10. Bearing Preload

Bearing is usually selected to have a small clearance during normal operation, but some bearings are selected to have a negative clearance, when mounted, to generate the internal stress, so that various effects can be achieved.

This is so-called preload method, which can be applied only to the rolling bearings, not sliding ones.

10-1 Purpose of Preload

The objectives and application examples of preloading are shown in the Table 10-1.

10-2 Methods and Characteristics of Preload

There are two main types of preload, namely, a position preload and a constant pressure preload.

Position preload can be further divided into several sub-groups, namely, a method tightly fitting a pair of preloaded bearings, a method adjusting the dimensions of a spacer or seam to obtain the proper preload without using a matched pair of bearings, and a method employing the direct control of proper degree of fastening force to apply the appropriate amount of preload by measuring the starting friction moment without using spacer or seam.

These kinds of position preload allow a bearing to keep the constant relative position regardless of its operation status.

The constant pressure preload is a method that uses any of coil spring, plate spring, or board spring to apply a proper amount of preload to bearing. Because the rigidity of preload springs is generally and sufficiently smaller than that of bearing, the preloads are kept almost constant although bearing's relative positions vary during operation.

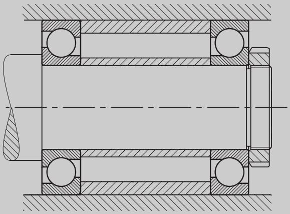
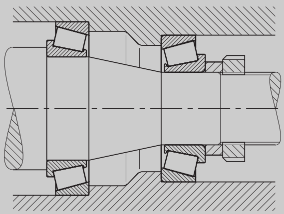
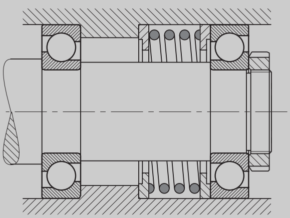
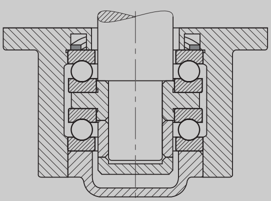
The comparisons between position preload and constant pressure preload are listed below.

- Influence on the increase of bearing rigidity :
  Constant pressure preload < Position preload
- Variation of bearing rigidity by bearing load :
  Constant pressure preload > Position preload
- Variation of preload by temperature and load :
  Constant pressure preload < Position preload

Table 10-1 Preload Purposes and Application Examples

Preload Purpose	Applications
To precisely determine the position of a shaft in radial and axial directions, and to increase its rotating precision at the same time.	Precision bearings for position controlling, used for main shaft bearing of machining tools or precision measuring instruments.
To increase the bearing rigidity	Pinion bearings of main shaft bearing of machining tools or automotive differentials.
To prevent vibration or abnormal noise generated by trembling shaft.	Bearings for small motors of home appliances and others.
To prevent false brinelling	Used where vibration is strong. Bearings for motors required to stop frequently and kingpin thrust ball bearings of automotive vehicles.
To restrict the sliding revolution and sliding rotation of rolling element.	Angular contact ball bearings for high frequency motors or cylindrical roller bearings for jet engines
To restrict the gyration sliding of rolling element	Ball bearings with contact angles or roller bearings of high speed rotation
For exact position control of rolling element against the rings.	For a thrust ball bearing or thrust self-aligning roller bearing used on the side shaft, or to prevent skidding due to ring's own weight load when stopped.

Table 10-2 Methods and Characteristics of Preload

Preloading Method	Example Drawing	Method of Preload Application	Application Examples	Application
Position Preloading		Angular contact ball bearings	ID and OD width variation or a small amount of specified preload is applied.	Grinder Lathe Measuring instrument
		Tapered roller bearings Thrust ball bearings Angular contact ball bearings	The amount of preload is adjusted by controlling the fastening of screws, and the amount of preload is determined by measuring the starting friction torque of a bearing.	Lathe Printer Automotive pinion Automotive wheel
Constant Pressure Preload		Angular contact ball bearings Deep groove ball bearings Tapered roller bearings	Preload is applied by using coil or spring	Motor Winder spindle Grinder
		Thrust ball bearings Thrust spherical roller bearings Thrust cylindrical roller bearings	Preload is applied by using coil or spring	Rolling mill Extruder

10-3 Preload and Rigidity of Bearing

It is necessary to know the correlations between the applied load and displacement of bearing to find out correlations between preload and rigidity, and to theoretically determine the proper amount of preload.

The correlations between load and displacement, when only axial load is applied to bearing, is easy to analyze, because all rolling elements receive same amount of load. But, when the radial or combined load is applied, it's difficult because of varying load distribution.

Axial displacement against axial load can be calculated as follows.

For ball bearings, the axial displacement, δ_a is

$$\delta_a = \frac{c}{\sin\alpha}(Q^2/D_a)^{1/3} \quad \text{(Equation 10-1)}$$

Where,

δ_a : Axial displacement [mm]

c : Constant(Refer to Table 10-3)

α : Contact angle

Q : Weight of rolling element [kgf]

D_a : Ball diameter [mm]

For tapered roller bearings, the axial displacement, δ_a is

$$\delta_a = \frac{0.0006}{\sin\alpha} \cdot \frac{Q^{0.9}}{l_a^{0.8}} \quad \text{(Equation 10-2)}$$

Where,

l_a : Effective contact length of roller [mm]

Table 10-3 Corelations between f and c

f	0.51	0.515	0.5175	0.52	0.525	0.53	0.54
$c \times 10^5$	176	194	201	207	218	227	242

("f" is the ratio of radius of raceway groove to ball diameter.)

$$Q = \frac{F_a}{Z\sin\alpha} \quad \text{(Equation 10-3)}$$

Where,

F_a : Axial load [kgf]

Z : Number of rolling elements

In case of tapered roller bearings, because their contact angles do not change regardless of the axial loads, the same nominal contact angles as determined in the design can be used. But for ball bearings, the following Equation has to be used to obtain effective contact angles, because their contact angles change depending on the axial loads.

$$\frac{\cos\alpha_o}{\cos\alpha} = 1 + \frac{c}{f_o + f_i - 1}(Q/D_a^{\,2})^{2/3} \quad \text{(Equation 10-4)}$$

In the above Equation, f_o and f_i represent the ratios of raceway radius of outer and inner rings to ball diameter, D_a, and in case of ball bearings, their initial contact angle, α_o, can be obtained by using the inside residual clearance, Δ_r, as follows.

$$\cos\alpha_o = 1 + \frac{\Delta_r}{2(f_o + f_i - 1)D_a} \quad \text{(Equation 10-5)}$$

10-4 Evaluation of Preload

As mentioned earlier, various effects can be achieved by applying the preload appropriately, but application of excessive preload can become the causes for excessive heat generation, increased friction moment, and/or reduction of bearing life, etc.

Therefore the amount of preload should be decided after careful analysis of bearing operating conditions and the purpose of preload, and others.

For example, the main purpose of preload for the bearings of main shaft of machining tools is to increase its rigidity, so the amount of preload can be calculated by using the elastic modulus required for bearing in the shaft system. But, in case of machining tools, RPM range of main shaft is generally very wide, which means that good result can be obtained when heavy cutting job is carried out at low speeds, while the light cutting job at high speeds may generate excessive heat.

Also, in case the main purpose is to prevent false brinelling, the exact amount of preload needs be calculated just enough to prohibit the creation of clearance by vibration load, so as to prevent rolling element from being vibrated by outside vibration when shaft is not rotating.

However, for electric motors, it is essential to review whether the heat generation and shortening of bearing life, caused by preload, has some effect on the performances or system life of the electric motor or not.

Therefore, the appropriate amount of preload should be decided only after comprehensive analysis of theoretically calculated values as well as the empirical/experimental data.

10-5 Controlling of Preload

Various preload control methods are shown below.

(1) Control by measuring the starting friction moment of bearing

This method uses the starting friction moment, which is measured by using the co-relations between itself and axial load, so as to control the preload. This method is widely used for tapered roller bearings when they are applied with the preload.

(2) Control by measuring the spring displacements

This method is used for constant pressure preload. By using the findings of corelations between the load of preload spring and its displacement, preload can be controlled in accordance with the spring displacements.

(3) Control by measuring the axial displacement of bearing

By using the findings of co-relations between the axial load and axial displacements, preload can be controlled in accordance with its axial displacements.

(4) Control by measuring the torque(fastening force) of nut

In case that the preload is applied by using the fastening nut on a matched pair of bearings without using a spacer or seam, if the nut has been sufficiently smoothened and fastened by applying sufficiently strong torque, the fastening force, in other word, the preload, can be applied within a comparatively minor fluctuation, which makes it possible to control the preload. This method is widely used for tapered roller bearings in the automotive vehicles.