5.3 Rolling bearing preload

5.3.1 The characteristics, theory and types of bearing preload

The bearing preload is defined as a given volume initial force and elastic deformation are kept between rolling elements and raceway when mounting to reduce the actual bearing deformation under running load.

The suitable preload can increase the support stiffness, running accuracy, life, dampness, and can reduce running noise. The research shows that the preload has positive and negative effect on accuracy, life, dampness and noise. At the beginning, the preload has a obviously effect on running accuracy, stiffness, life, dampness and reducing noise, but on the contrary, when the preload reaches a given degree, the effect will not obvious if the preload farther enhanced, and the more the preload, the higher the temperature, and the bearing life declined. Therefore, the bearing preload should be appropriate.

To these bearings in each precision machine tool, their temperature increase has a limit, table 5-8 lists the permission temperature of the each precision machine tool bearing under high speed, unload and continuous running. The ambient temperature is 20 centigrade, and lubricated well. If the ambient temperature is not 20 centigrade, but t centigrade, the permission temperature can be calculated by the below equation because of the change of lubricant viscosity.

$$T=T_{20}+K_T(t-20)$$

Where, K_T is lubrication correct factor, and the K_T based on the selected lubricant. The K_T= 0.6~0.5 if L-HM-L-HV.HS 662 and 32 liquefaction oil are applied, and if applies 3~6 shaft lubricant, the K_T= 0.85~0.8, and K_T= 0.9 if lubricating greases applied.

Table 5-8 The permission temperature of machine tool bearing

The precise level of machine tool	
Normal Level	Mini type Machine tool 45 - 50 large-scale Machine tool 50 - 55
Precise Level	35 - 40
High Precise Level	28 - 30

The bearing preload depends on the relatively movement between inner ring and outer ring, and to thrust bearing, the preload depends on the relatively movement between bearing ring and seating. The preload can eliminate the clearance and achieve the interference. The preload can be divided into radial preload and axial preload based on the direction of preload, and the preload also can be divided into located preload and static preload. In the actual application, the located preload applied in ball bearing, and the static preload applied in cylindrical roller bearing.

5.3.2 Radial preload

The radial preload utilizes the interference fit between bearing and shaft seating, so that the radial clearance can be eliminated and the pre-deformation can be achieved through the bearing inner ring expansion or outer ring compressing.

To bearings with a tapered bore, the different expansion can be achieved depends on the different locating of bearing inner ring on the cylindrical shaft seating. The preload structure illustrated in the design of support structure in this chapter.

5.3.3 Axial preload

(1) Located preload means the bearing axial position statically, see figure 5-2. The preload can be achieved through the difference width of spacer sleeve between two bearings or through the width of inner and outer ferrule on thin seating.

(2) Constant pressure preload means the bearing axial preload force statically, see figure 5-3. The preload can be achieved through the spring compression.

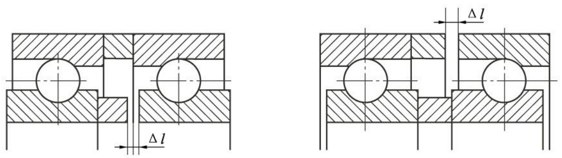


Diagram 5-2 Located preload

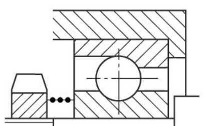


Diagram 5-3 Constant pressure preload

(3) The selection of located and constant pressure preload. On the same preload distortion, it can't obviously increase the axial stiffness of support by constant pressure preload, and the temperature has no impact on the distortion. On the located preload, the axial extension and radial expansion have impact on the preload distortion. The axial induced by the temperature difference between bearing and housing, and the radial expansion induced by the temperature difference between bearing inner ring and outer ring. Therefore, the selection of preload must depend on the technical requirement in detail. Generally, the located preload is applied for high stiffness while the constant pressure preload for high speed.

5.3.4 Determining preload

The preload is mainly used to adjust and control during the mounting, and this is a very carefulness task in bearing mounting procedure.

The suitable preload depends on the value of bearing load and the requirement of usage, and can be confirmed by calculation combined practical test and actual rotation. Generally it can be divided into below case.

(1) The light preload applied under high speed and light load, or to reduce the vibration and noise of support system, in order to improve running accuracy.

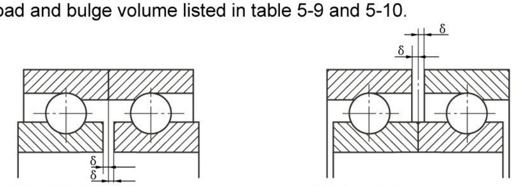
(2) The moderate and heavy preload are applied under moderate speed with middling load or low speed with heavy load, to improve the support stiffness.

(3) To same type angular contact ball bearing paired mounting (figure 5-4), the additional axial preload Fa less than 2.83*Fao (Fao is preload). Otherwise, the situation of one bearing enduring entire axial preload should be avoided.

(4) To same type taper roller bearing paired mounting, the additional axial preload Fa less than 2*Fao (Fao is preload). Otherwise, the situation of one bearing enduring entire axial preload should be avoided.

(5) To the preload of angular contact ball bearing mounted face-to-face or back-to-back, UBC stipulates axial deformations under three preloads (light preload, moderate preload, heavy preload) for design convenience.

In order to the bulge volume is δ which is between one ring cover bulging another ring cover of single bearing, a certain deformation should be rubbed out on the cover of inner ring or outer ring of two bearing paired mounted. When the paired bearings mounted at the shaft and housing, the two bearing achieve the preload by pressing out the related end plates with retained tools, see figure 5-4. This bearing preload and bulge volume listed in table 5-9 and 5-10.



(a) Back-to back arrangement (b) Face-to-face arrangement

Diagram 5-4 Preload mounting of paired angular contact ball bearing

(6) Minimum axial preload. To angular contact ball bearing, taper roller bearing, thrust ball bearing, thrust roller bearing, the roller under centrifugal effect when rotation, there is sliding opposite between roller and raceway. To ensure the bearing action normally, a certain axial preload must be brought, the minimum axial preload Famin listed in table 5-11.

Table 5-9 The preload of angular contact ball bearing paired mounted

Bearing series / Preload / d/mm	7000C			7200C			7000AC			7200AC			7200B			7300B		
	Light	Medium	Heavy	Light	Medium	Heavy	Light	Medium	Heavy	Light	Medium	Heavy	Light	Medium	Heavy	Light	Medium	Heavy
10	25	50	100	50	100	200	40	80	160	75	150	300	-	-	-	-	-	-
12	25	50	100	60	120	240	40	80	160	90	180	360	-	-	-	-	-	-
15	30	60	120	70	140	280	45	90	180	105	210	420	-	-	-	-	-	-
17	35	70	140	90	180	360	55	110	220	140	280	560	-	-	-	-	-	-
20	50	100	200	115	230	460	80	160	320	175	350	700	175	350	700	-	-	-
25	60	120	240	130	260	520	90	180	360	200	400	800	195	390	780	320	640	1280
30	80	160	320	180	360	720	110	220	440	270	540	1080	250	500	1000	400	800	1600
35	150	300	600	250	500	1000	210	420	840	380	760	1520	335	670	1340	470	940	1880
40	155	310	620	280	560	1120	220	440	880	435	870	1740	400	800	1600	580	1160	2320
45	190	380	760	310	620	1240	280	560	1120	480	960	1920	445	890	1780	735	1470	2440
50	200	400	800	330	660	1320	290	580	1160	500	1000	2000	480	960	1950	840	1680	3360
55	270	540	1080	410	820	1640	405	810	1620	620	1240	2480	570	1140	2280	970	1940	3880
60	280	560	1120	400	980	1960	430	860	1720	750	1500	3000	690	1380	1760	1010	2020	4040
65	280	560	1120	515	1030	2060	440	880	1760	780	1560	3120	780	1560	3210	1270	2540	5080
70	350	700	1400	560	1120	2240	530	1060	2120	850	1700	3400	865	1730	3460	1410	2820	5640
75	360	720	1440	640	1280	2560	540	1080	2160	970	1940	3880	900	1800	3600	1620	3240	6480
80	450	900	1800	690	1380	2760	655	1330	2660	1045	2090	4180	990	1980	3960	1660	3320	6640
85	460	920	1840	800	1600	3200	685	1370	2740	1220	2440	4880	1150	2300	4600	1820	3640	7280
90	550	1100	2200	945	1890	3780	850	1700	3400	1440	2880	5760	1310	2620	5240	1950	3900	7800
95	570	1140	2280	1085	2170	4340	875	1750	3500	1650	3300	6600	1485	2970	5940	2120	4240	8480
100	580	1160	2320	1200	2400	4800	895	1790	3580	1830	3660	7320	1600	3200	6400	2340	4680	9360
105	650	1300	2600	1340	2620	5240	1000	2000	4000	1995	3990	7980	1765	3530	7060	2485	4970	9940
110	780	1560	3120	1420	2840	5680	1190	2380	4760	2160	4320	8640	1895	3790	7580	2660	5320	10640
120	790	1580	3160	1530	3060	6120	1215	2430	4860	2330	4660	9320	-	-	-	-	-	-
130	940	1880	3760	1590	3180	6360	1460	2920	5840	2415	4830	9660	-	-	-	-	-	-

Note: The table doesn't list the preload of these bearings that inner diameter d>100mm.
7000C series: The light, medium, heavy preload equal 0.009, 0.018, 0.036 times dynamic load rating respectively.
7200C series: The light, medium, heavy preload equal 0.010, 0.020, 0.040 times dynamic load rating respectively.
7000AC series: The light, medium, heavy preload equal 0.015, 0.030, 0.060 times dynamic load rating respectively.
7200AC,7200B,7300B series: The light, medium, heavy preload equal 0.016, 0.032, 0.064 times dynamic load rating respectively.

Table 5-10 Bearing preload and bulge volume

μm

$\Delta\delta_1+\Delta\delta_2$ (Face-to-Face or Back-to-Back), $\Delta\delta_1-\Delta\delta_2$ (Tandem)																			
Preload / Bearing series / d/mm		7000C				7200C				7000AC 7200B				7200AC 7300B					
>	≤ to	Light Medium		Heavy		Light Medium		Heavy		Light Medium		Heavy		Light		Medium		Heavy	
		min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max
-	18	-0.5	+0.5	-1	+1	-0.5	+0.5	-1	+1	-0.5	+0.5	-0.5	+0.5	-0.5	+0.5	-0.5	+0.5	-0.5	+0.5
18	30	-1	+1	-1	+1	-1	+1	-1	+1	-0.5	+0.5	-1	+1	-0.5	+0.5	-0.5	+0.5	-1	+1
30	50	-1	+1	-1	+1	-1	+1	-1.5	+1.5	-0.5	+0.5	-1	+1	-0.5	+0.5	-1	+1	-1	+1
50	80	-1	+1	-1.5	+1.5	-1.5	+1.5	-2	+2	-1	+1	-1.5	+1.5	-1	+1	-1	+1	-1.5	+1.5
30	120	-2	+2	-2	+2	-2	+2	-2.5	+2.5	-1	+1	-1.5	+1.5	-1	+1	-2	+2	-2	+2
120	150	-2	+2	-2	+2	-2.5	+2.5	-3	+3	-1	+1	-2	+2	-1	+1	-2	+2	-3	+3

Note: To these paired bearing with inner diameter d>150mm, the tolerance of bulge volume between two bearings is $\triangle\delta 1\pm\triangle\delta 2$, it is permitted that the bulge volume is larger 1μm than the value listed in the d=120~150mm.

Table5-11 Preload of angular contact ball bearing paired mounted

Bearing types	Under load *Famin*		Description
	Pure axial load	Combined load	
Angular contact ball bearing	$\geqslant 0.35Fa$	$\geqslant 1.7F_{r\mathrm{I}}+\tan\alpha_{\mathrm{I}}-\frac{F_a}{2}$ $\geqslant 1.7F_{r\mathrm{II}}\tan\alpha_{\mathrm{II}}-\frac{F_a}{2}$	$F_{r\mathrm{I}}$ —— Radial load that bearing Ⅰ endured, KN $F_{r\mathrm{II}}$ —— Radial load that bearing Ⅱ endured, KN
Taper roller bearing	$\geqslant 0.5Fa$	$\geqslant 1.9F_{r\mathrm{I}}\tan\alpha_{\mathrm{I}}-\frac{F_a}{2}$ $\geqslant 1.9F_{r\mathrm{II}}\tan\alpha_{\mathrm{II}}-\frac{F_a}{2}$ Select larger one	α_{II}、α_{I} – Contact angle of bearing Ⅰ, Ⅱ
Thrust ball bearing	$=A\left(\frac{n}{1000}\right)^2$		F_a —— Axial load, KN F_r —— Radial load, KN
Cylindrical, taper roller thrust bearing	$\frac{Coa}{1000}\leqslant Famin>A\left(\frac{n}{1000}\right)^2$		Coa —— Bearing basic static load rating, KN (Listed in table of bearing dimension, 2 chapter)
Self-aligning roller thrust bearing		$\frac{Coa}{1000}\leqslant Famin>1.8F_r+A\left(\frac{n}{1000}\right)^2$	A —— Minimum constant of load (Listed in table of bearing dimension, 2 chapter)
Thrust needle bearing		$\frac{Coa}{2000}\leqslant Famin>1.8F_r+A\left(\frac{n}{1000}\right)^2$	n —— Speed, r/min

5.3.5 The control of preload and design of preload structure

In actually application, it's difficult to achieve optimal clearance by calculation and measurement. To the last mounting step of angular contact ball bearing, taper roller bearing and taper bore double row cylindrical roller bearing, it need to adjust clearance precisely, that is to say to control the preload. Especially, to these shafts that have a strict requirement of running accuracy, noise and temperature increase, such as shaft of machine tool, clearance need to be adjusted not only during first time mounting, but also in using. There are many methods for control preload. Several methods for control preload and problem in the design of preload structure are introduced below.

(1) Several methods for control preload.

1. Measure the bearing friction moment of run up. Measure the relationship between the bearing friction moment of run up and axial load in advance, so that the preload can be adjusted by control bearing friction moment of run up. This method is often applied for the preload of taper roller bearing paired mounted.
2. Measure the bearing axial displacement. To taper bore bearing, measure the relationship between axial load and axial displacement in advance, so that the preload can be adjusted by control the axial displacement.
3. Measure the deformation of preload spring. Measure the relationship between the spring preload and deformation beforehand, so that the constant pressure preload can be adjusted by control the deformation.
4. Measure the retain moment of nut. Adjusting the preload to control the retain moment of nut, when bearing with nut preload is used.
5. Pad with bearing end plates (No.4 diagram in Table 5-3). Tightening the one bearing end plate, not shimming another bearing, and screwing down the bolt. If the shaft can't rotate freely, it means that there is no clearance between bearing and shaft, and measure the gap between the end plate and housing cover by gauge, the thickness of shim can be calculated by adding this gap and needed clearance.
6. Application of midst spacer sleeve (No.6 diagram in Table 5-3). The length of spacer sleeve in inner ring can be calculated depends on the length of spacer sleeve in outer ring and bearing dimension, and it also can be directly measured.

(2) Detect and control of preload. At present, it's difficult to detect bearing work preload in our country, the majority detecting axial and radial displacement or friction moment of run up by using dial gauge, and the few using special instrument. Some bearing companies overseas detect and adjust the preload by using special instrument and some structure for controlling the preload, to achieve the optimal preload.

(3) Some problems should be pay attention in the design of preload structure.

1. Application of compressed spring to constant pressure preload, and the spring dimension and parameter can be decided by calculation, and the structure which is convenience to adjust preload.
2. Though the located preload can meet the preload requirement, but the precision of initial preload will be impacted when bearing running because of friction. Therefore, the design of preload structure should be convenience to adjust.
3. To achieve simple structure and convenience to adjust preload, a spacer sleeve placed between two inner rings or two outer rings, and the preload can be adjusted by nuts.
4. When adjusting preload by nuts, the selection of structure of nut and manufacture precision have a greatly impact on the control of preload and the adjustment precision.

5.4 Roll bearing fit

5.4.1 Purpose of the load

Fit purpose is firm set of bearing inner ring and outer ring with shaft and shell , and prevent harmful axial direction slippage of fit surface.

It will cause abnormal high temperature, fit surface fray (fray ferrous powder into the bearing) and vibration and so on problem by harmful axial direction slippage, and cannot full unleash action of the bearing.

The bearing is general rotating load.

5.4.2 Tolerances and fit of shaft and shell

Metric series tolerances of shaft and shell bore by GB/T275-93 <<roll bearings with shaft and shell fit>> standardization .

Shaft and shell fit relation of size tolerances and class P0 precision for bearing, to meet figure 5-5

5.4.3 Selection of fit

Generally according to bellow principle.

Basis load direction, nature, inner and outer ring revolution direction, so there are three difference conditions: rotating load, stationary load and direction of load indeterminate. Ferrule is used interference fit of rotating load and direction of load indeterminate, and Ferrule is used transition fit and clearance fit of stationary load.

When the bearings have too large load, vibration and attack, So must to augment interference. For the hollow shaft, Thin wall bearing box, light alloy and plastics bearing box, the same to augment interference.

When keep high rotating precision, that use high precision bearing, and increase size precision of shaft and bearing box, prevent too large interference. If it is too large, that should influence shaft and bearing box precision, and cause to damage with bearing rotating precision.

It is used interference fit of no separate bearing. But bearing is not convenient with mounting and dismounting, that it is used clearance fit of one inner ring.

5.4.3.1 Property of the load

Basis load nature, there are three difference conditions: inner ring rotating load, outer ring rotating load and direction of load indeterminate, to meet figure 5-12.

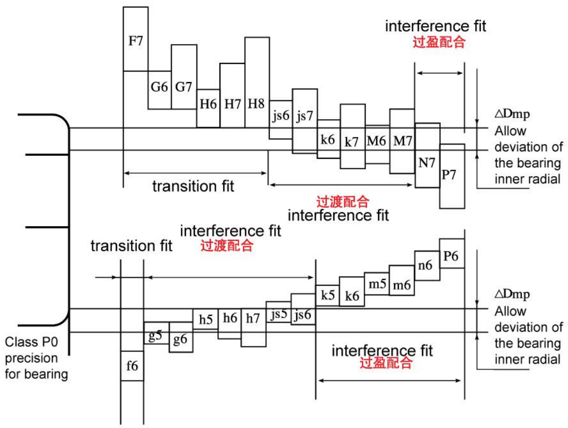
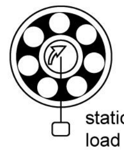
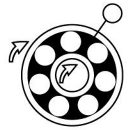
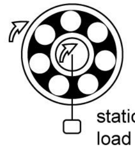


Figure 5-5 Shaft and shell fit relation of size tolerances (Class P0 precision for bearing)

Table 5-12 Property of the load and fit of Relationship

Operating conditions	Load condition	Schematic illustration	Recommended fits
Rotating inner ring Stationary outer ring Constant load direction	 stationary load	Rotating load on inner ring Stationary load on outer ring	Interference fit for inner ring Loose fit for outer ring
Stationary inner ring Rotating outer ring Load rotates with outer ring	unbalance load 		
Stationary inner ring Rotating outer ring Constant load direction	 stationary load	Stationary load on inner ring Rotating load on outer ring	Loose fit for inner ring Interference fit for outer ring
Rotating inner ring Stationary outer ring Load rotates with outer ring	unbalance load 		

5.4.3.2 Magnitude of the load

The influence of rotating load the ring may begin to creep , the degree of interference must therefore be related to the magnitude of the load.

Interference calculation:

[$F_r \leq 0.25C_0$时]

$$\Delta d_F = 0.08\sqrt{\frac{d}{B}\cdot F_r} \times 10^{-3} \text{ …… (5-1)}$$

[$F_r > 0.25C_0$时]

$$\Delta d_F = 0.02\frac{F_r}{B} \times 10^{-3} \text{ ………… (5-2)}$$

Δd_F : Interference decrease of inner ring, mm

d : Nominal bore diameter , mm

B : Nominal width of inner ring, mm

F_r : Radial load , N(kgf)

C_0 : Rated stationary load , N(kgf)

So the heavier the load (C_0>25%), the greater the interference fit required, shock load need to be considered.

5.4.3.3 Roughness concentration of matching surface

If consideration plastic deformation of matching surface, So process quality of matching surface will influence effectual interference.

See formula:

[grinding shaft] $\triangle d_{eff} = \frac{d}{d+2} \triangle d$ …………… (5-3) [turning shaft] $\triangle d_{eff} = \frac{d}{d+3} \triangle d$ …………… (5-4)

Δdeff : Effectual interference, mm
Δd : Metrical interference, mm
d : Nominal bore diameter , mm

5.4.3.4 Temperature influence

Generally speaking, the bearing's temperature is higher than surrounding when running, and the inner ring temperature is higher than shaft. So, the effectual interference is minish by heat expansion. If Δt is difference in temperature between the bearing inner and crust, so (0.10-0.15) Δt is difference in temperature between inner and shaft.

So interference minish (Δdt) can be calculated by formula(5-5)

$dt = (0.10\text{-}0.15) \triangle t \cdot a \cdot d$ $\triangle dt = 0.0015 \triangle t \cdot d \times 10^{-3}$…… (5-5)

Δdt: Interference minish, mm
Δt: Difference in temperature between the bearing inner and crust,℃
a: line swell factor of bearing steel, (12.5×10^{-6})1/℃,
d : Nominal bore diameter , mm

So, when the bearing is higher than shaft temperature, must be interference fit.
Because of difference in temperature and line swell factor is difference between outer ring and crust, and it is increased with interference fit.

That is noted, when consider and use between outer ring and crust surface glide to avoid shaft swell factor.

5.4.3.5 The best stress of bearing inner by fit produce

When mounting the bearing to use interference fit, and stress is produced by ferrule swell and shrink. The best stress of bearing inner by fit produce can be calculated by formula (table 5-13). As reference, it is safe of the best interference not more than the shaft 1/1000 or see table 5-13 δnot more than 120MPa.

5.4.3.6 Others

When it require high with precision, and precision of shaft and crust by raise, crust is difficult process and low precision than shaft, so it is relaxed fit of outer ring and crust.

When using hollow shaft, thin wall crust, light alloy and cast aluminum, that fitting must be more tight than others.

When using separate crust, that it is loose fit with outer ring .

Table 5-13 The best stress of bearing inner by fit produce

shaft and inner ring		crust bore and inner ring	
(howllo shaft)	$\sigma = \frac{E}{2} \cdot \frac{\triangle d_{eff}}{d} \cdot \frac{\left[1 - \frac{d_o^2}{d^2}\right]\left[1 + \frac{d^2}{d_i^2}\right]}{\left[1 - \frac{d_o^2}{d_i^2}\right]}$	$(D_h \neq \infty)$	$\sigma = E \cdot \frac{\triangle D_{eff}}{D} \cdot \frac{\left[1 - \frac{D^2}{D_h^2}\right]}{\left[1 - \frac{D_e^2}{D_h^2}\right]}$
(solid shaft)	$\sigma = \frac{E}{2} \cdot \frac{\triangle d_{eff}}{d} \cdot \left[1 + \frac{d^2}{d_i^2}\right]$	$(D_h = \infty)$	$\sigma = E \cdot \frac{\triangle D_{eff}}{D} \cdot$

δ: The best stress, MPa(kgf/mm2)
d : Nominal bore diameter , mm
di: diameter of inner rollaway nest, mm
  Ball bearing…di=0.2(D+4d)
  Roll bearing …di=0.25(D+3d)
Δd_{eff} : Effectual interference of inner ring, mm
d_o: hollow shaft diameter, mm

D_e: outer rollaway nest ,mm
  Ball bearing…d_e=0.2(D+4d)
  Roll bearing …d_e=0.25(D+3d)
D: Nominal outer diameter, mm
ΔD_{eff} : Effectual interference of outer ring, mm
D_h: crust outside diameter, mm
E: elastic modulus, 2.08×10^5MPa(21200kgf/mm2)