7 Preload and lubrication for Bearings

7.1 Preload

There shall be appropriate clearances for bearings in some running situations. According to different usage, some bearings are preloaded to get a negative clearance, which is called preload. When angular contact ball bearings and tapered roller bearings are used in pairs, suitable internal clearances must be adjusted through preload. According to the directions of the preload.

7.1.1 Purpose of preload

It can be divided into axial preload and radial preload. In practical situations, ball bearings often adopt axial preload and cylindrical roller bearings adopt radial preload.

The fundamental purposes and examples of preload are shown in Table 7.1:

Purpose of preload	Example
To improve the radial and axial locating precision of the shaft, restrain shaft runout and increase running accuracy	Machine tool spindles shaft bearing, surveying instrument bearing
To improve the rigidity of bearings	Machine tool spindles shaft bearing, automobile differential gear pinion bearing
To reduce shock and prevent the bearing noise caused by resonance	Bearings for small motors
To restrain the slipping of rolling elements and reduce friction	High speed rotating angular contact ball bearings and thrust ball bearings
To maintain the correct positions of rings and rolling elements	When thrust ball bearings and spherical thrust roller bearing are used on horizontal shafts

7.1.2 Axial preload

In most situations, the radial rigidity and angular rigidity of radial bearings can be improved through axial preload. Axial preload can also change the variation rule of rigidity.

For angular contact ball bearings, when the radial load is zero, the relations between its axial load F_a and axial deformation δ_a can be calculated with the following empirical formula:

$$\delta_a = \frac{0.002}{sina}\sqrt[3]{\frac{Q^2}{D_w}} = Ka \times F_a^{\frac{2}{3}}$$

In the equation:

$$Q = \frac{F_a}{Z \, sina}$$

K_a: The elastic deformation coefficient of the bearing. Since the actual contact angle of angular contact ball bearings depends on the axial load, K_a isn't a constant.

D_w: Rolling element diameter
Z: Number of rolling elements

The load-deformation curve can be made with the above formula. See Figure 7.1.It is observed that when single bearing has no preload, under the axial load Fa, the axial deformation is $\delta a1°$ .If the bearing's preload load F_{ao}, under the same additional axial load Fa, the axial deformation of the bearing is $\delta a2$. Apparently, $\delta a2 < \delta a1$.Therefore, the axial rigidity of single row angular contact ball bearings can be improved through preload.

For tapered roller bearings, when the radial load is zero, the relation of its axial load F_a and axial deformation δ_a is:

$$\delta_a = \frac{0.0006\,Q^{0.9}}{sina L_{we}^{0.8}} = K_a \times F_a^{0.9}$$

In the equation:

L_{we}: Effective length of tapered rollers

For two angular contact ball bearings or tapered roller bearings of the same type number mounted in pairs, according to the preload methods, preload can be divided into position preload and constant pressure preload.

7.1.3 Position preload

Position preload refers to an axial preload where the axial position of the bearing remain constant during working. See Fig. 7.2. A certain preload can be got by adjusting the width of the spacers between two bearings.
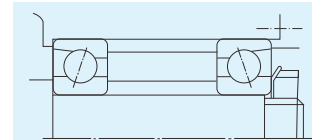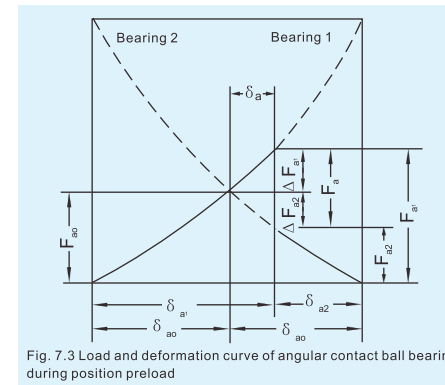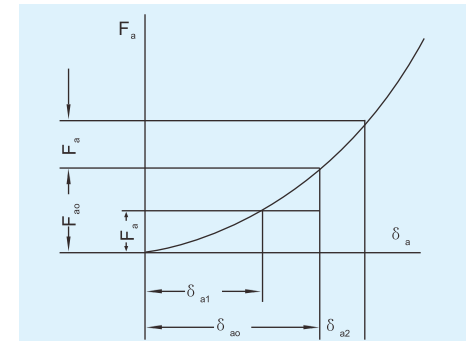

Fig. 7.2 Graphic of position preload

Fig. 7.1 Load and deformation curve of angular contact ball bearings

When two angular contact ball bearings of the same number is mounted in pairs, their axial load and deformation curves are shown in Fig. 7.3.In the figure the intersecting point of the load-deformation curves of the two bearings describes that under the preload F_{ao}, the amounts of preload deformation of the two bearings are both δ_{ao}.When additional axial load F_a is applied to the shaft, the shaft will move in the direction of F_a for δ_a. Then the deformation of Bearing 1 increases by δ_a, and the deformation of Bearing 2 decreases by δ_a.

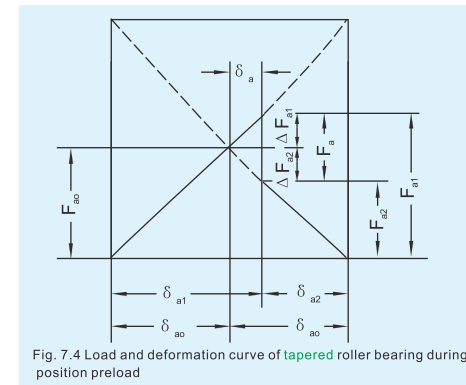Seen from the figure, the axial deformation amounts of the Bearing 1 and Bearing 2 are respectively:

Fig. 7.3 Load and deformation curve of angular contact ball bearing during position preload

Fig. 7.4 Load and deformation curve of tapered roller bearing during position preload

$\delta_{a1}=\delta_{ao}+\delta_a$

Correspondingly, the axial loads carried by bearing 1 and 2 are:

$$F_{a1} = F_{ao}+ \triangle F_{a1}$$
$$F_{a2}= F_{ao}- \triangle f_{a2}$$

The following can be obtained through the force condition of equilibrium:

$$F_a= F_{a1}-F_{a2}$$

It is observed that under the axial load F_a, the axial displacement of supporting system is δ_a. Therefore, the rigidity of the supporting system of the angular contact ball bearings mounted in pairs can be significantly improved by preload.

If F_a is increased and $\triangle F_{a1}$ =F_{ao}, the amount of movement of the shaft in the F_a direction $\delta_a=\delta_{ao}$. here, Bearing 2 carries no load, then:

$$\delta_{a1}=2\delta_{ao}$$
$$\delta_{a2}=0$$

The additional axial load where Bearing 2 carries no load called preload. When the preloaded bearings are a pair of angular contact ball bearings of the same number, their preload is:

$$F_{ax}=2^{\frac{2}{3}}F_{ao}=2.83F_{ao}$$

When the additional axial load F_a is greater than the above value, the axial load is completely carried by Bearing 1.Here, the angular contact ball bearings mounted in pairs is equal to one single bearings. This situation shall be avoided. When two tapered roller bearings of the same type number is mounted in pairs, their axial load and deformation curves are shown in Fig. 7.4.Seen from the figure, the rigidity of the tapered roller bearing mounted in pairs can be improved one time by preload:

$$F_{ax}= 2F_{ao}$$

7.1.4 Constant pressure preload

Pressure preload refers to an axial preload where the axial preload load of the bearing remain constant during working. See Fig. 7.5.A certain preload amount can be got by adjusting the amount of compression of the spring.
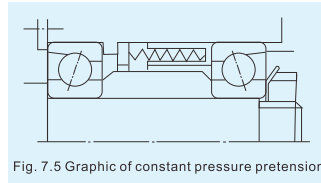

Fig. 7.5 Graphic of constant pressure pretension

When two angular contact ball bearings of the same number are mounted in pairs and adopt constant pressure preload, their axial load and deformation curves are shown in Fig. 7.6.Seen from the figure, under the preload F_{ao}, the amount of preload deformation of Bearing 1 and 2 are both δ_{ao}. When the additional axial load F_a is applied to the shaft, the shaft moves δ_a in the F_a direction.Bearing 2's outer ring under the effect of the spring is always compressing the inner ring.Since the rigidity of the spring is relatively smaller than that of the bearing, it can be approximately considered that under the effect of the additional axial load, the amount of deformation of Bearing 1 increases by δ_a whereas the amount of deformation and preload of Bearing 2 remain constant.
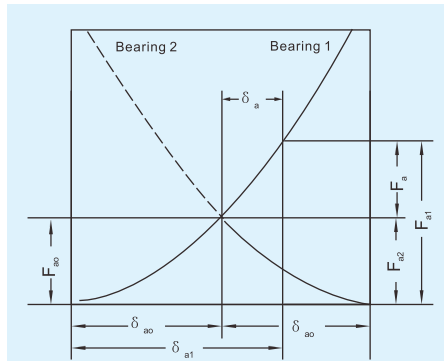

Fig. 7.6 Load and deformation curve during pressure preload

On condition that preload forces are identical, the axial displacement of bearing is relatively small when adopting position preload, and it is easier to attain high rigidity. Constant pressure preload can absorb the change of load with spring and cause the shrink of axle due to temperature difference between axle and housing in operation. Thus the change of preload force is small and a steady preload force is obtainable. Position preload can bring large preload force.

Seen from above, position preload is more suitable if high rigidity is desired; while when high rotation speed and prevention of axial vibration is needed or in case of thrust bearing used for horizontal axle, we ought to adopt constant pressure preload.

7.1.5 The choice of minimum axial preload

The size of preload should be determined according to load and operation requirement. Generally, when diminishing the vibration of supporting system or promoting running accuracy under high speed load condition, we should adopt preload that is relatively light; whereas when increasing the rigidity of supporting system under conditions of medium speed moderate loading or low speed heavy loading, we should adopt medium and heavy preload. However, the preload is so big that the rigidity of bearing cannot be promoted

Notably, while instead, the friction of bearing enlarged, the temperature increases and its service life decreases. Generally, the size of preload should be determined via calculation in conjunction with service experience. When use position preload, we should ensure the rollers keep contact with raceway groove. Therefore, the minimum axial preload can be determined according to the formula shown in Table 7.2.

Table 7.2 Minimum preload of position preload

Bearing type	Load condition	Minimum preload F_{aomin}
Angular contact ball bearing	Purely axial load	$F_{aomin}\geqslant 0.35F_a$
	Combination of radial and axial loading	$\begin{cases} F_{aomin}\geqslant 1.7F_{r1}tg_{a1}-0.5F_a \\ F_{aomin}\geqslant 1.7F_{r2}tg_{a2}+0.5F_a \end{cases}$ Select the bigger value
Tapered roller bearing	Purely axial load	$F_{aomin}\geqslant 0.5F_a$
	Combination of radial and axial loading	$\begin{cases} F_{aomin}\geqslant 1.9F_{r1}tg_{a1}-0.5F_a \\ F_{aomin}\geqslant 1.9F_{r2}tg_{a2}+0.5F_a \end{cases}$ Select the bigger value
Code meanings	F_{r1}: Radial loading taken by bearing 1 F_{r2}: Radial loading taken by bearing 2. $a1$: Contact angle of bearing 1 $a2$: Contact angle of bearing 2	

In practical situations, it is difficult to measure precisely the value of preload applied. We could control the amount of preload by measuring the following indexes of bearing, such as start-up friction torque, distance of axial displacement, amount of deformation of preloaded spring, and tightening torque of nuts etc. If in exceptional cases, please contact the technical center of C&U group.

7.1.6 Radial preload

The purpose of radial preload is to increase the contact frequency of rollering element in the loading area and improve load-taken rigidity. In the high-speed cylindrical roller bearing, radial preload could decrease sliding between roller and raceway groove under the force of centrifugal action.

For bearing with tapered inner bore, we adjust the relative position between inner ring and adapter sleeve by means of locknut, to reduce the radial clearance of bearing and then set radial preload.

7.1.7 Preload of matched pair angular contact ball bearing

In the mounting of face-to-face or back-to-back matched pair angular contact ball bearing, we have considered the amount of axial deformation caused by preload. We grinded a certain amount of deformation on the end surface of the inner and outer rings , so that the protruding amount between non-reference face of one single bearing and the reference face of another bearing are δ .When matched bearings are mounted to shaft and housing, we make the two bearings preloaded by tightening the corresponding end face. The requirement for the preload and protruding amount of such type of bearing is shown in Table 7.3 and Table 7.4.
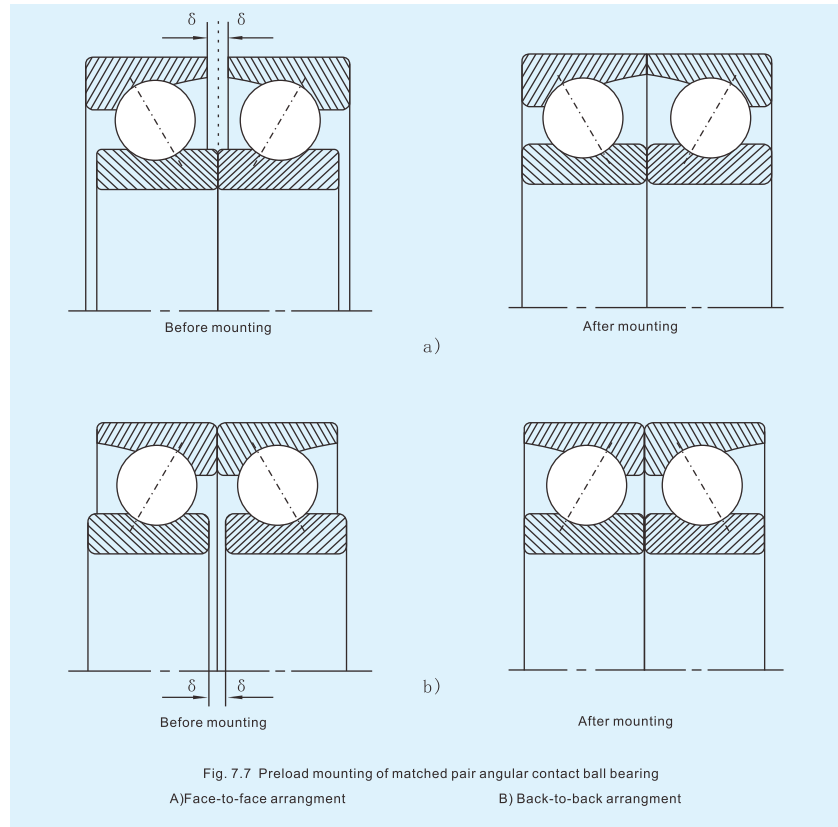

a)
Before mounting   After mounting

b)
Before mounting   After mounting

Fig. 7.7 Preload mounting of matched pair angular contact ball bearing
A)Face-to-face arrangment   B) Back-to-back arrangment

Table 7.3 Preload of matched pair angular contact ball bearing   Unit:N

Bearing series / preload value / d mm	7000 C			7200 C			7000 AC			7200 AC		
	GA	GB	GC	GA	GB	GC	GA	GB	GC	GA	GB	GC
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
25	60	120	240	130	260	520	90	180	360	200	400	800
30	80	160	320	180	360	720	110	220	440	270	540	1,080
35	150	300	600	250	500	1,000	210	420	840	380	760	1,520
40	155	310	620	280	560	1,120	220	440	880	435	870	1,740
45	190	380	760	310	620	1,240	280	560	1,120	480	960	1,920
50	200	400	800	330	660	1,320	290	580	1,160	500	1,000	2,000
55	270	540	1,080	410	820	1,640	405	810	1,620	620	1,240	2,480
60	280	560	1,120	490	980	1,960	430	860	1,720	750	1,500	3,000
65	280	560	1,120	515	1,030	2,060	440	880	1,760	780	1,560	3,120
70	350	700	1,400	560	1,120	2,240	530	1,060	2,120	850	1,700	3,400
75	360	720	1,440	640	1,280	2,560	540	1,080	2,160	970	1,940	3,880
80	450	900	1,800	690	1,380	2,760	665	1,330	2,660	1,045	2,090	4,180
85	460	920	1,840	800	1,600	3,200	685	1,370	2,740	1,220	2,440	4,880
90	550	1,100	2,200	945	1,890	3,780	850	1,700	3,400	1,440	2,880	5,760
95	570	1,140	2,280	1,085	2,170	4,340	875	1,750	3,500	1,650	3,300	6,600
100	580	1,160	2,320	1,200	2,400	4,800	895	1,790	3,580	1,830	3,660	7,320
105	650	1,300	2,600	1,310	2,620	5,240	1,000	2,000	4,000	1,995	3,990	7,980
110	780	1,560	3,120	1,420	2,840	5,680	1,195	2,390	4,780	2,160	4,320	8,640
120	790	1,580	3,160	1,530	3,060	6,120	1,215	2,430	4,860	2,330	4,660	9,320
130	940	1,880	3,760	1,590	3,180	6,360	1,460	2,920	5,840	2,415	4,830	9,660

Table 7.3 Preload of matched pair angular contact ball bearing(continuation)   Unit:N

preload value, Bearing series / d mm	7200 B			7300 B		
	GA	GB	GC	GA	GB	GC
20	175	350	700	—	—	—
25	195	390	780	320	640	1,280
30	250	500	1,000	400	800	1,600
35	335	670	1,340	470	940	1,880
40	400	800	1,600	580	1,160	2,320
45	445	890	1,780	735	1,470	2,940
50	480	960	1,920	840	1,680	3,360
55	570	1,140	2,280	970	1,940	3,880
60	690	1,380	2,760	1,010	2,020	4,040
65	780	1,560	3,120	1,270	2,540	5,080
70	865	1,730	3,460	1,410	2,820	5,640
75	900	1,800	3,600	1,620	3,240	6,480
80	990	1,980	3,960	1,660	3,320	6,640
85	1,150	2,300	4,600	1,820	3,640	7,280
90	1,310	2,620	5,240	1,950	3,900	7,800
95	1,485	2,970	5,940	2,120	4,240	8,480
100	1,600	3,200	6,400	2,340	4,680	9,360
105	1,765	3,530	7,060	2,485	4,970	9,940
110	1,895	3,790	7,580	2,660	5,320	10,640

Note: The preload of bearing with bore diameter >100mm is not listed in the table.
Series 7000C: Light, medium and heavy preload should be 0.009, 0.018, and 0.036 of bearing dynamic load rating respectively
Series 7200C: Light, medium and medium preload should be 0.010, 0.020, and 0.040 of bearing dynamic load rating respectively
Series 7000AC: Light, medium and heavy preload should be 0.015, 0.030, and 0.060 of bearing dynamic load rating respectively
Series 7200 AC, 7200 B and 7300 B: Light, medium and heavy preload should be 0.016, 0.032 and 0.064.of bearing dynamic load rating respectively.

Table 7.4 Protruding amount with preload   Unit: μ m

		△δ1+△δ2 (Face-to-face or back-to-back)、 △δ1—△δ2 (Tandem)																	
preload value, Bearing series / d mm		7000 C				7200 C				7000 AC / 7200 B				7200 AC / 7300 B					
		GA、GB		GC		GA、GB		GC		GA、GB		GC		GA		GB		GC	
Over	Up to	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
80	120	−2	+2	−2	+2	−2	+2	−2.5	+2.5	−1.5	+1.5	−1.5	+1.5	−1	+1	−2	+2	−2	+2
120	150	−2	+2	−2	+2	−2	+2.5	−3	+3	−1	+1	−1.5	+1.5	−1.5	+1.5	−2	+2	−3	+3

7.2 Lubrication

7.2.1 Lubrication of bearing

The purpose of bearing lubrication is to separate rollers from rolling surface by a thin oil film during running, thereby reduce the internal friction of bearing and friction between components and prevent heat. Its primary functions are as follows:

1 To lubricate every component of bearings, prevent metallic contact, and reduce friction, abrasion etc.

2 Keep the appropriate oil film on the rolling contact surface of bearing, and prolong bearing life.

3 Carry away heat either generated by friction or outside.

4 Prevent dirt or other carry away foreign matter from penetrating into the interior of bearing and occurrence of rust and corrosion.

7.2.2 Lubricating method

The lubricating method of bearing is divided into grease lubrication and oil lubrication. In order to maximize the use function of bearing, first we should choose lubricating method that meets working conditions. If only considering the lubricating effect, oil lubrication is more advantageous. Yet grease lubrication is also widely used as it has the advantage of simplifying working conditions. In recent years, sealed structure that use lubricating grease is increasingly adopted. Table 7.5 makes a comparison of the advantages and disadvantages of oil lubrication and grease lubrication.

Table 7.5 Comparision of oil lubrication and grease lubrication

Item	Oil lubrication	Grease lubrication	
		Open type bearing	Sheiled/Sealed type bearing
Shell mechanism device	Maintenance trouble	Can be simplified	Simplified
Rotational velocity	Be applicable to high speed rotation	The speed limit is 65%-80% of oil lubrication	
Cooling effect	Could carry away heat	None	None
Replacement of lubricating grease	Relatively simple	More difficult	No need for replacement
Control of dust impurity	Easier	Difficult	Professional control effect
Leakage	Easier	Easy	Not easy

7.2.3 Lubricating grease

Lubricating grease is the semisolid lubricant which use lubricating oil as its base oil and incorporate solid lipophilic thickener . Sometimes various additives are mixed into the grease to promote grease characteristics.

1) Base oil

The base oil of lubricating grease mostly use mineral oil, yet when special performances like low-temperature fluidity or high temperature stability are required, we also use synthetic oil such as diester oil, silicone oil, polyethylene diester oil and fluorocarbon oil etc.

Generally speaking, lubricating grease made of low viscosity base oil applies to high-speed bearing and low temperature conditions while that made of high viscosity base oil applies to heavy loading bearing and high temperature conditions.

2) Thickener

The thickener agent of lubricating grease mostly comprises of metallic soap base like lithium, calcium and sodium etc. Yet according to different purposes, we also use thickener with non-metallic soap base (inorganic substance such as silica gel, bernton etc.)