3. Bearing fitting practice

3.1 Load classifications

Bearing loads can be classified in various ways. With respect to magnitude, loads are classified as light, medium, or heavy; with respect to time, they are called stationary, fluctuating, or shock; and with respect to direction, they are divided into rotating (or “circumferential”), stationary (or “spot”), or indeterminate. The terms, “rotating”, “static”, and “indeterminate”, do not apply to the bearing itself, but instead are used to describe the load acting on each of the bearing rings.

Whether an interference fit or a loose fit should be adopted depends on whether the load applied to the inner and outer rings is rotating or stationary. A so-called “rotating load” is one where the loading direction on a bearing ring changes continuously regardless of whether the bearing ring itself rotates or remains stationary. On the other hand, a so called “stationary load” is one where the loading direction on a bearing ring is the same regardless of whether the bearing ring itself rotates or remains stationary.

As an example, when the load direction on a bearing remains constant and the inner ring rotates and the outer ring stays fixed, a rotating load is applied to the inner ring and a stationary load to the outer ring. In the case that the majority of the bearing load is an unbalanced load due to rotation, even if the inner ring rotates and the outer ring stays fixed, a stationary load is applied to the inner ring and a rotating load to the outer ring. (See Table 1).

Depending on the actual conditions, the situation is not usually as simple as described above. The loads may vary in complex ways with the load direction being a combination of fixed and rotating loads caused by mass, by imbalance, by vibration, and by power transmission. If the load direction on a bearing ring is highly irregular or a rotating load and stationary load are applied alternatively, such a load is called an indeterminate load.

The fit of a bearing ring on which a rotating load is applied should generally be an interference fit. If a bearing ring, on which a rotating load is applied, is mounted with a loose fit, the bearing ring may slip on the shaft or in the housing and, if the load is heavy, the fitting surface may be damaged or fretting corrosion may occur. The tightness of the fit should be sufficient to prevent the interference from becoming zero as a result of the applied load and a temperature difference between the inner ring and shaft or between the outer ring and housing during operation. Depending on the operation conditions, the inner ring fitting is usually k5, m5, n6, etc. and for the outer ring, it is N7, P7, etc.

For large bearings, to avoid the difficulty of mounting and dismounting, sometimes a loose fit is adopted for the bearing ring on which a rotating load is applied. In such a case, the shaft material must be sufficiently hard, its surface must be well finished, and a lubricant needs to be applied to minimize damage due to slipping.

There is no problem with slipping between the shaft or housing for a bearing ring on which a stationary load is applied; therefore, a loose fit or transition fit can be used. The looseness of the fit depends on the accuracy required in use and the reduction in the load distribution range caused by bearing-ring deformation. For inner rings, g6, h6, js5(j5), etc. are often used, and for outer rings, H7, JS7(J7), etc.

For indeterminate loads, it cannot be determined easily, but in most cases, both the inner and outer rings are mounted with an interference fit.

Table 1 Rotating and stationary load of inner rings

Rotating load on inner ring	(1) When bearing load direction is constant, the inner ring rotates and the outer ring remains fixed. (2) When the inner ring remains fixed, the outer ring rotates, and the load direction rotates with the same speed as the outer ring (unbalanced load, etc.).
Static load on inner ring	(1) When the outer ring remains fixed, the inner ring rotates, and the load direction rotates with the same speed as the inner ring (unbalanced load, etc.). (2) When the load direction is constant, the outer ring rotates, and the inner ring remains fixed.

3.2 Required effective interference due to load

The magnitude of the load is an important factor in determining the fit (interference tolerance) of a bearing.

When a load is applied to the inner ring, it is compressed radially and, at the same time, it expands circumferentially a little; thereby, the initial interference is reduced.

To obtain the interference reduction of the inner ring, Equation (1) is usually used.

$$\left.\begin{aligned}\Delta d_F &= 0.08\sqrt{\frac{d}{B}}F_r\times10^{-3} \quad (\text{N})\\ &= 0.25\sqrt{\frac{d}{B}}F_r\times10^{-3} \quad \{\text{kgf}\}\end{aligned}\right\} \cdots\cdots\cdots\cdots (1)$$

where Δd_F: Interference reduction of inner ring due to load (mm)
d: Inner ring bore diameter (mm)
B: Inner ring width (mm)
F_r: Radial load (N), {kgf}

Therefore, the effective interference Δd should be larger than the interference given by Equation (1).

The interference given by Equation (1) is sufficient for relatively low loads (less than about 0.2 C_{0r} where C_{0r} is the static load rating. For most general applications, this condition applies). However, under special conditions where the load is heavy (when F_r is close to C_{0r}), the interference becomes insufficient.

For heavy radial loads exceeding 0.2 C_{0r}, it is better to rely on Equation (2).

$$\left.\begin{aligned}\Delta d &\geqq 0.02\frac{F_r}{B}\times10^{-3} \quad (\text{N})\\ &\geqq 0.2\frac{F_r}{B}\times10^{-3} \quad \{\text{kgf}\}\end{aligned}\right\} \cdots\cdots\cdots\cdots (2)$$

where Δd: Required effective interference due to load (mm)
B: Inner ring width (mm)
F_r: Radial load (N), {kgf}

Creep experiments conducted by NSK with NU219 bearings showed a linear relation between radial load (load at creep occurrence limit) and required effective interference. It was confirmed that this line agrees well with the straight line of Equation (2).

For NU219, with the interference given by Equation (1) for loads heavier than 0.25 C_{0r}, the interference becomes insufficient and creep occurs.

Generally speaking, the necessary interference for loads heavier than 0.25 C_{0r} should be calculated using Equation (2). When doing this, sufficient care should be taken to prevent excessive circumferential stress.

Calculation example

For NU219, B=32 (mm) and assume
F_r=98 100 N {10 000 kgf}
C_{0r}=183 000 N {18 600 kgf}

$$\frac{F_r}{C_{0r}}=\frac{98\ 100}{183\ 000}=0.536>0.2$$

Therefore, the required effective interference is calculated using Equation (2).

$$\Delta d=0.02\times\frac{98\ 100}{32}\times10^{-3}=0.061\ (\text{mm})$$

This result agrees well with Fig. 1.

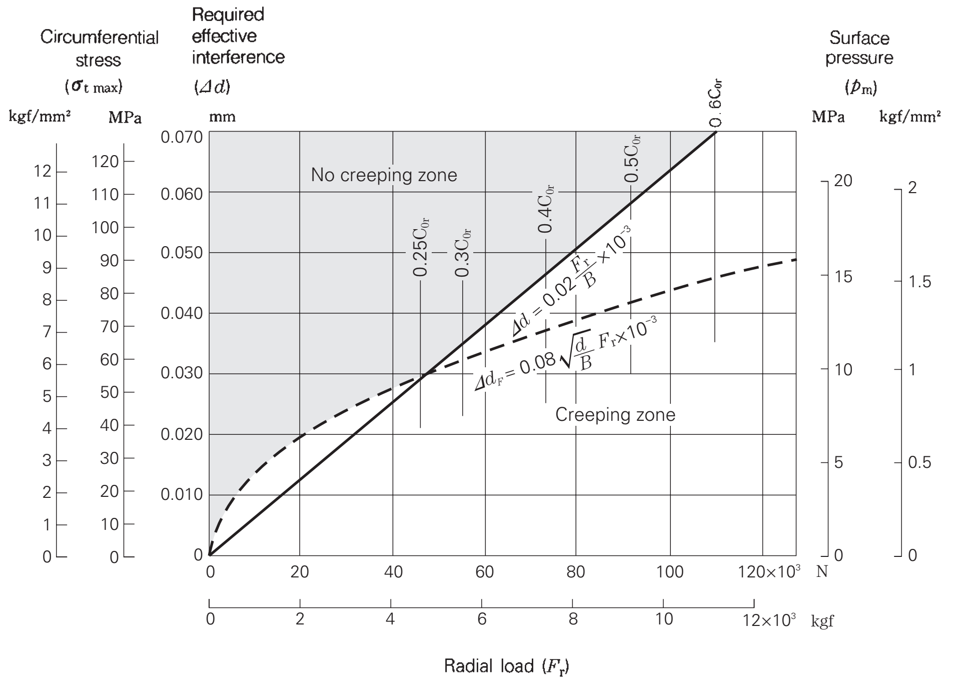


Fig. 1 Load and required effective interference for fit

3.3 Interference deviation due to temperature rise (aluminum housing, plastic housing)

For reducing weight and cost or improving the performance of equipment, bearing housing materials such as aluminum, light alloys, or plastics (polyacetal resin, etc.) are often used.

When non-ferrous materials are used in housings, any temperature rise occurring during operation affects the interference or clearance of the outer ring due to the difference in the coefficients of linear expansion. This change is large for plastics which have high coefficients of linear expansion.

The deviation ΔD_T of clearance or interference of a fitting surface of a bearing's outer ring due to temperature rise is expressed by the following equation:

$$\Delta D_T=(\alpha_1 \cdot \Delta T_1-\alpha_2 \cdot \Delta T_2)D \text{ (mm)} \quad \cdots\cdots (1)$$

where ΔD_T: Change of clearance or interference at fitting surface due to temperature rise

α_1: Coefficient of linear expansion of housing (1/°C)

ΔT_1: Housing temperature rise near fitting surface (°C)

α_2: Coefficient of linear expansion of bearing outer ring
Bearing steel .... $\alpha_2=12.5\times10^{-6}$ (1/°C)

ΔT_2: Outer ring temperature rise near fitting surface (°C)

D: Bearing outside diameter (mm)

In general, the housing temperature rise and that of the outer ring are somewhat different, but if we assume they are approximately equal near the fitting surfaces, ($\Delta T_1 \fallingdotseq \Delta T_2=\Delta T$), Equation (1) becomes,

$$\Delta D_T=(\alpha_1-\alpha_2)\ \Delta T \cdot D \text{ (mm)} \quad \cdots\cdots (2)$$

where ΔT: Temperature rise of outer ring and housing near fitting surfaces (°C)

In the case of an aluminum housing (α_1=23.7×10^{-6}), Equation (2) can be shown graphically as in Fig. 1.

Among the various plastics, polyacetal resin is one that is often used for bearing housings. The coefficients of linear expansion of plastics may vary or show directional characteristics. In the case of polyacetal resin, for molded products, it is approximately 9×10^{-5}. Equation (2) can be shown as in Fig. 2.

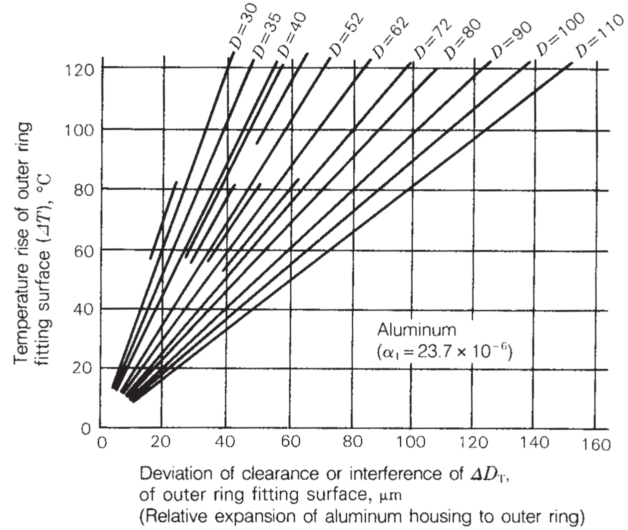


Fig. 1 Aluminum housing

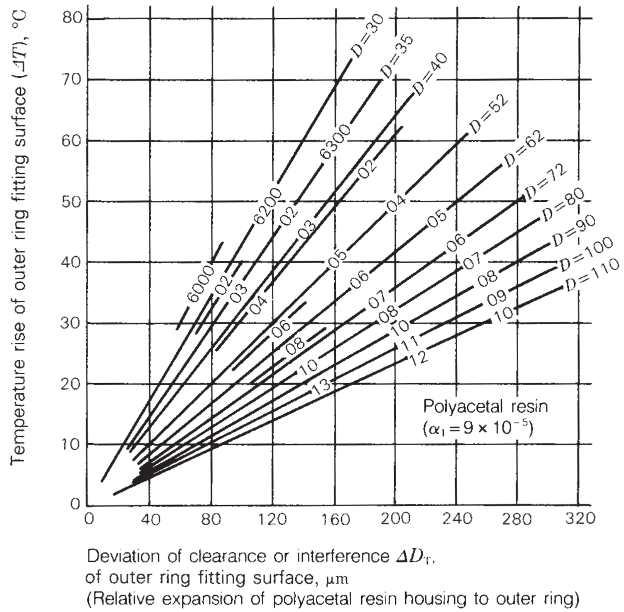


Fig. 2 Polyacetal resin housing

3.4 Fit calculation

It is easier to mount a bearings with a loose fit than with an interference fit. However, if there is clearance between the fitting surfaces or too little interference, depending on the loading condition, creep may occur and damage the fitting surfaces; therefore, a sufficient interference must be chosen to prevent such damage.

The most common loading condition is to have a fixed load and fixed direction with the inner ring (i.e. shaft) rotating and the outer ring stationary. This condition is referred to as a rotating load on the inner ring or a stationary load on the outer ring. In other words, a circumferential load is applied to the inner ring and a spot load on the outer ring.

In the case of automobile wheels, a circumferential load is applied to the outer ring (rotating load on outer ring) and a spot load on the inner ring. In any case, for a spot load, the interference can be almost negligible, but it must be tight for the bearing ring to which a circumferential load is applied.

For indeterminate loads caused by unbalanced weight, vibration, etc., the magnitude of the interference should be almost the same as for circumferential loads. The interference appropriate for the tolerances of the shaft and housing given in the bearing manufacturer's catalog is sufficient for most cases.

If a bearing ring is mounted with interference, the ring becomes deformed and stress is generated. This stress is calculated in the same way as for thick-walled cylinders to which uniform internal and external pressures are applied. The equations for both inner and outer rings are summarized in Table 1. The Young's modulus and Poisson's ratio for the shaft and housing are assumed to be the same as for the inner and outer rings.

What we obtain by measurement is called "apparent interference", but what is necessary is "effective interference" (Δd and ΔD given in Table 1 are effective interferences). Since the effective interference is related to the reduction of bearing internal clearance caused by fit, the relation between apparent interference and effective interference is important.

The effective interference is less than the apparent interference mainly due to the deformation of the fitting surface caused by the fit.

The relation between apparent interference Δd_a and effective interference Δd is not necessarily uniform. Usually, the following equations can be used though they differ a little from empirical equations due to roughness.

For ground shafts: $\Delta d = \frac{d}{d+2} \Delta d_a$ (mm)

For machined shafts: $\Delta d = \frac{d}{d+3} \Delta d_a$ (mm)

Satisfactory results can be obtained by using the nominal bearing ring diameter when estimating the expansion/contraction of a ring to correct the internal bearing clearance. It is not necessary to use the mean outside diameter (or mean bore diameter) which gives an equal cross sectional area.

Table 1 Fit conditions

	Inner ring and shaft	Outer ring and housing
Surface pressure p_m (MPa) {kgf/mm²}	Hollow shaft $p_m = \frac{\Delta d}{d} \frac{1}{\left[\frac{m_s-1}{m_s E_s} - \frac{m_i-1}{m_i E_i}\right] + 2\left[\frac{k_0^2}{E_s(1-k_0^2)} + \frac{1}{E_i(1-k_2)}\right]}$ Solid shaft $p_m = \frac{\Delta d}{d} \frac{1}{\left[\frac{m_s-1}{m_s E_s} - \frac{m_i-1}{m_i E_i}\right] + \frac{2}{E_i(1-k^2)}}$	Housing outside diameter $p_m = \frac{\Delta D}{D} \frac{1}{\left[\frac{m_e-1}{m_e E_e} - \frac{m_h-1}{m_h E_h}\right] + 2\left[\frac{h^2}{E_e(1-h^2)} + \frac{1}{E_h(1-h_0^2)}\right]}$
Expansion of inner ring raceway ΔD_i (mm) Contraction of outer ring raceway ΔD_e (mm)	$\Delta D_i = 2d \frac{p_m}{E_i} \frac{k}{1-k^2}$ $= \Delta d \cdot k \frac{1-k_0^2}{1-k^2 k_0^2}$ (hollow shaft) $= \Delta d \cdot k$ (solid shaft)	$\Delta D_e = 2D \frac{p_m}{E_e} \frac{h}{1-h^2}$ $= \Delta D \cdot h \frac{1-h_0^2}{1-h^2 h_0^2}$
Maximum stress $\sigma_{t\,max}$ (MPa) {kgf/mm²}	Circumferential stress at inner ring bore fitting surface is maximum. $\sigma_{t\,max} = p_m \frac{1+k^2}{1-k^2}$	Circumferential stress at outer ring bore surface is maximum. $\sigma_{t\,max} = p_m \frac{2}{1-h^2}$
Symbols	d : Shaft diameter, inner ring bore d_0: Hollow shaft bore D_i: Inner ring raceway diameter $k = d/D_i$, $k_0 = d_0/d$ E_i: Inner ring Young's modulus, 208 000 MPa {21 200 kgf/mm²} E_s: Shaft Young's modulus m_i: Inner ring poisson's number, 3.33 m_s: Shaft poisson's number	D : Housing bore diameter, outer ring outside diameter D_0: Housing outside diameter D_e: Outer ring raceway diameter $h = D_e/D$, $h_0 = D/D_0$ E_e: Outer ring Young's modulus, 208 000 MPa {21 200 kgf/mm²} E_h: Housing Young's modulus m_e: Outer ring poisson's number, 3.33 m_h: Housing poisson's number

3.5 Surface pressure and maximum stress on fitting surfaces

In order for rolling bearings to achieve their full life expectancy, their fitting must be appropriate. Usually for an inner ring, which is the rotating ring, an interference fit is chosen, and for a fixed outer ring, a loose fit is used. To select the fit, the magnitude of the load, the temperature differences among the bearing and shaft and housing, the material characteristics of the shaft and housing, the level of finish, the material thickness, and the bearing mounting/dismounting method must all be considered.

If the interference is insufficient for the operating conditions, ring loosening, creep, fretting, heat generation, etc. may occur. If the interference is excessive, the ring may crack. The magnitude of the interference is usually satisfactory if it is set for the size of the shaft or housing listed in the bearing manufacturer's catalog. To determine the surface pressure and stress on the fitting surfaces, calculations can be made assuming a thick-walled cylinder with uniform internal and external pressures. To do this, the necessary equations are summarized in Section 3.4 "Fit calculation". For convenience in the fitting of bearing inner rings on solid steel shafts, which are the most common, the surface pressure and maximum stress are shown in Figs. 2 and 3.

Fig. 2 shows the surface pressure p_m and maximum stress $\sigma_{t\ max}$ variations with shaft diameter when interference results from the mean values of the tolerance grade shaft and bearing bore tolerances. Fig. 3 shows the maximum surface pressure p_m and maximum stress $\sigma_{t\ max}$ when maximum interference occurs.

Fig. 3 is convenient for checking whether $\sigma_{t\ max}$ exceeds the tolerances. The tensile strength of hardened bearing steel is about 1 570 to 1 960 MPa {160 to 200 kgf/mm^2}. However, for safety, plan for a maximum fitting stress of 127 MPa {13 kgf/mm^2}. For reference, the distributions of circumferential stress σ_t and radial stress σ_r in an inner ring are shown in Fig. 1.

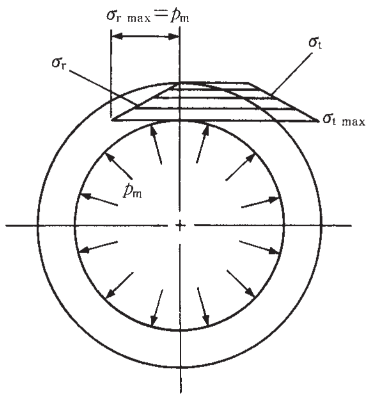


Fig. 1 Distribution of circumferential stress σ_t and radial stress σ_r

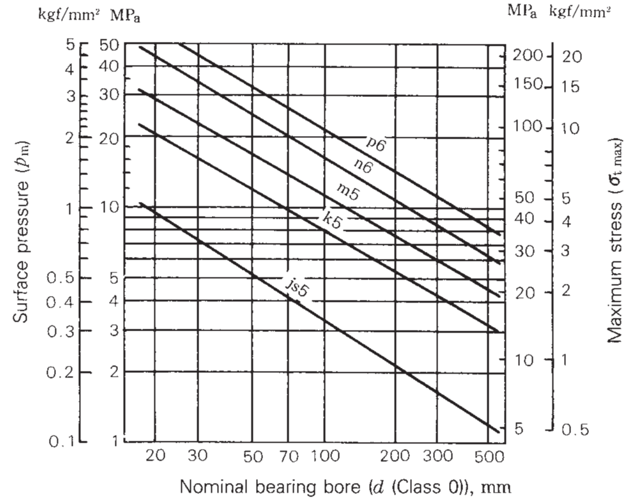


Fig. 2 Surface pressure p_m and maximum stress $\sigma_{t\ max}$ for mean interference in various tolerance grades

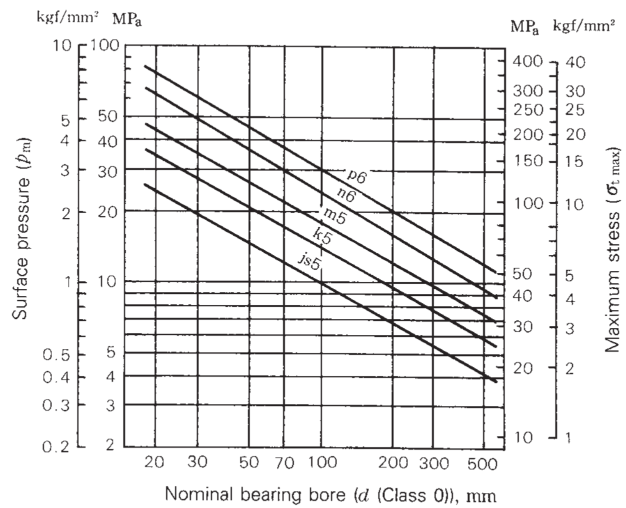


Fig. 3 Surface pressure p_m and maximum stress $\sigma_{t\ max}$ for maximum interference in various tolerance grades

3.6 Mounting and withdrawal loads

The push-up load needed to mount bearings on shafts or in a housing hole with interference can be obtained using the thick-walled cylinder theory.

The mounting load (or withdrawal load) depends upon the contact area, surface pressure, and coefficient of friction between the fitting surfaces.

The mounting load (or withdrawal load) K needed to mount inner rings on shafts is given by Equation (1).

$$K = \mu\, p_m\, \pi\, d\, B \text{ (N), \{kgf\}} \quad \cdots\cdots (1)$$

where μ: Coefficient of friction between fitting surfaces
μ=0.12 (for mounting)
μ=0.18 (for withdrawal)

p_m: Surface pressure (MPa), {kgf/mm^2}
For example, inner ring surface pressure can be obtained using Table 1 (Page 69)

$$p_m = \frac{E}{2}\,\frac{\Delta d}{d}\,\frac{(1-k^2)\,(1-k_0^2)}{1-k^2\,k_0^2}$$

d: Shaft diameter (mm)
B: Bearing width (mm)
Δd: Effective interference (mm)
E: Young's modulus of steel (MPa), {kgf/mm^2}
E=208 000 MPa {21 200 kgf/mm^2}
k: Inner ring thickness ratio
$k = d/D_i$
D_i: Inner ring raceway diameter (mm)
k_0: Hollow shaft thickness ratio
$k_0 = d_0/d$
d_0: Bore diameter of hollow shaft (mm)

For solid shafts, d_0=0, consequently k_0=0. The value of k varies depending on the bearing type and size, but it usually ranges between k=0.7 and 0.9. Assuming that k=0.8 and the shaft is solid, Equation (1) is:

$$\left.\begin{aligned} K &= 118\,000\mu\, \Delta d\, B \text{ (N)} \\ &= 12\,000\mu\, \Delta d\, B \text{ \{kgf\}} \end{aligned}\right\} \quad \cdots\cdots (2)$$

Equation (2) is shown graphically in Fig. 1. The mounting and withdrawal loads for outer rings and housings have been calculated and the results are shown in Fig. 2.

The actual mounting and withdrawal loads can become much higher than the calculated values if the bearing ring and shaft (or housing) are slightly misaligned or the load is applied unevenly to the circumference of the bearing ring hole. Consequently, the loads obtained from Figs. 1 and 2 should be considered only as guides when designing withdrawal tools, their strength should be five to six times higher than that indicated by the figures.

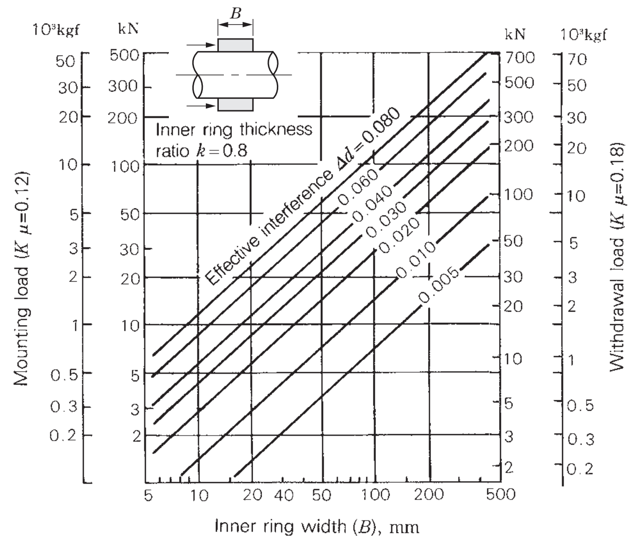


Fig. 1 Mounting and withdrawal loads for inner rings

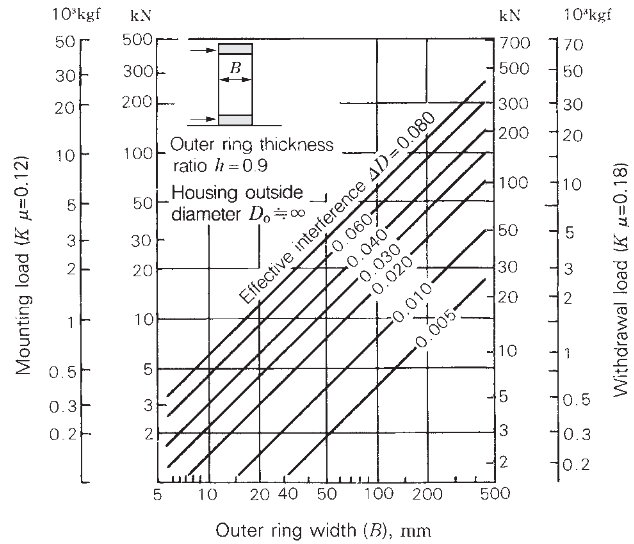


Fig. 2 Mounting and withdrawal loads for outer rings

3.7 Tolerances for bore diameter and outside diameter

The accuracy of the inner-ring bore diameter and outer-ring outside diameter and the width of rolling bearings is specified by JIS which complies with ISO.

In the previous JIS, the upper and lower dimensional tolerances were adopted to the average diameter of the entire bore or outside surfaces (d_m or D_m) regarding the dimensions of inner ring bore diameter and outer ring outside diameter which are important for fitting the shaft and housing.

Consequently, a standard was introduced for the upper and lower dimensional tolerances concerning the bore diameter, d, and outside diameter, D. However, there was no standard for the profile deviation like bore and outside out-of-roundness and cylindricity. Each bearing manufacturer specified independently the tolerances or criteria of the ellipse and cylindricity based on the maximum and minimum tolerances of d_m or D_m and d or D.

In the new JIS (JIS B 1514 : 1986, revised in July 1, 1986, Accuracy of rolling bearings) matched to ISO standards, tolerances, Δ_{dmpI}, Δ_{dmpII}, ... and Δ_{DmpI}, Δ_{DmpII}, ..., of the bore and outside mean diameters in a single radial plane, d_{mpI}, d_{mpII}, ... and D_{mpI}, D_{mpII}, ..., are within the allowable range between upper and lower limits.

The new JIS specifies the maximum values of bore and outside diameter variations within a single plane, V_{dp} and V_{Dp} which are equivalent to the out-of-roundness. Regarding the cylindricity, JIS also specifies the maximum values of the variations of mean bore diameters and mean outside diameters in a single radial plane, V_{dmp} and V_{Dmp}.

Table 1 Tolerances of radial bearing inner rings (Accuracy Class 0) except tapered roller bearings

Units: μm

Nominal bore diameter d (mm)		Single plane mean bore diameter deviation Δ_{dmp}		Bore diameter variation in a plane V_{dp} — Diameter series 7, 8, 9	0, 1	2, 3, 4	Mean bore diameter variation V_{dmp}	Radial runout of inner ring K_{ia}	Deviation of inner or outer ring width Δ_{Bs} (or Δ_{Cs}) — Single bearing		Matched set bearing(1)		Inner ring width variation V_{Bs}
over	incl	high	low	max.			max.	max.	high	low	high	low	max.
omitted	omitted	omitted	omitted	omitted	omitted	omitted	omitted	omitted	omitted	omitted	omitted	omitted	omitted
10	**18**	0	− 8	10	8	6	6	10	0	−120	0	−250	20
18	**30**	0	−10	13	10	8	8	13	0	−120	0	−250	20
30	**50**	0	−12	15	12	9	9	15	0	−120	0	−250	20
50	**80**	0	−15	19	19	11	11	20	0	−150	0	−380	25
80	**120**	0	−20	25	25	15	15	25	0	−200	0	−380	25
120	**180**	0	−25	31	31	19	19	30	0	−250	0	−500	30
omitted	omitted	omitted	omitted	omitted	omitted	omitted	omitted	omitted	omitted	omitted	omitted	omitted	omitted

Note (1) Applicable to individual rings manufactured for combined bearings.

[All radial planes]

$$d_m = \frac{d_s\ (\text{max.}) + d_s\ (\text{min.})}{2}$$

$$= \frac{d_{spI}\ (\text{max.}) + d_{spII}\ (\text{min.})}{2}$$

[Radial plane I]

$$d_{mpI} = \frac{d_{spI}\ (\text{max.}) + d_{spI}\ (\text{min.})}{2}$$

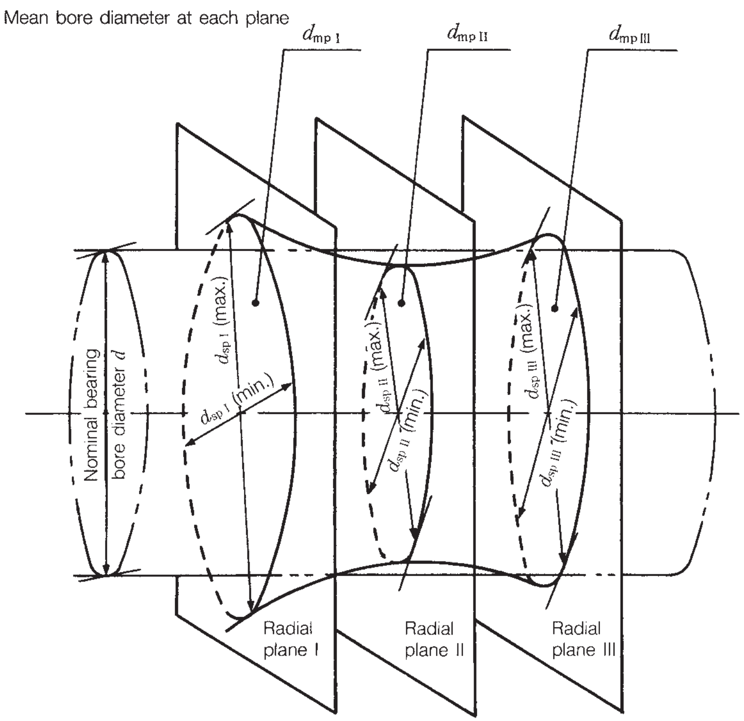
$$\Delta_{DmpI} = d_{mpI} - d$$

$$V_{dpI} = d_{spI}\ (\text{max.}) - d_{spI}\ (\text{min.})$$

[Three radial planes]

$$V_{dmp} = d_{mpI} - d_{mpII}$$

Suffix "s" means single measurement, "p" means radial plane.



3.8 Interference and clearance for fitting (shafts and inner rings)

The tolerances on bore diameter d and outside diameter D of rolling bearings are specified by ISO. For tolerance Class 0, js5(j5), k5, and m5 are commonly used for shafts and H7, JS7(J7) housings. The class of fit that should be used is given in the catalogs of bearing manufacturers. The maximum and minimum interference for the fit of shafts and inner rings for each fitting class are given in Table 1. The recommended fits given in catalogs are target values; therefore, the machining of shafts and housings should be performed aiming at the center of the respective tolerances.

Table 1 Interferences and clearances for inner ring and shaft fit

Units: μm

Nominal size (mm)		Bearing single plane mean bore diameter deviation (Bearing: Normal class) Δd_{mp}		Interferences or clearances													
				f6		g5		g6		h5		h6		js5		j5	
				Clearance		Clearance	Interference	Clearance	Interference	Clearance	Interference	Clearance	Interference	Clearance	Interference	Clearance	Interference
over	incl	high	low	max.	min	max.	max.	max.	max.	max.	max.	max.	max.	max.	max.	max.	max.
3	**6**	0	−8	18	2	9	4	12	4	5	8	8	8	—	—	—	—
6	**10**	0	−8	22	5	11	3	14	3	6	8	9	8	3	11	2	12
10	**18**	0	−8	27	8	14	2	17	2	8	8	11	8	4	12	3	13
18	**30**	0	−10	33	10	16	3	20	3	9	10	13	10	4.5	14.5	4	15
30	**50**	0	−12	41	13	20	3	25	3	11	12	16	12	5.5	17.5	5	18
50	**65**	0	−15	49	15	23	5	29	5	13	15	19	15	6.5	21.5	7	21
65	**80**	0	−15	49	15	23	5	29	5	13	15	19	15	6.5	21.5	7	21
80	**100**	0	−20	58	16	27	8	34	8	15	20	22	20	7.5	27.5	9	26
100	**120**	0	−20	58	16	27	8	34	8	15	20	22	20	7.5	27.5	9	26
120	**140**	0	−25	68	18	32	11	39	11	18	25	25	25	9	34	11	32
140	**160**	0	−25	68	18	32	11	39	11	18	25	25	25	9	34	11	32
160	**180**	0	−25	68	18	32	11	39	11	18	25	25	25	9	34	11	32
180	**200**	0	−30	79	20	35	15	44	15	20	30	29	30	10	40	13	37
200	**225**	0	−30	79	20	35	15	44	15	20	30	29	30	10	40	13	37
225	**250**	0	−30	79	20	35	15	44	15	20	30	29	30	10	40	13	37
250	**280**	0	−35	88	21	40	18	49	18	23	35	32	35	11.5	46.5	16	42
280	**315**	0	−35	88	21	40	18	49	18	23	35	32	35	11.5	46.5	16	42
315	**355**	0	−40	98	22	43	22	54	22	25	40	36	40	12.5	52.5	18	47
355	**400**	0	−40	98	22	43	22	54	22	25	40	36	40	12.5	52.5	18	47
400	**450**	0	−45	108	23	47	25	60	25	27	45	40	45	13.5	58.5	20	52
450	**500**	0	−45	108	23	47	25	60	25	27	45	40	45	13.5	58.5	20	52

for each shaft tolerance																						Nominal size (mm)	
js6		j6		k5		k6		m5		m6		n6		p6		r6							
Clearance	Interference	Clearance	Interference	Interference		Interference		Interference		Interference		Interference		Interference		Interference							
max.	max.	max.	max.	min.	max.	min.	max.	min.	max.	min.	max.	min.	max.	min.	max.	min.	max.					over	incl
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—					**3**	**6**
4.5	12.5	2	15	—	—	—	—	—	—	—	—	—	—	—	—	—	—					**6**	**10**
5.5	13.5	3	16	—	—	—	—	—	—	—	—	—	—	—	—	—	—					**10**	**18**
6.5	16.5	4	19	2	21	2	25	—	—	—	—	—	—	—	—	—	—					**18**	**30**
8	20	5	23	2	25	2	30	9	32	9	37	—	—	—	—	—	—					**30**	**50**
9.5	24.5	7	27	2	30	2	36	11	39	11	45	—	—	—	—	—	—					**50**	**65**
9.5	24.5	7	27	2	30	2	36	11	39	11	45	20	54	—	—	—	—					**65**	**80**
11	31	9	33	3	38	3	45	13	48	13	55	23	65	37	79	—	—					**80**	**100**
11	31	9	33	3	38	3	45	13	48	13	55	23	65	37	79	—	—					**100**	**120**
12.5	37.5	11	39	3	46	3	53	15	58	15	65	27	77	43	93	63	113					**120**	**140**
12.5	37.5	11	39	3	46	3	53	15	58	15	65	27	77	43	93	65	115					**140**	**160**
12.5	37.5	11	39	3	46	3	53	15	58	15	65	27	77	43	93	68	118					**160**	**180**
14.5	44.5	13	46	4	54	4	63	17	67	17	76	31	90	50	109	77	136					**180**	**200**
14.5	44.5	13	46	4	54	4	63	17	67	17	76	31	90	50	109	80	139					**200**	**225**
14.5	44.5	13	46	4	54	4	63	17	67	17	76	31	90	50	109	84	143					**225**	**250**
16	51	16	51	4	62	4	71	20	78	20	87	34	101	56	123	94	161					**250**	**280**
16	51	16	51	4	62	4	71	20	78	20	87	34	101	56	123	98	165					**280**	**315**
18	58	18	58	4	69	4	80	21	86	21	97	37	113	62	138	108	184					**315**	**355**
18	58	18	58	4	69	4	80	21	86	21	97	37	113	62	138	114	190					**355**	**400**
20	65	20	65	5	77	5	90	23	95	23	108	40	125	68	153	126	211					**400**	**450**
20	65	20	65	5	77	5	90	23	95	23	108	40	125	68	153	132	217					**450**	**500**

Remarks 1. The interference figures are omitted if the stress due to fit between inner ring and shaft is excessive.
2. From now on the js class in recommended instead of the j class.

3.9 Interference and clearance for fitting (housing holes and outer rings)

The maximum and minimum interference for the fit between housings and outer rings are shown in Table 1. Inner rings are interference fitted in most cases, but the usual fit for outer rings is generally a loose or transition fit. With the J6 or N7 classes as shown in the Table 1, if the combination is a transition fit with a maximum size hole and minimum size bearing O.D., there will be a clearance between them. Conversely, if the combination is one with a minimum size hole and maximum size bearing O.D., there will be interference.

If the bearing load is a rotating load on the inner ring, there is no problem with a loose fit (usually H7) of the outer ring. If the loading direction on the outer ring rotates or fluctuates, the outer ring must also be mounted with interference. In such cases, the load characteristics determine whether it shall be a full interference fit or a transition fit with a target interference specified.

Table 1 Interference and clearance of fit of outer rings with housing

Units: μm

Nominal size (mm)		Bearing single plane mean outside diameter deviation (Bearing: Normal class) ΔD_{mp}		Interferences or clearances													
				G7		H6		H7		H8		J6		JS6		J7	
				Clearance		Clearance		Clearance		Clearance		Clearance	Interference	Clearance	Interference	Clearance	Interference
over	incl	high	low	max.	min.	max.	min.	max.	min.	max.	min.	max.	max.	max.	max.	max.	max.
6	**10**	0	− 8	28	5	17	0	23	0	30	0	13	4	12.5	4.5	16	7
10	**18**	0	− 8	32	6	19	0	26	0	35	0	14	5	13.5	5.5	18	8
18	**30**	0	− 9	37	7	22	0	30	0	42	0	17	5	15.5	6.5	21	9
30	**50**	0	−11	45	9	27	0	36	0	50	0	21	6	19	8	25	11
50	**80**	0	−13	53	10	32	0	43	0	59	0	26	6	22.5	9.5	31	12
80	**120**	0	−15	62	12	37	0	50	0	69	0	31	6	26	11	37	13
120	**150**	0	−18	72	14	43	0	58	0	81	0	36	7	30.5	12.5	44	14
150	**180**	0	−25	79	14	50	0	65	0	88	0	43	7	37.5	12.5	51	14
180	**250**	0	−30	91	15	59	0	76	0	102	0	52	7	44.5	14.5	60	16
250	**315**	0	−35	104	17	67	0	87	0	116	0	60	7	51	16	71	16
315	**400**	0	−40	115	18	76	0	97	0	129	0	69	7	58	18	79	18
400	**500**	0	−45	128	20	85	0	108	0	142	0	78	7	65	20	88	20
500	**630**	0	−50	142	22	94	0	120	0	160	0	—	—	72	22	—	—
630	**800**	0	−75	179	24	125	0	155	0	200	0	—	—	100	25	—	—
800	**1 000**	0	−100	216	26	156	0	190	0	240	0	—	—	128	28	—	—

for each housing tolerance																		Nominal size (mm)	
JS7		K6		K7		M6		M7		N6		N7		P6		P7			
Clearance	Interference	Clearance	Interference	Clearance	Interference	Clearance	Interference	Clearance	Interference	Clearance	Interference	Clearance	Interference	Interference		Interference			
max.	max.	max.	max.	max.	max.	max.	max.	max.	max.	max.	max.	max.	max.	min.	max.	min.	max.	over	incl
15	7	10	7	13	10	5	12	8	15	1	16	4	19	4	21	1	24	**6**	**10**
17	9	10	9	14	12	4	15	8	18	1([1])	20	3	23	7	26	3	29	**10**	**18**
19	10	11	11	15	15	5	17	9	21	2([1])	24	2	28	9	31	5	35	**18**	**30**
23	12	14	13	18	18	7	20	11	25	1([1])	28	3	33	10	37	6	42	**30**	**50**
28	15	17	15	22	21	8	24	13	30	1([1])	33	4	39	13	45	8	51	**50**	**80**
32	17	19	18	25	25	9	28	15	35	1([1])	38	5	45	15	52	9	59	**80**	**120**
38	20	22	21	30	28	10	33	18	40	2([1])	45	6	52	18	61	10	68	**120**	**150**
45	20	29	21	37	28	17	33	25	40	5	45	13	52	11	61	3	68	**150**	**180**
53	23	35	24	43	33	22	37	30	46	8	51	16	60	11	70	3	79	**180**	**250**
61	26	40	27	51	36	26	41	35	52	10	57	21	66	12	79	1	88	**250**	**315**
67	28	47	29	57	40	30	46	40	57	14	62	24	73	11	87	1	98	**315**	**400**
76	31	53	32	63	45	35	50	45	63	18	67	28	80	10	95	0	108	**400**	**500**
85	35	50	44	50	70	24	70	24	96	6	88	6	114	28	122	28	148	**500**	**630**
115	40	75	50	75	80	45	80	45	110	25	100	25	130	13	138	13	168	**630**	**800**
145	45	100	56	100	90	66	90	66	124	44	112	44	146	0	156	0	190	**800**	**1 000**

Note ([1]) Minimum interferences are listed.

Remarks In the future, JS class in recommended instead of J class.

3.10 Interference dispersion (shafts and inner rings)

The residual clearance in bearings is calculated by subtracting from the initial radial clearance the expansion or contraction of the bearing rings caused by their fitting.

In this residual clearance calculation, usually the pertinent bearing dimensions (shaft diameter, bore diameter of inner ring, bore diameter of housing, outside diameter of outer ring) are assumed to have a normal (Guassian) distribution within their respective tolerance specifications.

If the shaft diameter and inner-ring bore diameter both have normal (Gaussian) distributions and their reject ratios are the same, then the range of distribution of interference R (dispersion) that has the same reject ratio as the shaft and inner-ring bore is given by the following equation:

$$R=\sqrt{R_s^2+R_i^2} \qquad (1)$$

where R_s: Shaft diameter tolerance (range of specification)

R_i: Inner-ring bore diameter tolerance (range of specification)

The mean interference and its dispersion R based on the tolerances on inner-ring bore diameters d of radial bearings of Normal Class and shafts of Classes 5 and 6 are shown in Table 1.

Table 1 Mean value and dispersion of interference for fitting of inner rings with shafts

Units: μm

Nominal size (mm)		Bearing single plane mean bore diameter deviation (Bearing: Normal class) Δd_{mp}		Fit with Class 5 shaft						Fit with Class 6 shaft								
				Mean value of interference					Dispersion of interference	Mean value of interference ([1])								Dispersion of interference
over	incl	high	low	h5	js5	j5	k5	m5	$R=\sqrt{R_s^2+R_i^2}$	h6	js6	j6	k6	m6	n6	p6	r6	$R=\sqrt{R_s^2+R_i^2}$
—	3	0	−8	2	4	4	6	8	±4.5	1	4	5	7	9	11	13	17	±5
3	6	0	−8	1.5	4	4.5	7.5	10.5	±4.5	0	4	6	9	12	16	20	23	±5.5
6	10	0	−8	1	4	5	8	13	±5	−0.5	4	6.5	9.5	14.5	18.5	23.5	27.5	±6
10	18	0	−8	0	4	5	9	15	±5.5	−1.5	4	6.5	10.5	16.5	21.5	27.5	32.5	±7
18	30	0	−10	0.5	5	5.5	11.5	17.5	±6.5	−1.5	5	7.5	13.5	19.5	26.5	33.5	39.5	±8
30	50	0	−12	0.5	6	6.5	13.5	20.5	±8	−2	6	9	16	23	31	40	48	±10
50	65	0	−15	1	7.5	7	16	25	±10	−2	7.5	10	19	28	37	49	58	±12
65	80	0	−15	1	7.5	7	16	25	±10	−2	7.5	10	19	28	37	49	60	±12
80	100	0	−20	2.5	10	8.5	20.5	30.5	±12.5	−1	10	12	24	34	44	58	72	±15
100	120	0	−20	2.5	10	8.5	20.5	30.5	±12.5	−1	10	12	24	34	44	58	75	±15
120	140	0	−25	3.5	12.5	10.5	24.5	36.5	±15.5	0	12.5	14	28	40	52	68	88	±17.5
140	160	0	−25	3.5	12.5	10.5	24.5	36.5	±15.5	0	12.5	14	28	40	52	68	90	±17.5
160	180	0	−25	3.5	12.5	10.5	24.5	36.5	±15.5	0	12.5	14	28	40	52	68	93	±17.5
180	200	0	−30	5	15	12	29	42	±18	0.5	15	16.5	33.5	46.5	60.5	79.5	106.5	±21
200	225	0	−30	5	15	12	29	42	±18	0.5	15	16.5	33.5	46.5	60.5	79.5	109.5	±21
225	250	0	−30	5	15	12	29	42	±18	0.5	15	16.5	33.5	46.5	60.5	79.5	113.5	±21
250	280	0	−35	6	17.5	13	33	49	±21	1.5	17.5	17.5	37.5	53.5	67.5	89.5	127.5	±23.5
280	315	0	−35	6	17.5	13	33	49	±21	1.5	17.5	17.5	37.5	53.5	67.5	89.5	131.5	±23.5
315	355	0	−40	7.5	20	14.5	36.5	53.5	±23.5	2	20	20	42	59	75	100	146	±27
355	400	0	−40	7.5	20	14.5	36.5	53.5	±23.5	2	20	20	42	59	75	100	152	±27
400	450	0	−45	9	22.5	16	41	59	±26	2.5	22.5	22.5	47.5	65.5	82.5	110.5	168.5	±30

Note ([1]) Negative mean value of the interference indicates clearance.

3.11 Interference dispersion (housing bores and outer rings)

In a manner similar to the previous interference dispersion for shafts and inner rings, that for housings and outer rings is shown in **Table 1**. The interference dispersion R in **Table 1** is given by the following equation:

$$R=\sqrt{R_e^{\,2}+R_H^{\,2}} \quad \cdots\cdots (1)$$

where R_e: Tolerance on outside diameter of outer ring (range of specification value)

R_H: Tolerance on bore diameter of housing (range of specification value)

This is based on the property that the sum of two or more numbers, which are normally distributed, is also distributed normally (rule for the addition of Gaussian distributions).

Table 1 shows the mean value and dispersion R of interference for the fitting of radial bearings of Normal Class and housings of Classes 6 and 7.

This rule for the addition of Gaussian distributions is widely used for calculating residual clearance and estimating the overall dispersion of a series of parts which are within respective tolerance ranges.

Table 1 Mean value and dispersion of interference for the fitting of outer rings with housings

Units: μm

Nominal size (mm)		Bearing single plane mean outside diameter deviation (Bearing: Normal class) ΔD_{mp}		Fit with Class 6 housing								Fit with Class 7 housing							
				Mean value of interference (1)							Dispersion of interference $R=\sqrt{R_e^2+R_H^2}$	Mean value of interference (1)							Dispersion of interference $R=\sqrt{R_e^2+R_H^2}$
over	incl	high	low	H6	J6	JS6	K6	M6	N6	P6		H7	J7	JS7	K7	M7	N7	P7	
3	**6**	0	−8	−8	−5	−4	−2	1	5	9	±5.5	−10	−4	−4	−1	2	6	10	±7
6	**10**	0	−8	−8.5	−4.5	−4	−1.5	3.5	7.5	12.5	±6	−11.5	−4.5	−4	−1.5	3.5	7.5	12.5	±8.5
10	**18**	0	−8	−9.5	−4.5	−4	−0.5	5.5	10.5	16.5	±7	−13	−5	−4	−1	5	10	16	±10
18	**30**	0	−9	−11	−6	−4.5	0	6	13	20	±8	−15	−6	−4.5	0	6	13	20	±11.5
30	**50**	0	−11	−13.5	−7.5	−5.5	−0.5	6.5	14.5	23.5	±9.5	−18	−7	−5.5	0	7	15	24	±13.5
50	**80**	0	−13	−16	−10	−6.5	−1	8	17	29	±11.5	−21.5	−9.5	−6.5	−0.5	8.5	17.5	29.5	±16.5
80	**120**	0	−15	−18.5	−12.5	−7.5	−0.5	9.5	19.5	33.5	±13.5	−25	−12	−7.5	0	10	20	34	±19
120	**150**	0	−18	−21.5	−14.5	−9	−0.5	11.5	23.5	39.5	±15.5	−29	−15	−9	−1	11	23	39	±22
150	**180**	0	−25	−25	−18	−12.5	−4	8	20	36	±17.5	−32.5	−18.5	−12.5	−4.5	7.5	19.5	35.5	±23.5
180	**250**	0	−30	−29.5	−22.5	−15	−5.5	7.5	21.5	40.5	±21	−38	−22	−15	−5	8	22	41	±27.5
250	**315**	0	−35	−33.5	−26.5	−17.5	−6.5	7.5	23.5	45.5	±23.5	−43.5	−27.5	−17.5	−7.5	8.5	22.5	44.5	±31.5
315	**400**	0	−40	−38	−31	−20	−9	8	24	49	±27	−48.5	−30.5	−20	−8.5	8.5	24.5	49.5	±35
400	**500**	0	−45	−42.5	−35.5	−22.5	−10.5	7.5	24.5	52.5	±30	−54	−34	−22.5	−9	9	26	54	±38.5
500	**630**	0	−50	−47	—	−25	−3	23	41	75	±33.5	−60	—	−25	10	36	54	88	±43
630	**800**	0	−75	−62.5	—	−37.5	−12.5	17.5	37.5	75.5	±45	−77.5	—	−37.5	2.5	32.5	52.5	90.5	±55
800	**1000**	0	−100	−78	—	−50	−22	12	34	78	±57.5	−95	—	−50	−5	29	51	95	±67

Note (1) Negative mean value of the interference indicates clearance.

3.12 Fits of four-row tapered roller bearings (metric) for roll necks

Bearings of various sizes and types are used in steel mill rolling equipment, such as rolling rolls, reducers, pinion stands, thrust blocks, table rollers, etc. Among them, roll neck bearings are the ones which must be watched most closely because of their severe operating conditions and their vital role.

As a rule for rolling bearing rings, a tight fit should be used for the ring rotating under a load. This rule applies for roll neck bearings, the fit of the inner ring rotating under the load should be tight.

However, since the rolls are replaced frequently, mounting and dismounting of the bearings on the roll necks should be easy. To meet this requirement, the fit of the roll neck and bearing is loose enabling easy handling. This means that the inner ring of the roll neck bearing which sustains relatively heavy load, may creep resulting in wear or score on the roll neck surface. Therefore, the fitting of the roll neck and bearing should have some clearance and a lubricant (with an extreme pressure additive) is applied to the bore surface to create a protective oil film.

If a loose fit is used, the roll neck tolerance should be close to the figures listed in Table 1. Compared with the bearing bore tolerance, the clearance of the fit is much larger than that of a loose fit for general rolling bearings.

The fit between the bearing outer ring and chock (housing bore) is also a loose fit as shown in Table 2.

Even if the clearance between the roll neck and bearing bore is kept within the values in Table 1, steel particles and dust in the fitting clearance may roughen the fitting surface.

Roll neck bearings are inevitably mounted with a loose fit to satisfy easy mounting/dismounting. If the roll neck bearing replacement interval is long, a tight fit is preferable.

Some rolling mills use tapered roll necks. In this case, the bearing may be mounted and dismounted with a hydraulic device.

Also, there are some rolling mills that use four-row cylindrical roller bearings where the inner ring is tightly fitted with the roll neck. By the way, inner ring replacement is easier if an induction heating device is used.

Table 1 Fits between bearing bore and roll neck

Units: μm

Nominal bore diameter d (mm)		Single plane mean bore diameter deviation Δd_{mp}		Deviation of roll neck diameter		Clearance		Wear limit of roll neck outside diameter
over	incl	high	low	high	low	min.	max.	
50	**80**	0	−15	−90	−125	75	125	250
80	**120**	0	−20	−120	−150	100	150	300
120	**180**	0	−25	−150	−175	125	175	350
180	**250**	0	−30	−175	−200	145	200	400
250	**315**	0	−35	−210	−250	175	250	500
315	**400**	0	−40	−240	−300	200	300	600
400	**500**	0	−45	−245	−300	200	300	600
500	**630**	0	−50	−250	−300	200	300	600
630	**800**	0	−75	−325	−400	250	400	800
800	**1000**	0	−100	−375	−450	275	450	900
1000	**1250**	0	−125	−475	−500	300	500	1000
1250	**1600**	0	−160	−510	−600	350	600	1200

Table 2 Fits between bearing outside diameter and chock bore

Units: μm

Nominal outside diameter D (mm)		Single plane mean outside diameter ΔD_{mp}		Deviation of chock bore diameter		Clearance		Wear limit and permissible ellipse of chock bore diameter
over	incl	high	low	high	low	min.	max.	
120	**150**	0	−18	+57	+25	25	75	150
150	**180**	0	−25	+100	+50	50	125	250
180	**250**	0	−30	+120	+50	50	150	300
250	**315**	0	−35	+115	+50	50	150	300
315	**400**	0	−40	+110	+50	50	150	300
400	**500**	0	−45	+105	+50	50	150	300
500	**630**	0	−50	+100	+50	50	150	300
630	**800**	0	−75	+150	+75	75	225	450
800	**1000**	0	−100	+150	+75	75	250	500
1000	**1250**	0	−125	+175	+100	100	300	600
1250	**1600**	0	−160	+215	+125	125	375	750
1600	**2000**	0	−200	+250	+150	150	450	900