure additives are recommended for use in heavy load applications. For long use without replenishment, an antioxidant should be added.

Consistency – Consistency indicates the “softness” of the grease. The following table shows the relationship between consistency and working conditions.

Consistency Number
(Given by the National Lubricating Grease Institute (NLGI) Scale)

	0	1	2	3	4
Consistency[1] (1/10 mm)	385~355	340~310	295~265	250~220	205~175
Working Condition	For centralized oiling. When false brinelling is liable to occur.	For centralized oiling. When fretting is liable to occur. For low temperature.	For general use. For sealed bearings.	For high temperature. For general use. For sealed bearings	For high temperature. For grease seals

1) Consistency: Depth into grease attained by a cone when pressed with a specified weight, indicated in units of 1/10 mm. The larger the value, the softer the grease.

Mixing Different Types of Grease – In general, grease of different types must not be mixed. Mixing grease with different types of thickeners may destroy the composition and physical properties of the grease. Even if the thickeners are of the same type, possible differences in the additives may cause detrimental effects.

Figure 10.50 — Grease Properties

		Lithium Grease			Sodium Grease (Fiber Grease)	Calcium Grease (Cup Grease)	Mixed Base Grease	Complex Grease	Non-Soap Base Grease	
Popular Name		Lithium Grease			Sodium Grease (Fiber Grease)	Calcium Grease (Cup Grease)	Mixed Base Grease	Complex Grease	Non-Soap Base Grease	
Thickener		Li Soap			Na Soap	Ca Soap	Na+Ca Soap, Li +Ca Soap, etc.	Ca Complex, A1 Complex, etc.	Silica Gel, Bentonite, Carbon Black, Polyurea, Flouric Compounds, Heat Resistant Organic Compound, etc.	
Base Oil		Mineral Oil	Diester Oil	Silicone Oil	Mineral Oil	Mineral Oil	Mineral Oil	Mineral Oil	Mineral Oil	Synthetic Oil
Property(1)	Dropping Point, C°	170~190	170~195	200~210	170~210	70~90	160~190	180~300	230	240~
	Working Temp., C°	-20~110	-50~130	-50 ~160	-20~130	-20 ~60	-20~80	-20 ~130	-10 ~130	~250
	Working Speed, %(2)	70	100	60	70	40	70	70	70	40~100
	Mechanical Stability	Good	Good	Good	Good	Poor	Good	Good	Good	Good
	Pressure Resistance	Fair	Fair	Poor	Fair	Poor	Fair to Good	Fair to Good	Fair	Fair
	Water Resistance	Good	Good	Good	Poor	Good	Poor for Na Soap Grease	Good	Good	Good
	Rust Prevention	Good	Good	Poor	Poor to Good	Good	Fair to Good	Fair to Good	Fair to Good	Fair to Good
	Remarks	General purpose lubricant.	Good low temperature and torque characteristics. Often used for small motor and instrument bearings	Mainly for high temperature applications. Unsuitable for bearings under high speed or heavy load conditions or for sliding contact areas (roller bearings)	Long and short fiber types available. Long fiber grease is not suitable for high speeds or for sliding contact areas (roller bearings)	Not suitable for high temp. and heavy loads. Extreme pressure grease containing high viscosity oil and extreme pressure additive (Pb soap, etc.) is available	Often used for roller bearings and large ball bearings	Suitable for extreme pressures. Mechanically stable.	Medium and high temperature lubricant	Recommended for special environments with very high and low temperatures, acids, alkalis, radioactivity, and exposure to flames.

(1)The grease properties shown here can vary between different brands.
(2) The values listed are percentages of the limiting speeds given in the bearing tables.

Lubricating Oil

Lubricating oil used for bearings is usually a highly refined mineral or synthetic oil which has a high film strength and superior oxidation and corrosion resistance. When selecting an oil, the viscosity of the operating conditions is very important. If the viscosity is too low, a proper oil film is not formed and abnormal wear and seizure may occur. On the other hand, if the viscosity is too high, excessive viscous resistance may cause heating or a large power loss. In general, low viscosity oils should be used at high speeds. Higher viscosity oils should be used for heavy loads or for the larger bearings. The following table shows the generally recommended viscosity for certain bearing types.

Bearing Types	Proper Viscosity at the Operating Temperature
Ball Bearings and Cylindrical Roller Bearings	Higher than 13 cSt
Tapered Roller Bearings and Spherical Roller Bearings	Higher than 20 cSt
Spherical Roller Thrust Bearings	Higher than 32 cSt

The following chart shows the relationship between temperature and viscosity for use in selection of the proper lubricating oil.

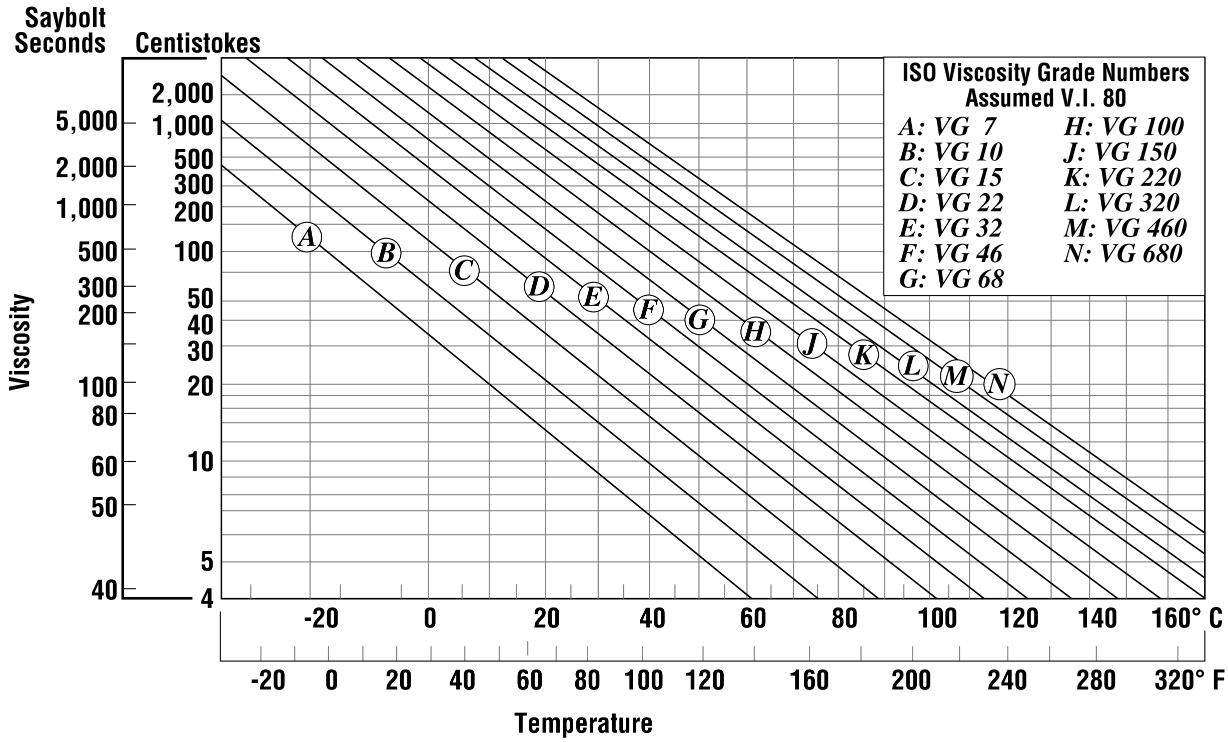


Table 10.51 – Temperature – Viscosity Chart

Oil Replacement Interval – The oil replacement interval depends on the operating conditions and oil quantity. In those cases where the operating temperature is less than 120°F and the environmental conditions are good, oil should be replaced approximately once a year. However, where the oil temperature is about 212°F the oil must be changed at least once every three months.

In dirty environmental conditions, or if moisture or foreign material is mixed in the oil, the replacement interval must be shortened.

Mixing different brands of lubricating oil should be avoided.

How To Handle Bearings

Rolling bearings are high precision machine parts and need to be handled carefully. When installing or removing a bearing, correct procedures should be followed. Careless handling during mounting and removal could result in a serious accident, injuring people and damaging property.

Whether installing, removing, mounting, dismounting, replacing or inspecting, a few simple precautions must be followed:

Keep Bearings and Surroundings Clean!

Dust and dirt, even if invisible to the naked eye, can harm bearings. To prevent the entry of dust and dirt, keep bearings and their environment as clean as possible. Never remove a bearing from its package until you are ready to mount it.

Handle With Care!

Heavy shocks during handling may cause bearings to be scratched or otherwise damaged. Excessively strong impacts when mounting, dismounting or handling may cause brinelling, breaking or cracking.

Use Proper Tools!

Always use the proper equipment and tools to install or remove bearings. Avoid using general purpose tools such as hammers, screwdrivers, wrenches and pliers.

Protect Bearings From Corrosion!

Keep hands clean when handling bearings. Perspiration and other contaminants on the hands can cause corrosion on the bearings. Wear gloves, if possible. Apply oil or grease to non-sealed bearings immediately after installation for further protection.

Mounting--Factors To Consider

Bearings are very precise and their mounting requires careful attention. The following items must be considered:

- Cleaning related parts
- Dimensions and finish of related parts
- Mounting procedures
- Inspection after mounting
- Supply of lubricants.

Prelubricated bearings and bearings lubricated with ordinary oil or grease should not be washed before installation. The preservative used on the bearing to protect it during storage is compatible with most common lubricants.

Bearings used for instruments or high speed applications, such as machine tool bearings, can be washed before installation to remove the anti-corrosion agent used in manufacturing. These bearings must be washed in clean, filtered oil and protected from corrosion until they are installed and lubricated.

Bearing mounting methods depend on bearing type and the type of fit. As bearings are usually used with rotating shafts, the inner rings require a tight fit. Bearings with cylindrical bores are usually mounted by pressing through the inner ring on the shafts (press fit) or heating them to expand their diameter (shrink fit). Bearings with tapered bores can be mounted directly on tapered shafts or on cylindrical shafts by using tapered sleeves.

Bearings are usually mounted in housings with a loose fit. However, if the outer ring has an interference fit, a press may be used. Bearings can be interference fitted by cooling before mounting, using dry ice. If this is done, a rust preventive treatment must be applied to the bearings because moisture in the air will condense on bearing surfaces.

Mounting Bearings with Cylindrical Bores

Press Fits – Fitting with a press is widely used for small bearings. Before mounting, oil should be applied to the fitted shaft surface to make insertion smoother. A mounting tool is placed on the inner ring as shown in Figure 10.52. The mounting tool must not be placed on the outer ring for press mounting, because this may damage the bearing. The bearing is slowly pressed onto the shaft until the side of the inner ring rests against the shoulder of the shaft.

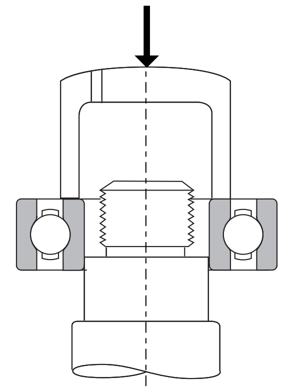


Figure 10.52 – Press Mounting of Inner Ring

Using a hammer for mounting should only be done if pressing equipment is not available. Any time a hammer is used, a mounting tool must be placed on the inner ring. For tight interference fits or for medium and large bearings, a hammer should never be used.

When both the inner and outer rings of non-separable bearings, such as deep groove ball bearings, require a tight fit, a mounting tool should be placed on both rings and both rings fitted at the same time using a screw or hydraulic press. See Figure 10.53.

When mounting separable bearings, such as cylindrical roller bearings and tapered roller bearings, the inner and outer rings may be mounted separately.

A mounting tool such as that shown in Figure 10.53 should also be used for mounting self-aligning bearings. Assembly of the inner and outer rings which were previously mounted separately must be done carefully to align them correctly. Careless or forced assembly may cause scratches on the rolling contact surfaces.

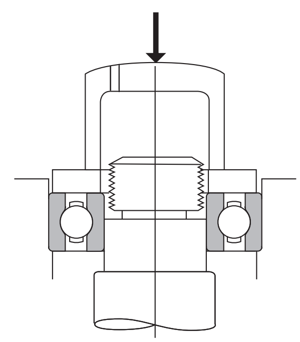


Figure 10.53 – Simultaneous Press Mounting of Inner & OuterRing

Shrink Fits – Shrink fitting is often used to avoid the large force involved in press fitting large bearings. This method eliminates the need to impose excessive force on the bearings. For shrink fitting, the bearings are first heated in oil, or in an induction heater, to expand them, then mounted and allowed to cool.

This amount of expansion of the inner ring for various temperature differences and bearing sizes are shown in Figure 10.54

A few precautions to be considered when making shrink fits:

- Do not heat bearings to more than 248°F.
- Put bearings on a wire netting or suspend them in the oil tank to prevent them from touching the tank bottom.

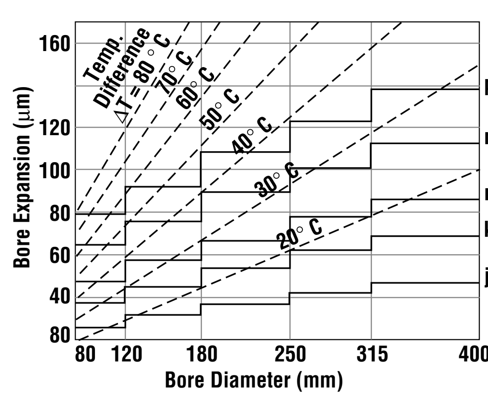


Figure 10.54 – Temperature and Expansion of Inner Ring

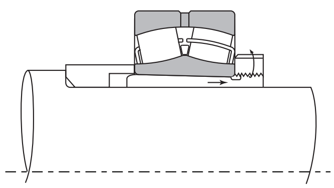
- Heat bearings to a temperature 68 to 86°F higher than the lowest temperature required for mounting, because the inner ring will cool a little during mounting.

After mounting, the bearings will shrink in the axial direction as well as the radial direction while cooling. Therefore, while mounting, press the bearing firmly against the shaft shoulder to avoid excessive clearance between the bearing and the shoulder.Mixing different brands of lubricating oil should be avoided.

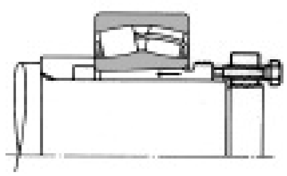
Mounting Bearings with Tapered Bores

Bearings with tapered bores can be mounted on tapered shafts directly or on cylindrical shafts by using tapered adapters or withdrawal sleeves.

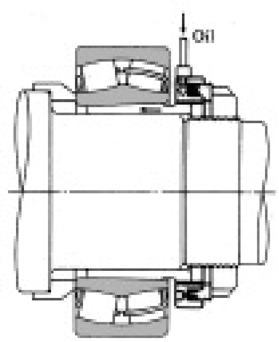
Large spherical bearings are often mounted using hydraulic pressure. Figure 10.55 shows two different hydraulic mounting methods. One method is a sleeve with a hydraulic nut. The other method uses a sleeve with pressurized oil. Holes drilled in the sleeve are used to feed oil under pressure to the bearing seat. As the bearing expands radially, the sleeve is inserted axially with adjusting bolts.



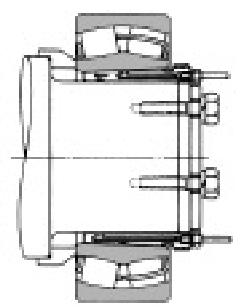
Mounting w/Adapter



Mounting with Withdrawal Sleeve



Mounting with Hydraulic Nut



Mounting w/Special Sleeve and Pressurized Oil

Figure 10.55 – Mounting Bearings with Tapered Bores

The internal clearance of a tapered bore bearing varies with the tightness of the interference fit. It is necessary to check the clearance often as the bearing is being mounted. The bearing should be pressed until the reduction of radial clearance is within the range shown in Table 10.56 on page 348.

Table 10.56 — Mounting of Spherical Roller Bearings with Tapered Bores

Units: Inch

Nominal Bore Diameter (mm)		Radial internal Clearance (inches)						Reduction in Radial Clearance		Axial Movement				Minimum Permissible Residual Clearance After Mounting		
		Normal		C3		C4				Taper 1:12		Taper 1:30				
over	incl.	min	max	min	max.	min.	max.	min.	max.	min.	max.	min.	max.	Normal	C3	C4
30	40	.0014	.0020	.0020	.0026	.0026	.0033	.0005	.0010	.011	.016	–	–	.0006	.0012	.0018
40	50	.0018	.0024	.0024	.0032	.0032	.0041	.0010	.0010	.014	.018	–	–	.0006	.0012	.0020
50	65	.0022	.0030	.0030	.0039	.0039	.0049	.0010	.0015	.018	.024	–	–	.0010	.0014	.0024
65	80	.0028	.0037	.0037	.0049	.0049	.0061	.0015	.0020	.024	.032	–	–	.0012	.0016	.0030
80	100	.0032	.0044	.0044	.0057	.0057	.0075	.0020	.0025	.027	.040	.070	.085	.0014	.0020	.0032
100	120	.0039	.0053	.0053	.0069	.0069	.0089	.0020	.0030	.030	.048	.075	.090	.0018	.0026	.0040
120	140	.0047	.0063	.0063	.0081	.0081	.0102	.0025	.0035	.040	.056	.090	.110	.0022	.0031	.0045
140	160	.0051	.0071	.0071	.0091	.0091	.0118	.0030	.0040	.048	.062	.100	.130	.0024	.0039	.0050
160	180	.0055	.0079	.0079	.0102	.0102	.0134	.0030	.0045	.048	.069	.110	.140	.0028	.0043	.0060
180	200	.0063	.0088	.0088	.0114	.0114	.0146	.0035	.0050	.056	.082	.130	.160	.0028	.0043	.0065
200	225	.0071	.0099	.0099	.0126	.0126	.0162	.0040	.0055	.064	.088	.140	.170	.0031	.0051	.0070
225	250	.0079	.0106	.0106	.0140	.0140	.0178	.0045	.0060	.072	.094	.160	.190	.0035	.0055	.0080
250	280	.0087	.0118	.0118	.0156	.0156	.0195	.0050	.0070	.080	.106	.170	.220	.0039	.0059	.0085
280	315	.0094	.0130	.0130	.0169	.0169	.0213	.0050	.0070	.080	.118	.190	.240	.0043	.0063	.0095
315	355	.0106	.0142	.0142	.0187	.0187	.0234	.0060	.0080	.096	.131	.220	.270	.0047	.0071	.0105
355	400	.0118	.0157	.0157	.0207	.0207	.0258	.0070	.0090	.104	.144	.240	.300	.0051	.0079	.0115
400	450	.0130	.0173	.0173	.0224	.0224	.0283	.0080	.0100	.128	.160	.270	.330	.0055	.0087	.0125
450	500	.0146	.0193	.0193	.0248	.0248	.0311	.0090	.0110	.136	.176	.300	.360	.0063	.0094	.0140
500	560	.0161	.0213	.0213	.0275	.0275	.0343	.0100	.0130	.152	.208	.340	.430	.0067	.0106	.0155
560	630	.0180	.0236	.0236	.0307	.0307	.0386	.0100	.0140	.160	.224	.360	.470	.0079	.0122	.0170
630	710	.0201	.0264	.0264	.0335	.0335	.0429	.0120	.0160	.192	.256	.410	.510	.0087	.0130	.0185
710	800	.0224	.0295	.0295	.0378	.0378	.0480	.0130	.0180	.208	.288	.450	.590	.0094	.0154	.0210
800	900	.0252	.0331	.0331	.0421	.0421	.0539	.0140	.0200	.224	.320	.490	.650	.0110	.0169	.0230
900	1000	.0280	.0366	.0366	.0470	.0470	.6000	.0160	.0220	.256	.352	.550	.730	.0122	.0185	.0260

For Pe less than 0.13Cr, use the lower half of the reduction range. For heavier loads Pe greater than 0.13Cr, carburized or TL inner rings should be specified and the upper half of the range can be used.

Radial internal clearance can be measured during mounting using a feeler gauge or other appropriate gauges. In this process, the clearances for both rows of rollers must be measured simultaneously and the two values kept roughly the same by adjusting the relative position of the outer and inner rings. This is shown in Fig. 1. The average of the two measurements taken for both rows may be used as the residual internal clearance.

In large bearings, the outer ring may deform slightly into an elliptical shape due to its own weight. In this case, for best results, measurements should be taken at locations **a**, **b**, and **c** (see Fig. 2) and entered into the following equation:

radial clearance = (**a** + **b** + **c**)/2

This method is used where the bearing is resting on its outer ring (radial clearance c at bottom). When a self-aligning ball bearing is mounted on a shaft adapter, sufficient clearance for easy alignment of the outer ring must be allowed.

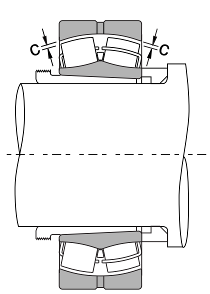


Figure 1

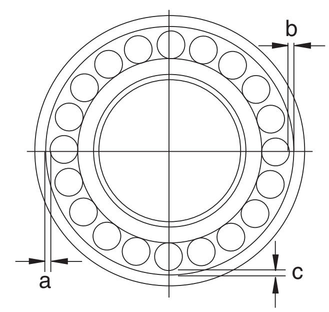


Figure 2

Inspecting and Troubleshooting

After mounting has been completed, a running test should be conducted to determine that the bearing has been mounted properly.

Small machines may be manually operated to assure that they rotate smoothly. Items to be checked include sticking due to foreign matter, visible flaws, uneven torque, and excessive torque caused by inadequate clearance, mounting error or seal friction.

Large machines which cannot be operated manually, may be started with no load, then the power immediately cut off to allow the machine to coast to a stop. There should be no abnormal vibration, noise or contact between rotating parts. Normal powered operation may be started after this examination. Powered operation should be started slowly, without load, and the operation should be observed until it is determined that no abnormalities exist. Items to be checked during the test operation include abnormal noise, excessive rise of bearing temperature, leakage and discoloration of lubricants. Abnormal noise conditions are indicated by a loud metallic sound or other irregular noise. Possible causes of noise may include incorrect lubrication, poor alignment of the shaft and housing, and foreign matter in the bearing.

Bearing temperature may generally be estimated by the temperature of the outside surface of the housing, but it is more desirable to directly measure the temperature of the outer ring using oil holes for access. Bearing temperature should rise gradually to the steady state level within one to two hours after operation. It the bearing or mountings are improper, bearing temperature may increase rapidly and become abnormally high. Possible causes may include an excessive amount of lubricant, insufficient clearance, incorrect mounting, or excessive friction of the seals. In the case of high speed operation, an incorrect selection of bearing type or lubricating method may also cause an abnormal temperature rise.

Possible causes and countermeasures for operating irregularities are shown in Table 10.57 on page 350.

Table 10.57 — Causes and Countermeasures for Operating Irregularities

Irregularities		Possible Causes	Countermeasures
Noise	Loud Metallic Sound	Abnormal Load	Correction of fit, internal clearance, preload, position of housing shoulder, etc.
		Incorrect mounting	Correction of alignment of shaft and housing, accuracy of mounting method.
		Insufficient or improper lubricant	Replenish lubricant or select proper lubricant.
		Squeaking noise	Replacement by low-noise bearings, selection of small clearance bearings.
		Sliding of balls	Adjustment of preload, selection of small clearance bearings, or adoption of softer grease.
		Contact of rotating parts	Correction of labyrinth seal, etc.
	Loud Regular Sound	Flaws, corrosion, or scratches on the raceways	Replacement of bearing, cleaning, improvement of sals, and usage of clean lubricant.
		Brinelling	Replacement of bearing and careful handling.
		Flaking on the raceways	Replacement of bearing
	Irregular Sound	Excessive clearance	Correction of fit and clearance and correction of preload
		Penetration by foreign particles	Replacement of bearing, cleaning, improvement of seals, and relubrication using clean lubricant.
		Flaws or flaking on the ball surfaces	Replacement of bearing
		Excessive amount of lubricant	Reduce amount of lubricant, select stiffer grease.
Abnormal Temperature Rise		Insufficient or improper lubricant	Replenish lubricant or select proper lubricant.
		Abnormal load	Correction of fit, internal clearance, preload, position of housing shoulder.
		Incorrect mounting	Correction of alignment of shaft and housing, accuracy of mounting, or mounting method.
		Creep of fitted surfaces, excessive seal friction.	Correction of seals, replacement of bearing, correction of fit or mounting.
Vibration		Brinelling	Replacement of bearings and careful handling.
		Flaking	Replacement of bearing
		Incorrect mounting	Correction of squareness between shaft and housing shoulder or side of spacer.
		Penetration by foreign particles	Replacement of bearing, cleaning, correction of seals.
Leakage or Discoloration of Lubricant		To much lubrication. Penetration by foreign particles or abrasion chips.	Reduce amount of lubricant, select stiffer grease. Replace bearing or lubricant. Clean housing and adjacent parts.

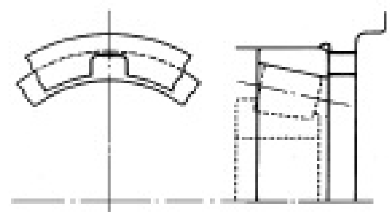
How to Dismount Bearings

It may be necessary to remove bearings for periodic inspection or for other reasons. If the removed bearing is to be used again, it should be dismounted as carefully as when it was mounted. If the bearing has a tight fit, removal may be difficult. Dismounting procedures and the sequence of removal should be studied carefully before beginning the job.

Dismounting of Outer Rings

Housings are not normally supplied with facilities to allow easy bearing removal. However, if it is necessary to periodically remove the bearing for inspection or replacement, special features can be incorporated to ease removal. One method is to provide tapped holes, in a minimum of three places equally spaced as illustrated in Figure 10.58. Larger bearings will require more holes. By placing bolts in the holes and tightening evenly, the bearing will be forced out of the housing.

Another method is to provide slots in the housing shoulder as shown here. This allows the use of a press to allow safe removal of the bearing.



Dismounting of Bearings with Cylindrical Bores

If the mounting design allows space to press out the inner ring, this is an easy and fast method. In this method, the withdrawal force should be imposed only on the inner ring. When it is not possible to use a press, bearing pullers like those shown in Figure 10.58 are often used. The claws of these tools must fully engage the face of the inner ring, therefore it may be necessary to cut grooves in the shoulder to accommodate the tools.

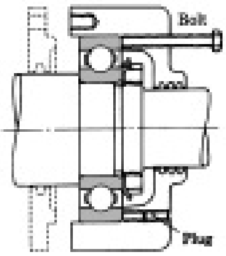
The oil injection method is usually used for the withdrawal of large bearings. Withdrawal is achieved easily by means of oil pressure applied through holes in the shaft. In the case of extra wide bearings, the oil injection method is often used along with bearing pullers.

Induction heating is used to remove the inner rings of rollneck type, four row cylindrical roller bearings. The inner rings are expanded by brief local heating and then withdrawn.

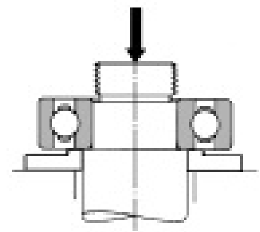
Dismounting of Bearings with Tapered Bores

When dismounting relatively small bearings with adapter sleeves, the inner ring is held by a backing ring fastened to the shaft and the nut is loosened several turns. This is followed by hammering on the sleeve using a suitable tool. See Figure 10.58. It may be possible to dismount a withdrawal sleeve by tightening the removal nut. If this procedure is difficult, it may be possible to drill and tap bolt holes in the nut and withdraw the sleeve by tightening the bolts. The two methods for removal of the sleeve are illustrated in Figure 10.58.

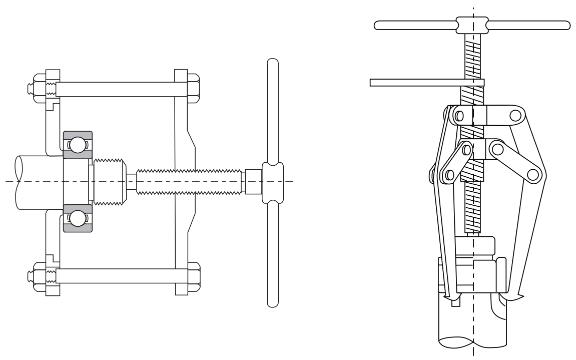
Large bearings with tapered bores may be withdrawn easily using oil pressure. Figure 10.58 illustrates the removal of a bearing by forcing oil under pressure through a hole and groove in a tapered shaft to expand the inner ring. When this method is used, the bearing may suddenly move axially when interference is relieved, so a stop nut is recommended for protection. Figure 10.58 also shows a withdrawal using a hydraulic nut.



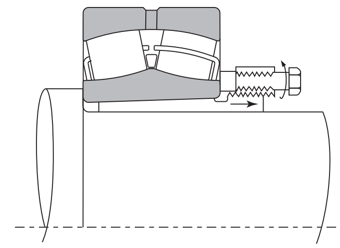
Removal of Outer Ring with Dismounting Bolts



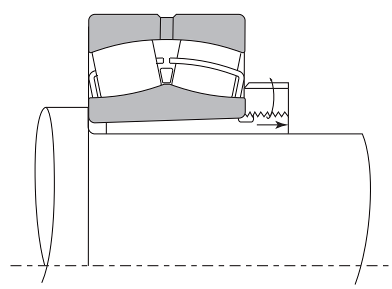
Removal of Inner Using a Press

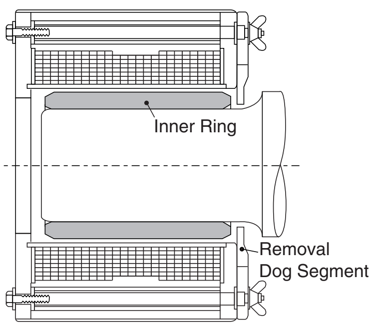


Removal of Inner Ring with Withdrawal Tools

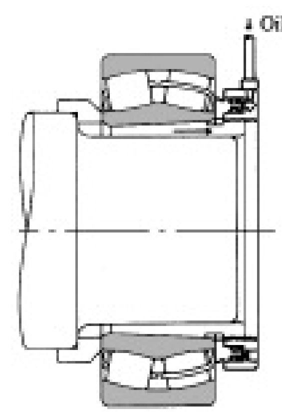


Removal of Withdrawal Sleeve with Withdrawal Nut

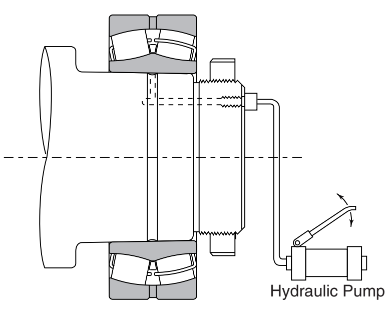




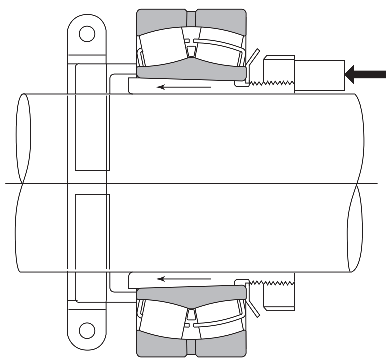
Removal of Inner Ring Using an Induction Heater



Removal Using a Hydraulic Nut



Removal Using Oil Injection



Removal of Adapter with Stop and Axial Pressure

Cleaning, Inspection and Evaluation

Cleaning Bearings

When bearings are inspected, their appearance should first be recorded and the amount and condition of the residual lubricant checked. After the lubricant has been sampled for examination, the bearing should be cleaned. In general, light oil or kerosene may be used as a washing solution. Dismounted bearings should first be given a preliminary cleaning followed by a finishing rinse. Each cleaning tank should be provided with a metal net to suspend the bearings in the oil without touching either the sides or bottom of the tank.

If the bearings are rotated with foreign matter in them during cleaning, the raceways may be damaged. The lubricant and other deposits should be removed in the oil bath during the initial rough cleaning with a brush or other means. After the bearing is relatively clean, it should be given a finishing rinse. The bearing should be rotated while immersed in the rinsing oil. The rinsing oil must always be kept clean.

Inspection and Evaluation

After being thoroughly cleaned, bearings should be examined for the condition of their raceways and external surfaces, the amount of cage wear, the increase in internal clearance and degradation of tolerances. These must be carefully checked to determine the possibility of bearing reuse.

In the case of small non-separable ball bearings, hold the bearing horizontally in one hand and rotate the outer ring to confirm that it turns smoothly. Separable bearings such as tapered roller bearings, may be checked by individually examining their rolling elements and the outer ring raceway. Large bearings cannot be rotated manually. However, the rolling elements, raceway surfaces, cages and contact surface of the ribs should be carefully examined visually.

The determination to reuse a bearing should be made only after considering the degree of bearing wear, the function of the machine, the importance of the bearing in the machine, operating condition, and the time until next inspection. If any of the following defects exist, the bearing should be replaced:

- Cracks or dents in the inner or outer ring raceways, rolling elements or cage
- Flaking of the raceways or rolling elements
- Significant scratching of the raceway surfaces, ribs or rolling elements
- Worn cages or loose rivets
- Rust or flaws on the raceway surfaces or rolling elements
- Significant impact or brinell traces on the raceway surfaces or rolling elements
- Discoloration by heat
- Significant damage to the seals or shields of grease sealed bearings

Maintenance and Inspection

Correcting Irregularities

In order to maintain the original performance of a bearing for as long as possible, proper maintenance and inspection should be performed. If proper procedures are used, many bearing problems can be avoided. Periodic maintenance following specified procedures is mandatory. This includes supervision of operating conditions, supply or replacement of lubricants, and regular periodic inspection.

Items that should be regularly checked during operation include bearing noise, vibration, temperature and lubrication. If an irregularity is found during operation, the cause should be determined and the proper corrective action taken immediately. If necessary, the bearing should be dismounted and examined in detail. Refer to Table 10.57 on page 350 for causes and corrections of operating irregularities.

It is very important to detect signs of irregularities early in operation. The **NSK** Bearing Monitor is a device that checks the condition of bearings and gives a warning of any abnormality. It can also be used to stop the machine automatically in order to prevent serious damage. It also helps to improve the level of and attention to maintenance schedules and procedures. Contact **NSK** for further information.

Bearing Failures – Cause and Correction

In general, if rolling bearings are correctly used, they will survive to their predicted fatigue life. Premature failure is usually caused by improper mounting or dismounting, improper lubrication, penetration of foreign material, or inadequate inspection and maintenance.

It is often difficult to determine the real causes of premature failure. If all the conditions leading up to the time of failure are studied, it may be possible to avoid or reduce similar failures in the future.

The most frequent types of bearing failure, along with causes and corrective actions, are shown in Table 10.59 on page 355.

Table 10.59 — Causes and Countermeasures for Bearing Failures

	Type of Failure	Probable Cause	Counter Measures
Flaking	Flaking of one-side of the raceway of radial bearings Flaking of the raceways of double row bearings.	Abnormal axial load.	A loose fit should be used when mounting the outer ring of free-end bearings to allow axial expansion of the shaft.
	Flaking of the raceway in a symmetrical pattern	Out of roundness of the housing bore.	Correct the faulty housing.
	Flaking pattern inclined relative to the raceway in radial ball bearings. Flaking near the edge of the raceway and rolling surfaces in roller bearings.	Improper mounting, deflection of shaft, inadequate centering, inadequate tolerances for shaft and housing.	Use care in mounting and centering, select a bearing with a larger clearance, and correct the squareness of the shaft and housing shoulder.
	Flaking of raceway with same spacing as rolling elements.	Large shock load during mounting, rusting while bearing is out of operation for a prolonged period.	Use care in mounting and apply a rust preventive when machine operation is suspended for a long time.
	Premature flaking of raceways and rolling elements.	Insufficient clearance, excessive load, improper lubricant, rust, etc.	Select proper fit, bearing clearance, and lubricant.
	Premature flaking of duplex bearing	Excessive preload.	Adjust the preload.
Scoring and Smearing	Scoring or smearing between raceway and rolling surfaces.	Inadequate initial lubrication, excessively hard grease and high acceleration in starting.	Use a softer grease and avoid rapid acceleration.
	Spiral scoring or smearing of raceway surface of thrust ball bearing.	Raceway rings are not parallel and excessive speed.	Correct the mounting, apply a preload, or select another bearing type.
	Scoring or smearing between the end face of the rollers and guide rib.	Inadequate lubrication, incorrect mounting and large axial load.	Select proper lubricants and modify the mounting.
Cracks	Crack in outer or inner ring.	Excessive shock load, excessive interference fit, incorrect shaft cylindricity, improper amount of sleeve taper, large fillet radius, development of thermal cracks and advancement of flaking.	Examine the loading conditions, modify the fit of bearing sleeve. The fillet radius must be smaller than the bearing chamfer.
	Crack in rolling element. Break in rib.	Advancement of flaking, shock applied to the rib during mounting or dropped during handling.	Be careful in handling and mounting.
	Facture of cage.	Abnormal loading of cage due to incorrect mounting and improper lubrication.	Reduce the mounting error and review the lubricating method and lubricant.
Indentation	Indentations on raceway in same pattern as rolling elements	Shock load during mounting or excessive load when not rotating.	Use care in handling.
	Indentations on raceway and rolling elements.	Foreign matter such as metallic chips or sand.	Clean the housing, improve the seals, and use a clean lubricant.
Abnormal Wear	False brinelling (phenomenon similar to brinelling).	Vibration of the bearing without rotation during shipment or rocking motion of small amplitude.	Secure the shaft and housing, use oil as a lubricant and reduce vibration by applying a preload.
	Fretting.	Slight wearing of the fitting surface.	Increase interference and apply oil.
	Wearing of raceway, rolling elements, rib and cage.	Penetration by foreign matter, incorrect lubrication, and rust.	Use a different type of seal, clean the housing, and use a clean lubricant.
	Creep.	Insufficient interference or insufficient tightening of sleeve	Modify the fit or tighten the sleeve.
Seizure	Discoloration or welding of raceway, rolling elements, and rib.	Insufficient clearance, incorrect lubrication, or improper mounting.	Review the internal clearance and bearing fit, supply an adequate amount of the proper lubricant and improve the mounting method and related parts.
Electric Burns	Fluting or corrugation.	Melting due to electric arcing.	Install a ground wire to stop flow of electricity or insulate the bearing.
Corrosion and Rust	Rust and corrosion of fitting surfaces and bearing interior.	Condensation of water from the air, fretting, or penetration by corrosive substances.	Use care in storing and avoid high temperatures and high humidity; treatment for rust prevention is necessary when the operation is suspended for a long time.

Introduction
Ball Bearings
Cylindrical Roller Bearings
Spherical Roller Bearings
Tapered Roller Bearings
Thrust Bearings
Split Pillow Blocks
Super Precision Bearings
Linear Motion
Rolling Mill Bearings
Engineering Section

Appendix A –Tolerances for Shaft Diameters

Units: Inch

Shaft Diameter (mm)		Bearing Bore Tolerance	Shaft Tolerance							
over	incl	ABEC1	g6	h6	h9	h10	js5	js6	k5	k6
3	6	+0 -0.0003	-0.0002 -0.0005	+0 -0.0003	+0 -0.0012	+0 -0.0019	±0.0001	±0.0002	+0.0002 +0	+0.0004 +0
6	10	+0 -0.0003	-0.0002 -0.0006	+0 -0.0004	+0 -0.0014	+0 -0.0023	±0.0001	±0.0002	+0.0003 +0	+0.0004 +0
10	18	+0 -0.0003	-0.0002 -0.0007	+0 -0.0004	+0 -0.0017	+0 -0.0028	±0.0002	±0.0002	+0.0004 +0	+0.0005 +0
18	30	+0 -0.0004	-0.0003 -0.0008	+0 -0.0005	+0 -0.0020	+0 -0.0033	±0.0002	±0.0003	+0.0004 +0.0001	+0.0006 +0.0001
30	50	+0 -0.0005	-0.0004 -0.0010	+0 -0.0006	+0 -0.0024	+0 -0.0039	±0.0002	±0.0003	+0.0005 +0.0001	+0.0007 +0.0001
50	80	+0 -0.0006	-0.0004 -0.0011	+0 -0.0007	+0 -0.0029	+0 -0.0047	±0.0003	±0.0004	+0.0006 +0.0001	+0.0008 +0.0001
80	120	+0 -0.0008	-0.0005 -0.0013	+0 -0.0009	+0 -0.0034	+0 -0.0055	±0.0003	±0.0004	+0.0007 +0.0001	+0.0010 +0.0001
120	180	+0 -0.0010	-0.0006 -0.0015	+0 -0.0010	+0 -0.0039	+0 -0.0063	±0.0004	±0.0005	+0.0008 +0.0001	+0.0011 +0.0001
180	250	+0 -0.0012	-0.0006 -0.0017	+0 -0.0011	+0 -0.0045	+0 -0.0073	±0.0004	±0.0006	+0.0009 +0.0002	+0.0013 +0.0002
250	315	+0 -0.0014	-0.0007 -0.0019	+0 -0.0013	+0 -0.0051	+0 -0.0083	±0.0005	±0.0006	+0.0011 +0.0002	+0.0014 +0.0002
315	400	+0 -0.0016	-0.0007 -0.0021	+0 -0.0014	+0 -0.0055	+0 -0.0091	±0.0005	±0.0007	+0.0011 +0.0002	+0.0016 +0.0002
400	500	+0 -0.0018	-0.0008 -0.0024	+0 -0.0016	+0 -0.0061	+0 -0.0098	±0.0005	±0.0008	+0.0013 +0.0002	+0.0018 +0.0002
500	630	+0 -0.0020	-0.0009 -0.0026	+0 -0.0017	+0 -0.0069	+0 -0.0110		±0.0009		+0.0017 +0
630	800	+0 -0.0030	-0.0009 -0.0029	+0 -0.0020	+0 -0.0079	+0 -0.0126		±0.0010		+0.0020 +0
800	1000	+0 -0.0039	-0.0010 -0.0032	+0 -0.0022	+0 -0.0091	+0 -0.0142		±0.0011		+0.0022 +0
1000	1250	+0 -0.0049	-0.0011 -0.0037	+0 -0.0026	+0 -0.0102	+0 -0.0165		±0.0013		+0.0026 +0
1250	1600	+0 -0.0063	-0.0012 -0.0043	+0 -0.0031	+0 -0.0122	+0 -0.0197		±0.0015		+0.0031 +0
1600	2000	+0 -0.0079	-0.0013 -0.0049	+0 -0.0036	+0 -0.0146	+0 -0.0236		±0.0018		+0.0036 +0

Directions: The shaft tolerances are determined by adding the top number in the tolerance group to the shaft size and adding the bottom number to the shaft size. This provides the maximum shaft size and the minimum shaft size, respectively.

For example:

Shaft size = 0.4724”

Application = Electric Motor (Recommended shaft fit js6)

Shaft Tolerance (max) = 0.4724” + 0.0002” = 0.4726”

Shaft Tolerance (min) = 0.4724” - 0.0002” = 0.4722”

Appendix A –Tolerances for Shaft Diameters (continued)

Units: Inch

Shaft Diameter (mm)		Shaft Tolerance			
over	incl	m5	m6	n6	p6
3	6	+0.0004 +0.0002	+0.0005 +0.0002	+0.0006 +0.0003	+0.0008 +0.0005
6	10	+0.0005 +0.0002	+0.0006 +0.0002	+0.0007 +0.0004	+0.0009 +0.0006
10	18	+0.0006 +0.0003	+0.0007 +0.0003	+0.0009 +0.0005	+0.0011 +0.0007
18	30	+0.0007 +0.0003	+0.0008 +0.0003	+0.0011 +0.0006	+0.0014 +0.0009
30	50	+0.0008 +0.0004	+0.0010 +0.0004	+0.0013 +0.0007	+0.0017 +0.0010
50	80	+0.0009 +0.0004	+0.0012 +0.0004	+0.0015 +0.0008	+0.0020 +0.0013
80	120	+0.0011 +0.0005	+0.0014 +0.0005	+0.0018 +0.0009	+0.0023 +0.0015
120	180	+0.0013 +0.0006	+0.0016 +0.0006	+0.0020 +0.0011	+0.0027 +0.0017
180	250	+0.0015 +0.0007	+0.0018 +0.0007	+0.0024 +0.0012	+0.0031 +0.0020
250	315	+0.0017 +0.0008	+0.0020 +0.0008	+0.0026 +0.0013	+0.0035 +0.0022
315	400	+0.0018 +0.0008	+0.0022 +0.0008	+0.0029 +0.0015	+0.0039 +0.0024
400	500	+0.0020 +0.0009	+0.0025 +0.0009	+0.0031 +0.0016	+0.0043 +0.0027
500	630		+0.0028 +0.0010	+0.0035 +0.0017	+0.0048 +0.0031
630	800		+0.0031 +0.0012	+0.0039 +0.0020	+0.0054 +0.0035
800	1000		+0.0035 +0.0013	+0.0044 +0.0022	+0.0061 +0.0039
1000	1250		+0.0042 +0.0016	+0.0052 +0.0026	+0.0073 +0.0047
1250	1600		+0.0050 +0.0019	+0.0061 +0.0031	+0.0086 +0.0055
1600	2000		+0.0059 +0.0023	+0.0072 +0.0036	+0.0103 +0.0067

Units: Inch

Shaft Diameter (inch)		Shaft Tolerance	
over	incl	r6	r7
3	6	+0.0009 +0.0006	+0.0007 +0.0006
6	10	+0.0011 +0.0007	+0.0013 +0.0007
10	18	+0.0013 +0.0009	+0.0016 +0.0009
18	30	+0.0016 +0.0011	+0.0019 +0.0011
30	50	+0.0020 +0.0013	+0.0023 +0.0013
50	65	+0.0024 +0.0016	+0.0028 +0.0016
65	80	+0.0024 +0.0017	+0.0029 +0.0017
80	100	+0.0029 +0.0020	+0.0034 +0.0020
100	120	+0.0030 +0.0021	+0.0035 +0.0021
120	140	+0.0035 +0.0025	+0.0041 +0.0025
140	160	+0.0035 +0.0026	+0.0041 +0.0026
160	180	+0.0037 +0.0027	+0.0043 +0.0027
180	200	+0.0042 +0.0030	+0.0048 +0.0030
200	225	+0.0043 +0.0031	+0.0050 +0.0031
225	250	+0.0044 +0.0033	+0.0051 +0.0033
250	280	+0.0050 +0.0037	+0.0057 +0.0037
280	315	+0.0051 +0.0039	+0.0059 +0.0039
315	355	+0.0057 +0.0043	+0.0065 +0.0043
355	400	+0.0059 +0.0045	+0.0067 +0.0045
400	450	+0.0065 +0.0050	+0.0074 +0.0050
450	500	+0.0068 +0.0052	+0.0077 +0.0052
500	560	+0.0076 +0.0059	+0.0087 +0.0059
560	630	+0.0078 +0.0061	+0.0089 +0.0061
630	710	+0.0089 +0.0069	+0.0100 +0.0069
710	800	+0.0093 +0.0073	+0.0104 +0.0073
800	900	+0.0105 +0.0083	+0.0118 +0.0083
900	1000	+0.0109 +0.0087	+0.0122 +0.0087
1000	1120	+0.0124 +0.0098	+0.0140 +0.0098
1120	1250	+0.0128 +0.0102	+0.0144 +0.0102
1250	1400	+0.0149 +0.0118	+0.0167 +0.0118
1400	1600	+0.0161 +0.0130	+0.0179 +0.0130
1600	1800	+0.0182 +0.0146	+0.0205 +0.0146
1800	2000	+0.0194 +0.0157	+0.0217 +0.0157

Appendix B – Tolerances for Housing Bore Diameters

Units: Inch

Housing Bore Diameter (mm)		Bearing O.D. Tolerance	Housing Bore Tolerance						
over	incl	ABEC1	G7	H6	H7	H8	J6	J7	JS6
10	18	+0 -0.0003	+0.0009 +0.0002	+0.0004 +0	+0.0007 +0	+0.0011 +0	+0.0002 -0.0002	+0.0004 -0.0003	±0.0002
18	30	+0 -0.0004	+0.0011 +0.0003	+0.0005 +0	+0.0008 +0	+0.0013 +0	+0.0003 -0.0002	+0.0005 -0.0004	±0.0003
30	50	+0 -0.0004	+0.0013 +0.0004	+0.0006 +0	+0.0010 +0	+0.0015 +0	+0.0004 -0.0002	+0.0006 -0.0004	±0.0003
50	80	+0 -0.0005	+0.0016 +0.0004	+0.0007 +0	+0.0012 +0	+0.0018 +0	+0.0005 -0.0002	+0.0007 -0.0005	±0.0004
80	120	+0 -0.0006	+0.0019 +0.0005	+0.0009 +0	+0.0014 +0	+0.0021 +0	+0.0006 -0.0002	+0.0009 -0.0005	±0.0004
120	150	+0 -0.0007	+0.0021 +0.0006	+0.0010 +0	+0.0016 +0	+0.0025 +0	+0.0007 -0.0003	+0.0010 -0.0006	±0.0005
150	180	+0 -0.0010	+0.0021 +0.0006	+0.0010 +0	+0.0016 +0	+0.0025 +0	+0.0007 -0.0003	+0.0010 -0.0006	±0.0005
180	250	+0 -0.0012	+0.0024 +0.0006	+0.0011 +0	+0.0018 +0	+0.0028 +0	+0.0009 -0.0003	+0.0012 -0.0006	±0.0006
250	315	+0 -0.0014	+0.0027 +0.0007	+0.0013 +0	+0.0020 +0	+0.0032 +0	+0.0010 -0.0003	+0.0014 -0.0006	±0.0006
315	400	+0 -0.0016	+0.0030 +0.0007	+0.0014 +0	+0.0022 +0	+0.0035 +0	+0.0011 -0.0003	+0.0015 -0.0007	±0.0007
400	500	+0 -0.0018	+0.0033 +0.0008	+0.0016 +0	+0.0025 +0	+0.0038 +0	+0.0013 -0.0003	+0.0017 -0.0008	±0.0008
500	630	+0 -0.0020	+0.0036 +0.0009	+0.0017 +0	+0.0028 +0	+0.0043 +0	– –	– –	±0.0009
630	800	+0 -0.0030	+0.0041 +0.0009	+0.0020 +0	+0.0031 +0	+0.0049 +0	– –	– –	±0.0010
800	1000	+0 -0.0039	+0.0046 +0.0010	+0.0022 +0	+0.0035 +0	+0.0055 +0	– –	– –	±0.0011
1000	1250	+0 -0.0049	+0.0052 +0.0011	+0.0026 +0	+0.0041 +0	+0.0065 +0	– –	– –	±0.0013
1250	1600	+0 -0.0063	+0.0061 +0.0012	+0.0031 +0	+0.0049 +0	+0.0077 +0	– –	– –	±0.0015
1600	2000	+0 -0.0079	+0.0072 +0.0013	+0.0036 +0	+0.0059 +0	+0.0091 +0	– –	– –	±0.0018
2000	2500	+0 -0.0098	+0.0082 +0.0013	+0.0043 +0	+0.0069 +0	+0.0110 +0	– –	– –	±0.0022

Directions: The housing bore tolerances are determined by adding the top number in the tolerance group to the housing bore size and adding the bottom number to the housing bore size. This provides the maximum and minimum housing bore, respectively.

For example:

Housing bore = 1.2598”

Application = Electric Motor (Recommended Housing fit H7)

Housing Bore Tolerance (max) = 1.2598” + 0.0007” = 1.2605”

Housing Bore Tolerance (min) = 1.2598” + 0” = 1.2598”

Appendix B – Tolerances for Housing Bore Diameters (continued)

Units: Inch

Housing Bore Diameter (mm)		Housing Bore Tolerance							
over	incl	JS7	K6	K7	M6	M7	N6	N7	P7
10	18	±0.0004	+0.0001 -0.0004	+0.0002 -0.0005	-0.0002 -0.0006	+0 -0.0007	-0.0004 -0.0008	-0.0002 -0.0009	-0.0004 -0.0011
18	30	±0.0004	+0.0001 -0.0004	+0.0002 -0.0006	-0.0002 -0.0007	+0 -0.0008	-0.0004 -0.0009	-0.0003 -0.0011	-0.0006 -0.0014
30	50	±0.0005	+0.0001 -0.0005	+0.0003 -0.0007	-0.0002 -0.0008	+0 -0.0010	-0.0005 -0.0011	-0.0003 -0.0013	-0.0007 -0.0017
50	80	±0.0006	+0.0002 -0.0006	+0.0004 -0.0008	-0.0002 -0.0009	+0 -0.0012	-0.0006 -0.0013	-0.0004 -0.0015	-0.0008 -0.0020
80	120	±0.0007	+0.0002 -0.0007	+0.0004 -0.0010	-0.0002 -0.0011	+0 -0.0014	-0.0006 -0.0015	-0.0004 -0.0018	-0.0009 -0.0023
120	180	±0.0008	+0.0002 -0.0008	+0.0005 -0.0011	-0.0003 -0.0013	+0 -0.0016	-0.0008 -0.0018	-0.0005 -0.0020	-0.0011 -0.0027
180	250	±0.0009	+0.0002 -0.0009	+0.0005 -0.0013	-0.0003 -0.0015	+0 -0.0018	-0.0009 -0.0020	-0.0006 -0.0024	-0.0013 -0.0031
250	315	±0.0010	+0.0002 -0.0011	+0.0006 -0.0014	-0.0004 -0.0016	+0 -0.0020	-0.0010 -0.0022	-0.0006 -0.0026	-0.0014 -0.0035
315	400	±0.0011	+0.0003 -0.0011	+0.0007 -0.0016	-0.0004 -0.0018	+0 -0.0022	-0.0010 -0.0024	-0.0006 -0.0029	-0.0016 -0.0039
400	500	±0.0012	+0.0003 -0.0013	+0.0007 -0.0018	-0.0004 -0.0020	+0 -0.0025	-0.0011 -0.0026	-0.0007 -0.0031	-0.0018 -0.0043
500	630	±0.0014	+0 -0.0017	+0 -0.0028	-0.0010 -0.0028	-0.0010 -0.0038	-0.0017 -0.0035	-0.0017 -0.0045	-0.0031 -0.0058
630	800	±0.0016	+0 -0.0020	+0 -0.0031	-0.0012 -0.0031	-0.0012 -0.0043	-0.0020 -0.0039	-0.0020 -0.0051	-0.0035 -0.0066
800	1000	±0.0018	+0 -0.0022	+0 -0.0035	-0.0013 -0.0035	-0.0013 -0.0049	-0.0022 -0.0044	-0.0022 -0.0057	-0.0039 -0.0075
1000	1250	±0.0020	+0 -0.0026	+0 -0.0041	-0.0016 -0.0042	-0.0016 -0.0057	-0.0026 -0.0052	-0.0026 -0.0067	-0.0047 -0.0089
1250	1600	±0.0024	+0 -0.0031	+0 -0.0049	-0.0019 -0.0050	-0.0019 -0.0068	-0.0031 -0.0061	-0.0031 -0.0080	-0.0055 -0.0104
1600	2000	±0.0030	+0 -0.0036	+0 -0.0059	-0.0023 -0.0059	-0.0023 -0.0082	-0.0036 -0.0072	-0.0036 -0.0095	-0.0067 -0.0126
2000	2500	±0.0034	+0 -0.0043	+0 -0.0069	-0.0027 -0.0070	-0.0027 -0.0096	-0.0043 -0.0087	-0.0043 -0.0112	-0.0077 -0.0146

Conversion Factors

	To Convert From	To	Multiply By	To Convert From	To	Multiply By
Length						
	Inch [in]	Millimeter [mm]	25.400 000	Millimeter [mm]	Inch [in]	0.039 370
	Foot [ft]	Meter [m]	0.304 800	Meter [m]	Foot [ft]	3.280 840
	Yard [yd]	Meter [m]	0.914 400	Meter [m]	Yard [yd]	1.093 613
	Mile (U.S. Statute) [mi]	Kilometer [km]	1.609 347	Kilometer [km]	Mile (U.S. Statute) [mi]	0.621 370
Area						
	Square Inch [in2]	Square Millimeter [mm2]	645.16	Square Millimeter [mm2]	Square Inch [in2]	0.001550
	Square Foot [ft2]	Square Meter [m2]	0.092 903	Square Meter [m2]	Square Foot [ft2]	10.763 915
	Square Yard [yd2]	Square Meter [m2]	0.836 127	Square Meter [m2]	Square Yard [yd2]	1.195 991
	Square Mile [mi2] (U.S. Statute)	Square Kilometer [km2]	2.589 998	Square Kilometer [km2]	Square Mile [mi2] (U.S. Statute)	0.386 101
	Acre	Square Meter [m2]	4046.873	Square Meter [m2]	Acre	0.000 247
	Acre	Hectare	0.404 687	Hectare	Acre	2.471 046
Volume						
	Cubic Inch [in3]	Cubic Millimeter [mm3]	16387.06	Cubic Millimeter [mm3]	Cubic Inch [in3]	0.000061
	Cubic Foot [ft3]	Cubic Meter [m3]	0.028 317	Cubic Meter [m3]	Cubic Foot [ft3]	35.314 662
	Cubic Yard [yd3]	Cubic Meter [m3]	0.764 555	Cubic Meter [m3]	Cubic Yard [yd3]	1.307 950
	Gallon (U.S. Liquid) [gal]	Litre [l]	3.785 412	Litre [l]	Gallon (U.S. Liquid) [gal]	0.264 172
	Quart (U.S. Liquid) [qt]	Litre [l]	0.946 353	Litre [l]	Quart (U.S. Liquid) [qt]	1.056 688
Mass						
	Ounce (Avoirdupois) [oz]	Gram [g]	28.349 520	Gram [g]	Ounce (Avoirdupois)	0.035 274 [oz]
	Pound (Avoirdupois) [lb]	Kilogram [kg]	0.453 592	Kilogram [kg]	Pound (Avoirdupois) [lb]	2.204 624
	Short Ton	Kilogram [kg]	907.185	Kilogram [kg]	Short Ton	0.00110
Force						
	Pound-Force [lbf]	Kilogram [kg]	0.453 592	Kilogram [kg]	Pound-Force [lbf]	2.204 624
	Pound-Force [lbf]	Newton [N]	4.448 222	Newton [N]	Pound-Force [lbf]	0.224 809
Bending Moment						
	Pound-Force-Inch [lbf-in]	Newton-Meter [N-m]	0.112 985	Newton-Meter [N-m]	Pound-Force-Inch [lbf-in]	8.850 732
	Pound-Force-Foot [lbf-ft]	Newton-Meter [N-m]	1.355 818	Newton-Meter [N-m]	Pound-Force-Foot [lbf-ft]	0.737 562
Pressure, Stress						
	Pound-Force per Square Inch [lbf/in2]	Kilopascal [kPa]	6.894 757	Kilopascal [kPa]	Pound-Force per Square Inch [lbf/in2]	0.145 038
	Foot of Water (39.2 F)	Kilopascal [kPa]	2.988 980	Kilopascal [kPa]	Foot of Water (39.2 F)	0.334 562
	Inch of Mercury (32 F)	Kilopascal [kPa]	3.386 380	Kilopascal [kPa]	Inch of Mercury (32 F)	0.295 301
Energy, Work, Heat						
	Foot-Pound-Force [ft-lbf]	Joule [J]	1.355 818	Joule [J]	Foot-Pound-Force [ft-lbf]	0.737 562
	British Thermal Unit [Btu]	Joule [J]	1055.056	Joule [J]	British Thermal Unit [Btu]	0.000948
	Calorie [cal]	Joule [J]	4.186 800	Joule [J]	Calorie [cal]	0.238 846
	Kilowatt Hour [kW-h]	Joule [J]	3600000	Joule [J]	Kilowatt Hour [kW-h]	2.78-7
Power						
	Foot-Pound-Force /Second [ft-lbs/s]	Watt [W]	1.355 818	Watt [W]	Foot-Pound-Force / Second [ft-lbs/s]	0.737 562
	British Thermal Unit / Hour [Btu/h]	Watt [W]	0.293 071	Watt [W]	British Thermal Unit / Hour [Btu/h]	3.412 142
	Horsepower (550 Ft. Lbf/s) [hp]	Kilowatt [kW]	0.745 700	Kilowatt [kW]	Horsepower (550 Ft. Lbf/s) [hp]	1.341 022
Angle						
	Degree	Radian [rad]	0.017 453	Radian [rad]	Degree	57.295 788
Temperature						
	Degree Fahrenheit [F]	Degree Celsius [C]	(F° -32)/1.8	Degree Celsius [C]	Degree Fahrenheit [F]	1.8xC°+32