6. Preload and axial displacement

6.1 Position preload and constant-pressure preload

Bearings for machine-tool head spindles, hypoid-gear pinion shafts, and other similar applications are often preloaded to increase bearing rigidity and, thereby, reduce as far as possible undesirable bearing displacement due to applied loads.

Generally, a preload is applied as shown in Fig. 1, using a spacer, shim, etc. to set the displacement dimensionally (position preload), or, as shown in Fig. 2, using a spring (constant pressure preload).

The effect of a position preload on rigidity is apparent in preload graphs such as Fig. 3. This graph is similar to data generally found in bearing makers' catalogs. That is, Fig. 3 shows that the relation between the axial displacement δ_a and external load F_a (axial load) under the preload of F_{a0}. This graph of position preload is derived from the displacement curves for the two side-by-side bearings, A and B.

By substituting a spring displacement curve (a straight line) for the bearing B displacement curve and plotting it together with the displacement curve for bearing A, a graph for a constant-pressure preload is formed.

Fig. 4 is a preload graph for a constant-pressure preload. Because spring rigidity is, as a rule, small compared with bearing rigidity, the displacement curve for the spring is a straight line that is nearly parallel to the horizontal axis of the graph. It also follows that an increase in rigidity under a constant-pressure preload will be nearly the same as an increase in rigidity for a single bearing subjected to an F_{a0} preload.

Fig. 5 compares the rigidity provided by various preload methods on a 7212A angular contact ball bearing.

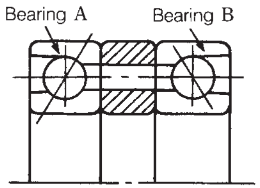


Fig. 1 Position preload

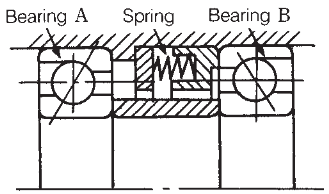


Fig. 2 Constant-pressure preload

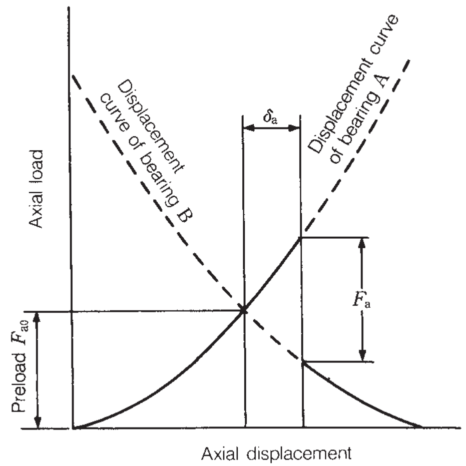


Fig. 3 Preload graph for position preload

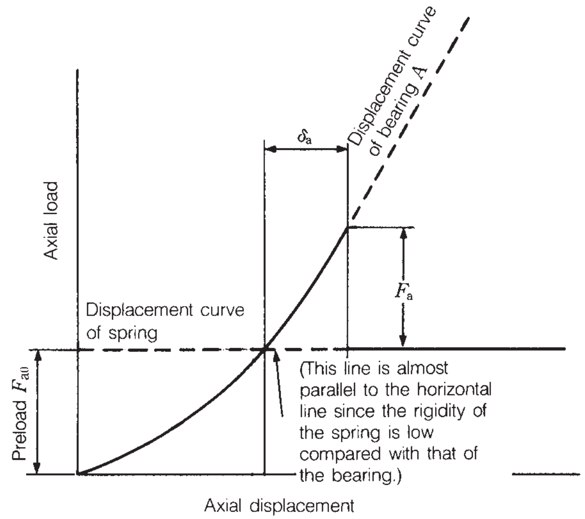


Fig. 4 Preload graph for constant-pressure preload

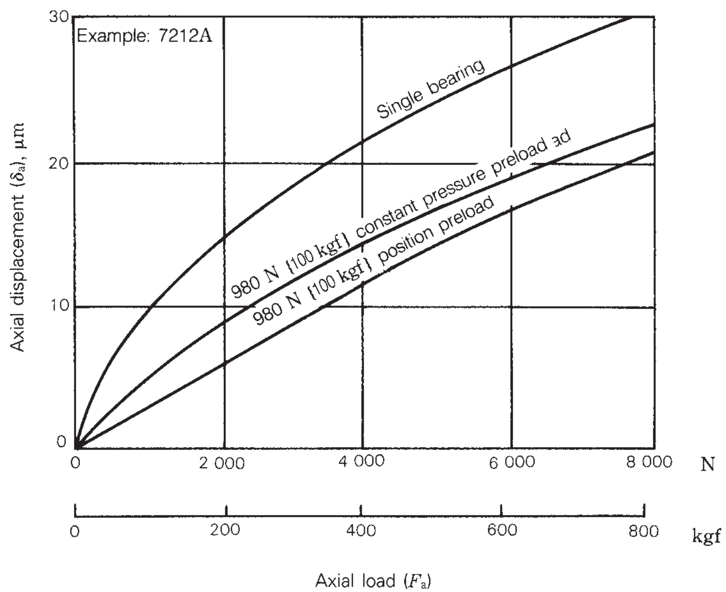


Fig. 5 Comparison of rigidity among different preload methods

6.2 Load and displacement of position-preloaded bearings

Two (or more) ball or tapered roller bearings mounted side by side as a set are termed duplex (or multiple) bearing sets. The bearings most often used in multiple arrangements are single-row angular contact ball bearings for machine tool spindles, since there is a requirement to reduce the bearing displacement under load as much as possible.

There are various ways of assembling sets depending on the effect desired. Duplex angular contact bearings fall into three types of arrangements, Back-to-Back, with lines of force convergent on the bearing back faces, Face-to-Face, with lines of force convergent on the bearing front faces, and Tandem, with lines of force being parallel. The symbols for these are DB, DF, and DT arrangements respectively (Fig. 1).

DB and DF arrangement sets can take axial loads in either direction. Since the distance of the load centers of DB bearing set is longer than that of DF bearing set, they are widely used in applications where there is a moment. DT type sets can only take axial loads in one direction. However, because the two bearings share some load equally between them, a set can be used where the load in one direction is large.

By selecting the DB or DF bearing sets with the proper preloads which have already been adjusted to an appropriate range by the bearing manufacturer, the radial and axial displacements of the bearing inner and outer ring can be reduced as much as allowed by certain limits. However, the DT bearing set cannot be preloaded.

The amount of preload can be adjusted by changing clearance between bearings, δ_{a0}, as shown in Figs. 3 to 5. Preloads are divided into four graduated classification — Extra light (EL), Light (L), Medium (M), and Heavy (H). Therefore, DB and DF bearing sets are often used for applications where shaft misalignments and displacements due to loads must be minimized.

Triplex sets are also available in three types (symbols: DBD, DFD, and DTD) of arrangements as shown in Fig. 2. Sets of four or five bearings can also be used depending on the application requirements.

Duplex bearings are often used with a preload applied. Since the preload affects the rise in bearing temperature during operation, torque, bearing noise, and especially bearing life, it is extremely important to avoid applying an excessive preload.

Generally, the axial displacement δ_a under an axial load F_a for single-row angular contact ball bearings is calculated as follows,

$$\delta_a = c\, F_a^{2/3} \quad \cdots\cdots (1)$$

where, c: Constant depending on the bearing type and dimensions.

Fig. 3 shows the preload curves of duplex DB arrangement, and Figs. 4 and 5 show those for triplex DBD arrangement.

If the inner rings of the duplex bearing set in Fig. 3 are pressed axially, A-side and B-side bearings are deformed δ_{a0A} and δ_{a0B} respectively and the clearance (between the inner rings), δ_{a0}, becomes zero. This condition means that the preload F_{a0} is applied on the bearing set. If an external axial load F_a is applied on the preloaded bearing set from the A-side, then the A-side bearing will be deformed δ_{a1} additionally and the displacement of B-side bearing will be reduced to the same amount as the A-side bearing displacement δ_{a1}. Therefore, the displacements of A- and B-side bearings are $\delta_{aA}=\delta_{a0A}+\delta_{a1}$ and $\delta_{aB}=\delta_{a0B}+\delta_{a1}$ respectively. That is, the load on A-side bearing including the preload is $(F_{a0}+F_a-F_a')$ and the B-side bearing is $(F_{a0}-F_a')$.

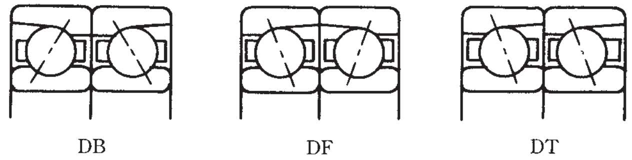


Fig. 1 Duplex bearing arrangements

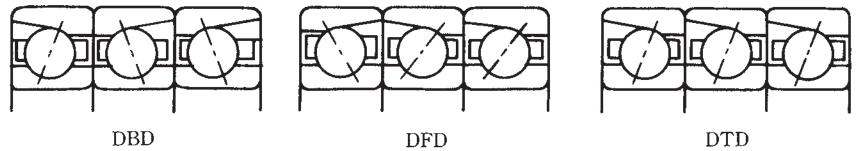


Fig. 2 Triplex bearing arrangements

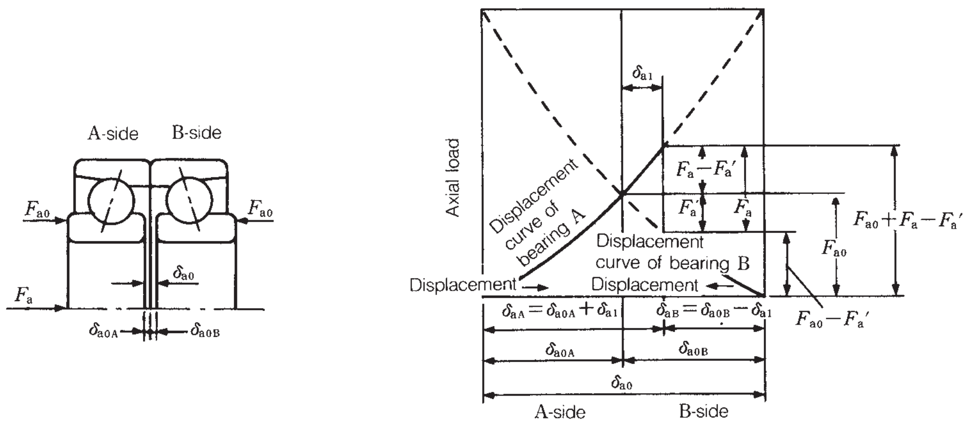


Fig. 3 Preload graph of DB arrangement duplex bearings

If the bearing set has an applied preload, the A-side bearing should have a sufficient life and load capacity for an axial load ($F_{a0}+F_a-F_a'$) under the speed condition. The axial clearance δ_{a0} is shown in **Tables 3** to **7** of Section **6.3** (Pages 151 to 155).

In **Fig. 4**, with an external axial load F_a applied on the AA-side bearings, the axial loads and displacements of AA- and B-side bearings are summarized in **Table 1**.

In **Fig. 5**, with an external axial load F_a applied on the A-side bearing, the axial loads and displacements of A- and BB-side bearings are summarized in **Table 2**.

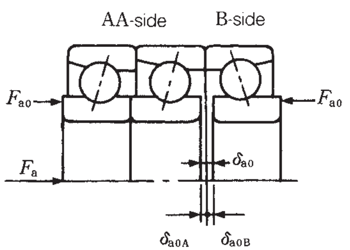
The examples, **Figs. 6** to **11**, show the relation of the axial loads and axial displacements using duplex DB and triplex DBD arrangements of 7018C and 7018A bearings under several preload ranges.

Table 1

Direction	Displacement	Axial load
AA-side	$\delta_{a0A}+\delta_{a1}$	$F_{a0}+F_a-F_a'$
B-side	$\delta_{a0B}-\delta_{a1}$	$F_{a0}-F_a'$

Table 2

Direction	Displacement	Axial load
A-side	$\delta_{a0A}+\delta_{a1}$	$F_{a0}+F_a-F_a'$
BB-side	$\delta_{a0B}-\delta_{a1}$	$F_{a0}-F_a'$



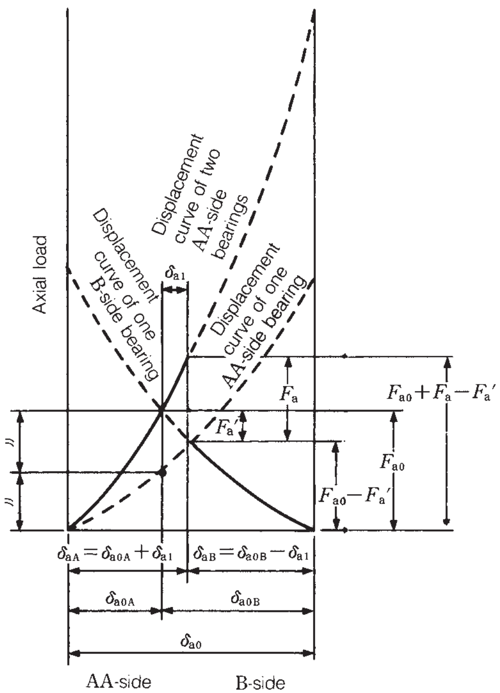


Fig. 4 Preload graph of triplex DBD bearing set (Axial load is applied from AA-side)

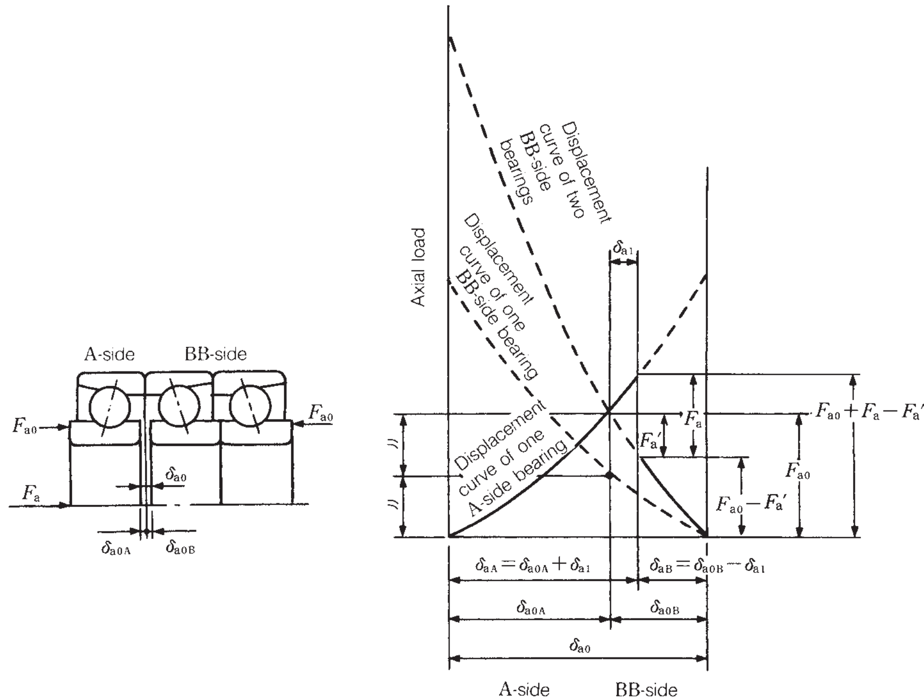


Fig. 5 Preload graph of triplex DBD bearing set (Axial load is applied from A-side)

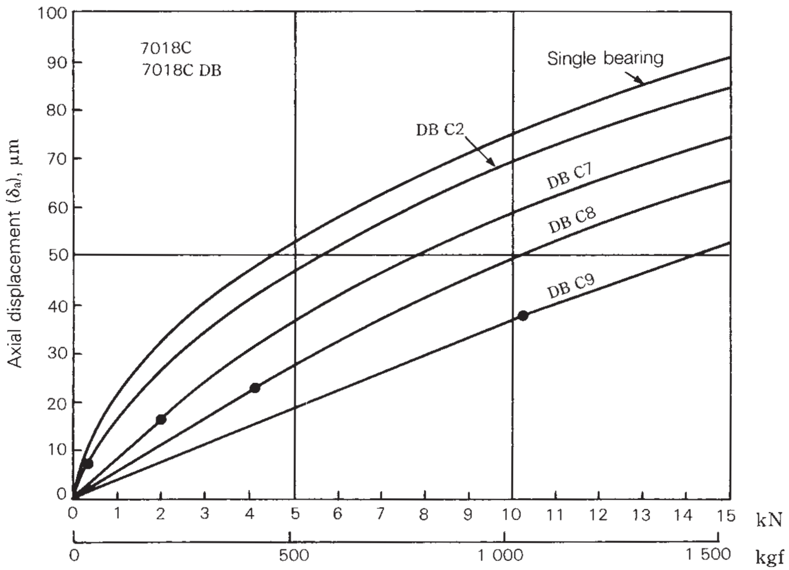


Fig. 6

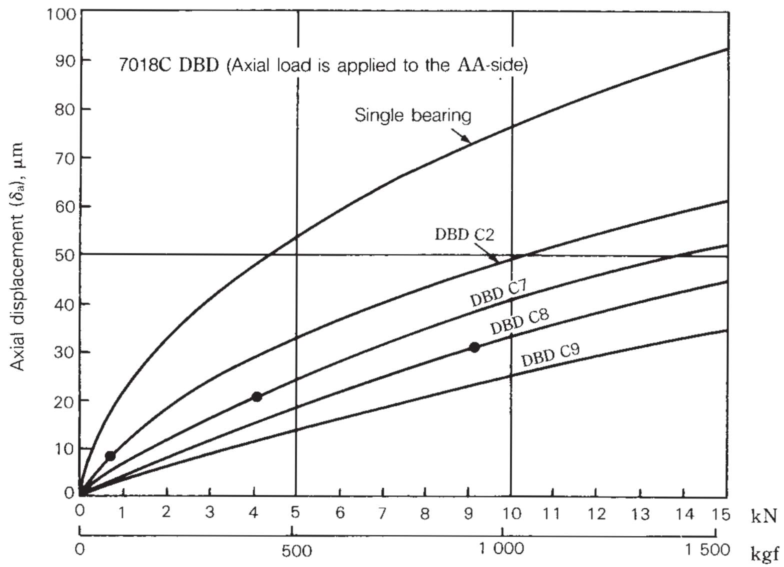


Fig. 7

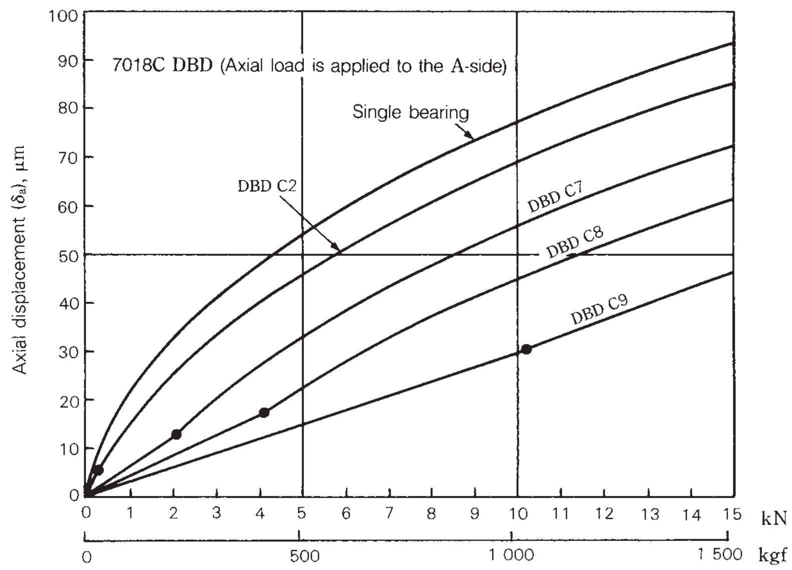


Fig. 8

Remarks A (•) mark on the axial load or displacement curve indicates the point where the preload is zero. Therefore, if the axial load is larger than this, the opposed bearing does not impose a load.

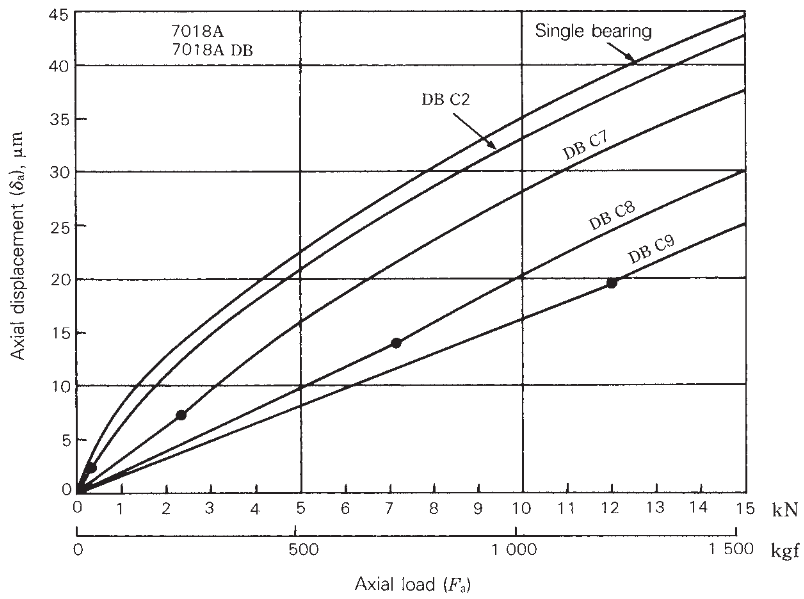


Fig. 9

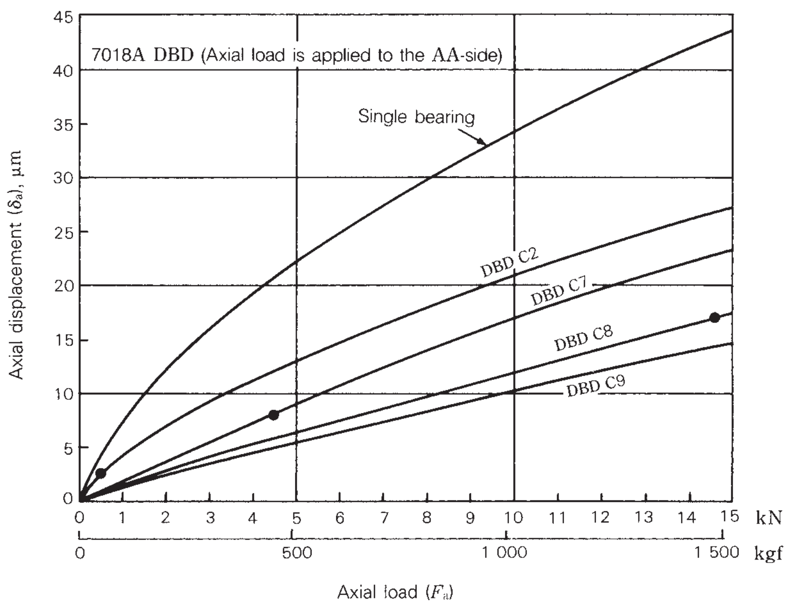


Fig. 10

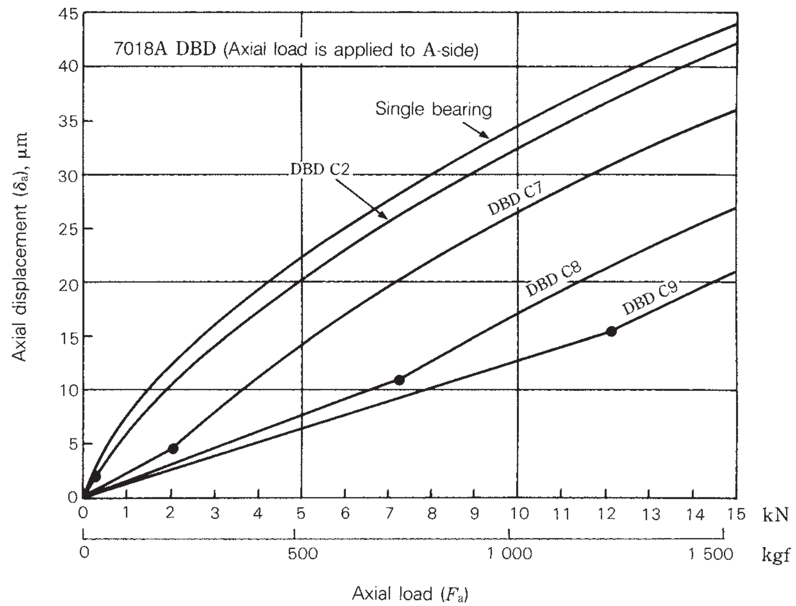


Fig. 11

Remarks A (•) mark on the axial load or displacement curve indicates the point where the preload is zero. Therefore, if the axial load is larger than this, the opposed bearing does not impose a load.

6.3 Average preload for duplex angular contact ball bearings

Angular contact ball bearings are widely used in spindles for grinding, milling, high-speed turning, etc. At NSK, preloads are divided into four graduated classifications — Extra light (EL), Light (L), Medium (M), and Heavy (H) — to allow the customer to freely choose the appropriate preload for the specific application. These four preload classes are expressed in symbols, EL, L, M, and H, respectively, when applied to DB and DF bearing sets.

The average preload and axial clearance (measured) for duplex angular contact ball bearing sets with contact angles 15° and 30° (widely used on machine tool spindles) are given in Tables 3 to 7.

The measuring load when measuring axial clearance is shown in Table 1.

The recommended axial clearance to achieve the proper preload was determined for machine-tool spindles and other applications requiring ISO Class 5 and above high-precision bearing sets. The standard values given in Table 2 are used for the shaft — inner ring and housing — outer ring fits. The housing fits should be selected in the lower part of the standard clearance for bearings in fixed-end applications and the higher part of the standard clearance for bearings in free-end applications.

As general rules when selecting preloads, grinding machine spindles or machining center spindles require extra light to light preloads, whereas lathe spindles, which need rigidity, require medium preloads.

The bearing preloads, if the bearing set is mounted with tight fit, are larger than those shown in Tables 3 to 7. Since excessive preloads cause bearing temperature rise and seizure, etc., it is necessary to pay attention to fitting.

Table 1 Measuring load of axial clearance

Nominal bearing outside diameter D (mm)		Measuring load
over	incl	(N)
10*	50	24.5
50	120	49
120	200	98
200	—	196

*10 mm is included in this range.

Table 2 Target of fitting

Units: μm

Bore or outside diameter d or D (mm)		Shaft and inner ring	Housing and outer ring
over	incl	Target interference	Target clearance
—	18	0 to 2	—
18	30	0 to 2.5	2 to 6
30	50	0 to 2.5	2 to 6
50	80	0 to 3	3 to 8
80	120	0 to 4	3 to 9
120	150	—	4 to 12
150	180	—	4 to 12
180	250	—	5 to 15

Table 3 Average preloads and axial clearance for bearing series 79C

Bearing No.	Extra light EL		Light L		Medium M		Heavy H	
	Preload	Axial clearance	Preload	Axial clearance	Preload	Axial clearance	Preload	Axial clearance
	(N)	(μm)	(N)	(μm)	(N)	(μm)	(N)	(μm)
7900C	7	5	15	2	29	−1	59	−6
7901C	8.6	4	15	2	39	−3	78	−8
7902C	12	3	25	0	49	−4	100	−11
7903C	12	3	25	0	59	−5	120	−12
7904C	19	1	39	−3	78	−8	150	−15
7905C	19	1	39	−2	100	−9	200	−17
7906C	24	0	49	−3	100	−8	200	−16
7907C	34	2	69	−2	150	−9	290	−18
7908C	39	1	78	−3	200	−12	390	−22
7909C	50	0	100	−5	200	−11	390	−21
7910C	50	0	100	−4	250	−13	490	−24
7911C	60	−1	120	−5	290	−15	590	−26
7912C	60	−1	120	−5	290	−15	590	−25
7913C	75	−2	150	−7	340	−16	690	−27
7914C	100	−4	200	−10	490	−22	980	−36
7915C	100	−4	200	−9	490	−21	980	−35
7916C	100	−4	200	−9	490	−21	980	−34
7917C	145	−6	290	−14	640	−25	1 270	−41
7918C	145	−3	290	−9	740	−23	1 470	−39
7919C	145	−3	290	−9	780	−24	1 570	−40
7920C	195	−5	390	−13	880	−28	1 770	−46

Remarks In the axial clearance column, the measured value is given.

Table 4 Average preloads and axial clearance for bearing series 70C

Bearing No.	Extra light EL		Light L		Medium M		Heavy H	
	Preload (N)	Axial clearance (μm)	Preload (N)	Axial clearance (μm)	Preload (N)	Axial clearance (μm)	Preload (N)	Axial clearance (μm)
7000C	12	3	25	0	49	−5	100	−12
7001C	12	3	25	0	59	−6	120	−14
7002C	14	3	29	−1	69	−7	150	−16
7003C	14	2	29	−1	69	−7	150	−16
7004C	24	0	49	−4	120	−12	250	−22
7005C	29	−1	59	−5	150	−14	290	−24
7006C	39	1	78	−3	200	−13	390	−24
7007C	60	−1	120	−7	250	−16	490	−28
7008C	60	−1	120	−6	290	−17	590	−30
7009C	75	−3	150	−8	340	−19	690	−33
7010C	75	−2	150	−8	390	−20	780	−34
7011C	100	−4	200	−11	490	−24	980	−40
7012C	100	−4	200	−10	540	−25	1 080	−42
7013C	125	−6	250	−13	540	−24	1 080	−39
7014C	145	−7	290	−14	740	−30	1 470	−48
7015C	145	−7	290	−14	780	−31	1 570	−49
7016C	195	−6	390	−14	930	−31	1 860	−52
7017C	195	−6	390	−14	980	−32	1 960	−52
7018C	245	−8	490	−18	1 180	−37	2 350	−60
7019C	270	−9	540	−19	1 180	−36	2 350	−58
7020C	270	−9	540	−18	1 270	−37	2 550	−60

Remarks In the axial clearance column, the measured value is given.

Table 5 Average preloads and axial clearance for bearing series 72C

Bearing No.	Extra light EL		Light L		Medium M		Heavy H	
	Preload (N)	Axial clearance (μm)	Preload (N)	Axial clearance (μm)	Preload (N)	Axial clearance (μm)	Preload (N)	Axial clearance (μm)
7200C	14	3	29	−1	69	−8	150	−18
7201C	19	1	39	−3	100	−12	200	−22
7202C	19	1	39	−3	100	−11	200	−21
7203C	24	0	49	−4	150	−16	290	−28
7204C	34	−2	69	−7	200	−20	390	−33
7205C	39	1	78	−4	200	−14	390	−27
7206C	60	−1	120	−7	290	−20	590	−35
7207C	75	−3	150	−10	390	−25	780	−43
7208C	100	−5	200	−13	490	−29	980	−47
7209C	125	−7	250	−16	540	−30	1 080	−49
7210C	125	−7	250	−15	590	−31	1 180	−50
7211C	145	−8	290	−17	780	−38	1 570	−60
7212C	195	−11	390	−22	930	−42	1 860	−67
7213C	220	−12	440	−23	1 080	−44	2 160	−70
7214C	245	−9	490	−20	1 180	−42	2 350	−69
7215C	270	−10	540	−21	1 230	−42	2 450	−68
7216C	295	−12	590	−24	1 370	−47	2 750	−76
7217C	345	−14	690	−27	1 670	−53	3 330	−85
7218C	390	−15	780	−29	1 860	−57	3 730	−90
7219C	440	−18	880	−33	2 060	−63	4 120	−99
7220C	490	−20	980	−36	2 350	−68	4 710	−107

Remarks In the axial clearance column, the measured value is given.

Table 6 Average preloads and axial clearance for bearing series 70A

Bearing No.	Extra light EL		Light L		Medium M		Heavy H	
	Preload (N)	Axial clearance (μm)	Preload (N)	Axial clearance (μm)	Preload (N)	Axial clearance (μm)	Preload (N)	Axial clearance (μm)
7000A	25	0	100	−5	210	−10	330	−15
7001A	25	0	110	−5	220	−10	360	−15
7002A	25	0	110	−5	240	−10	390	−15
7003A	25	0	120	−5	250	−10	420	−15
7004A	25	0	130	−5	280	−10	470	−15
7005A	25	0	140	−5	290	−10	510	−15
7006A	50	0	190	−5	390	−10	640	−15
7007A	50	0	210	−5	420	−10	700	−15
7008A	50	0	220	−5	460	−10	760	−15
7009A	50	0	230	−5	480	−10	1 180	−20
7010A	50	0	250	−5	530	−10	1 270	−20
7011A	50	0	250	−5	880	−15	1 270	−20
7012A	50	0	250	−5	930	−15	1 370	−20
7013A	50	0	270	−5	980	−15	1 470	−20
7014A	50	0	270	−5	1 080	−15	2 060	−25
7015A	50	0	280	−5	1 080	−15	2 160	−25
7016A	100	0	760	−10	1 770	−20	3 040	−30
7017A	100	0	780	−10	1 860	−20	3 240	−30
7018A	100	0	780	−10	2 450	−25	3 920	−35
7019A	100	0	810	−10	2 550	−25	4 120	−35
7020A	100	0	840	−10	2 750	−25	4 310	−35

Remarks In the axial clearance column, the measured value is given.

Table 7 Average preloads and axial clearance for bearing series 72A

Bearing No.	Extra light EL		Light L		Medium M		Heavy H	
	Preload (N)	Axial clearance (μm)	Preload (N)	Axial clearance (μm)	Preload (N)	Axial clearance (μm)	Preload (N)	Axial clearance (μm)
7200A	25	0	100	−5	210	−10	—	—
7201A	25	0	110	−5	220	−10	360	−15
7202A	25	0	110	−5	240	−10	390	−15
7203A	25	0	120	−5	250	−10	410	−15
7204A	25	0	260	−10	440	−15	650	−20
7205A	50	0	350	−10	580	−15	840	−20
7206A	50	0	380	−10	630	−15	910	−20
7207A	50	0	400	−10	660	−15	1 270	−25
7208A	50	0	440	−10	730	−15	1 470	−25
7209A	50	0	450	−10	1 080	−20	1 860	−30
7210A	50	0	480	−10	1 180	−20	2 060	−30
7211A	50	0	490	−10	1 670	−26	2 650	−35
7212A	50	0	510	−10	1 670	−25	2 750	−35
7213A	50	0	550	−10	1 860	−25	3 040	−35
7214A	100	0	1 080	−15	2 650	−30	3 920	−40
7215A	100	0	1 080	−15	2 750	−30	4 220	−40
7216A	100	0	1 080	−15	2 650	−30	4 020	−40
7217A	100	0	1 180	−15	3 430	−35	5 790	−50
7218A	100	0	1 670	−20	4 310	−40	5 980	−50
7219A	360	−5	1 670	−20	4 220	−40	6 670	−55
7220A	370	−5	1 670	−20	5 100	−45	7 650	−60

Remarks In the axial clearance column, the measured value is given.

6.4 Axial displacement of deep groove ball bearings

When an axial load F_a is applied to a radial bearing with a contact angle α_0 and the inner ring is displaced δ_a, the center Oi of the inner ring raceway radius is also moved to Oi' resulting in the contact angle α as shown in Fig. 1. If δ_N represents the elastic deformation of the raceway and ball in the direction of the rolling element load Q, Equation (1) is derived from Fig. 1.

$$(m_0+\delta_N)^2=(m_0\cdot\sin\alpha_0+\delta_a)^2+(m_0\cdot\cos\alpha_0)^2$$

$$\therefore\ \delta_N=m_0\left\{\sqrt{\left(\sin\alpha_0+\frac{\delta_a}{m_0}\right)^2+\cos^2\alpha_0}-1\right\} \quad \cdots\cdots\cdots\cdots (1)$$

Also there is the following relationship between the rolling element load Q and elastic deformation δ_N.

$$Q=K_N\cdot\delta_N^{3/2} \quad \cdots\cdots\cdots\cdots (2)$$

where, K_N: Constant depending on bearing material, type, and dimension

$\therefore$ If we introduce the relation of

$$m_0=\left(\frac{r_e}{D_w}+\frac{r_i}{D_w}-1\right)D_w=B\cdot D_w$$

Equations (1) and (2) are,

$$Q=K_N\ (B\cdot D_w)^{3/2}\left\{\sqrt{(\sin\alpha_0+h)^2+\cos^2\alpha_0}-1\right\}^{3/2}$$

where, $h=\dfrac{\delta_a}{m_0}=\dfrac{\delta_a}{B\cdot D_w}$

If we introduce the relation of $K_N=K\cdot\dfrac{\sqrt{D_w}}{B^{3/2}}$

$$Q=K\cdot D_w^{\,2}\left\{\sqrt{(\sin\alpha_0+h)^2+\cos^2\alpha_0}-1\right\}^{3/2} \quad \cdots\cdots\cdots\cdots (3)$$

On the other hand, the relation between the bearing axial load and rolling element load is shown in Equation (4) using Fig. 2:

$$F_a=Z\cdot Q\cdot\sin\alpha \quad \cdots\cdots\cdots\cdots (4)$$

Based on Fig. 1, we obtain,

$$(m_0+\delta_N)\ \sin\alpha=m_0\cdot\sin\alpha_0+\delta_a$$

$$\therefore\ \sin\alpha=\frac{m_0\cdot\sin\alpha_0+\delta_a}{m_0+\delta_N}=\frac{\sin\alpha_0+h}{1+\dfrac{\delta_N}{m_0}}$$

If we substitute Equation (1),

$$\sin\alpha=\frac{\sin\alpha_0+h}{\sqrt{(\sin\alpha_0+h)^2+\cos^2\alpha_0}} \quad \cdots\cdots\cdots\cdots (5)$$

That is, the relation between the bearing axial load F_a and axial displacement δ_a can be obtained by substituting Equations (3) and (5) for Equation (4).

$$F_a=K\cdot Z\cdot D_w^{\,2}\cdot\frac{\left\{\sqrt{(\sin\alpha_0+h)^2+\cos^2\alpha_0}-1\right\}^{3/2}\times(\sin\alpha_0+h)}{\sqrt{(\sin\alpha_0+h)^2+\cos^2\alpha_0}} \quad \cdots\cdots\cdots\cdots (6)$$

where, K: Constant depending on the bearing material and design
D_w: Ball diameter
Z: Number of balls
α_0: Initial contact angle
In case of single-row deep groove ball bearings, the initial contact angle can be obtained using Equation (5) of Section 4.6 (Page 96)

Actual axial deformation varies depending on the bearing mounting conditions, such as the material and thickness of the shaft and housing, and bearing fitting. For details, consult with NSK regarding the axial deformation after mounting.

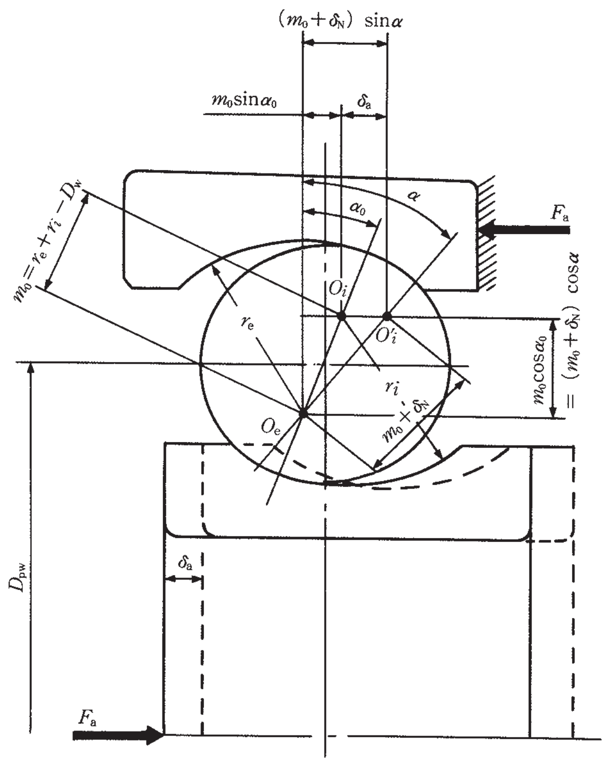


Fig. 1

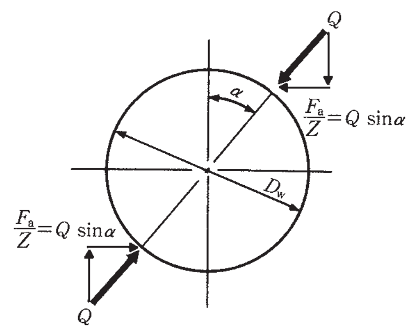


Fig. 2

Fig. 3 gives the relation between axial load and axial displacement for 6210 and 6310 single-row deep groove ball bearings with initial contact angles of α_0=0°, 10°, 15°. The larger the initial contact angle α_0, the more rigid the bearing will be in the axial direction and also the smaller the difference between the axial displacements of 6210 and 6310 under the same axial load. The angle α_0 depends upon the groove radius and the radial clearance.

Fig. 4 gives the relation between axial load and axial displacement for 72 series angular contact ball bearings with initial contact angles of 15° (C), 30° (A), and 40° (B). Because 70 and 73 series bearings with identical contact angles and bore diameters can be considered to have almost the same values as 72 series bearings.

Angular contact ball bearings that sustain loads in the axial direction must maintain their running accuracy and reduce the bearing elastic deformation from applied loads when used as multiple bearing sets with a preload applied.

To determine the preload to keep the elastic deformation caused by applied loads within the required limits, it is important to know the characteristics of load vs. deformation. The relationship between load and displacement can be expressed by Equation (6) as $F_a \propto \delta_a^{3/2}$ or $\delta_a \propto F_a^{3/2}$. That is, the axial displacement δ_a is proportional to the axial load F_a to the 2/3 power. When this axial load index is less than one, it indicates the relative axial displacement will be small with only a small increase in the axial load. (Fig. 4) The underlying reason for applying a preload is to reduce the amount of displacement.

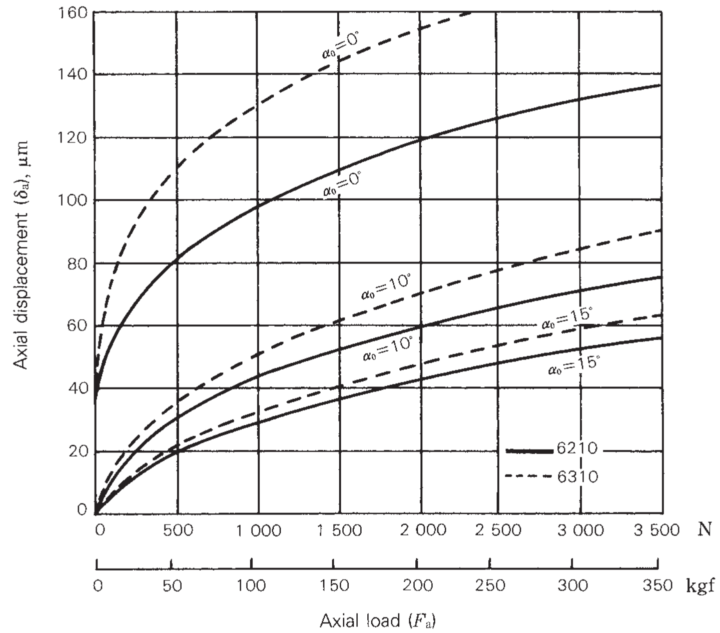


Fig. 3 Axial load and axial displacement of deep groove ball bearings

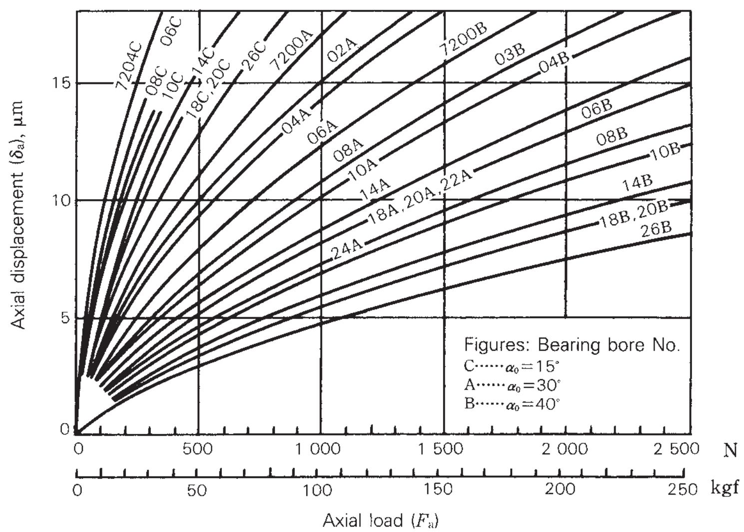


Fig. 4 Axial load and axial displacement of angular contact ball bearings

6.5 Axial displacement of tapered roller bearings

Tapered roller bearings are widely used in pairs like angular contact ball bearings. Care should be taken to select appropriate tapered roller bearings.

For example, the bearings of machine tool head spindles and automobile differential pinions are preloaded to increase shaft rigidity.

When a bearing with an applied preload is to be used in an application, it is essential to have some knowledge of the relationship between axial load and axial displacement. For tapered roller bearings, the axial displacement calculated using Palmgren's method, Equation (1) generally agrees well with actual measured values.

Actual axial deformation varies depending on the bearing mounting conditions, such as the material and thickness of the shaft and housing, and bearing fitting. For details, consult with NSK regarding the axial deformation after mounting.

$$\left.\begin{aligned}\delta_a &= \frac{0.000077}{\sin\alpha}\cdot\frac{Q^{0.9}}{L_{we}^{0.8}} \quad \text{(N)}\\ &= \frac{0.0006}{\sin\alpha}\cdot\frac{Q^{0.9}}{L_{we}^{0.8}} \quad \{\text{kgf}\}\end{aligned}\right\} \cdots\cdots\cdots (1)$$

where, δ_a: Axial displacement of inner, outer ring (mm)

α: Contact angle...1/2 the cup angle (°)

Q: Load on rolling elements (N), {kgf}

$$Q=\frac{F_a}{Z\sin\alpha}$$

L_{we}: Length of effective contact on roller (mm)

F_a: Axial load (N), {kgf}

Z: Number of rollers

Equation (1) can also be expressed as Equation (2).

$$\delta_a=K_a\cdot F_a^{0.9} \cdots\cdots\cdots (2)$$

where,

$$K_a=\frac{0.00007}{(\sin\alpha)^{1.9}\,Z^{0.9}\,L_{we}^{0.8}} \cdots\cdots\cdots \text{(N)}$$

$$=\frac{0.0006}{(\sin\alpha)^{1.9}\,Z^{0.9}\,L_{we}^{0.8}} \cdots\cdots\cdots \{\text{kgf}\}$$

Here, K_a: Coefficient determined by the bearing internal design.

Axial loads and axial displacement for tapered roller bearings are plotted in Fig. 1.

The amount of axial displacement of tapered roller bearings is proportional to the axial load raised to the 0.9 power. The displacement of ball bearings is proportional to the axial load raised to the 0.67 power, thus the preload required to control displacement is much greater for ball bearings than for tapered roller bearings.

Caution should be taken not to make the preload indiscriminately large on tapered roller bearings, since too large of a preload can cause excessive heat, seizure, and reduced bearing life.

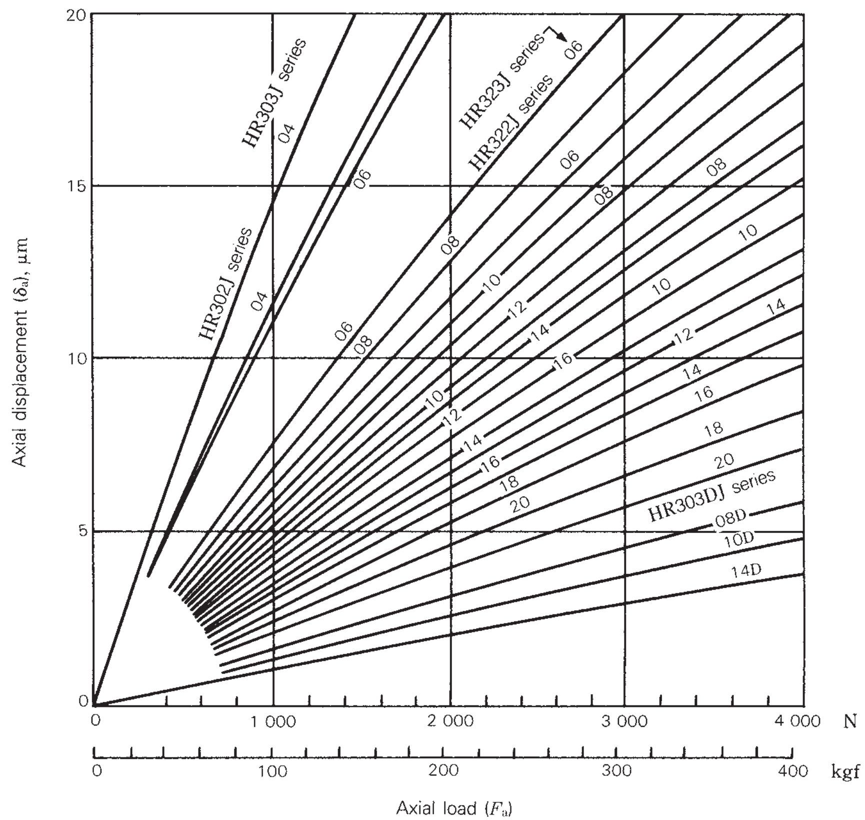


Fig. 1 Axial load and axial displacement for tapered roller bearings