B-2-5 Life (dynamic load limitation)

B-2-5.1 Life of Ball Screw

Although used in appropriate conditions and is ideally designed, the ball screw deteriorates after a certain operation period, and eventually becomes unusable. The period in this situation is the life of the ball screw. There are two life categories, "fatigue life" caused by flaking, and "life of accuracy" caused by deterioration in precision because of wear.

B-2-5.2 Fatigue Life

Fatigue life of the ball screw can be estimated by basic dynamic load rating (C_a) as is for the rolling bearing.

(1) Basic dynamic load rating C_a

Basic dynamic load rating is the axial load which allows a 90% of the group of the same ball screws to rotate 1 million times (10^6rev) under the same condition without causing flaking by rolling contact fatigue.

(2) Fatigue life calculation

Fatigue life is defined as a total rotation number in general. It is sometimes indicated by total rolling hours or total running distance. Fatigue life is obtained by the following formula.

$$L = \left(\frac{C_a}{F_a \cdot f_w}\right)^3 \cdot 10^6 \quad \cdots (\text{II-8})$$

$$L_t = \frac{L}{60n} \quad \cdots (\text{II-9})$$

$$L_s = \frac{L \cdot l}{10^6} \quad \cdots (\text{II-10})$$

In this formula:

- L : Rating fatigue life (rev)
- L_t : Life in hours (h)
- L_s : Life by running distance (km)
- C_a : Basic dynamic load rating (N)
- F_a : Axial load (N)
- n : Rotational speed (min^{-1})
- l : Lead (mm)
- f_w : Load factor (Coefficient by operating condition)

Load coefficients f_w in operation condition are shown in Table 5.1.

Table 5.1 Load coefficient f_w

Smooth operation without impact	1.0 – 1.2
Normal operation	1.2 – 1.5
Operation associated with impact or vibration	1.5 – 3.0

Setting too long fatigue life requires larger ball screw, and is not economical. Below are the general target values of operating life for machines. (reference)

Table 5.2 General target values of fatigue life

Machine tools	20000 hours
Industrial machines	10000 hours
Automatic control system	15000 hours
Measuring equipment	15000 hours

(3) Mean load

If the axial load varies often, to calculate a life, obtain a mean load which gives equivalent fatigue life under this varying load conditions.

①When load and rotational speed shift stepwise

Obtain the mean load F_m by the formula below.

Obtain mean rotational speed N_m by the formula below as Table 5.3, Fig. 5.1.

$$F_m = \left(\frac{F_1^3 \cdot n_1 \cdot t_1 + F_2^3 \cdot n_2 \cdot t_2 + \cdots F_n^3 \cdot n_n \cdot t_n}{n_1 \cdot t_1 + n_2 \cdot t_2 + \cdots + n_n \cdot t_n}\right)^{\frac{1}{3}} \quad \cdots (\text{II-11})$$

$$N_m = \frac{n_1 \cdot t_1 + n_2 \cdot t_2 + \cdots + n_n \cdot t_n}{t_1 + t_2 + \cdots + t_n} \quad \cdots (\text{II-12})$$

Table 5.3 Stepwise operation condition

Axial load (N)	Rotational speed (min^{-1})	Hours of use, or ratio of hours of use
F_1	n_1	t_1
F_2	n_2	t_2
:	:	:
F_n	n_n	t_n

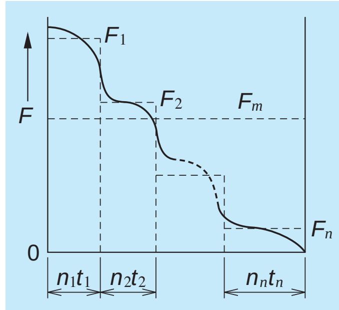


Fig. 5.1 Stepwise load variation

②When the rotational speed is constant, and the load changes linearly, obtain approximate value of the mean load F_m by the formula below.

$$F_m = \frac{1}{3}(F_{min} + 2F_{max}) \quad \cdots (\text{II-13})$$

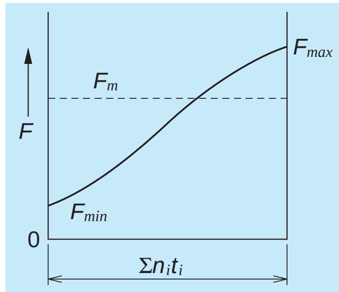


Fig. 5.2 Linear load change

③When rotational speed is constant, and the load changes in sinusoidal pattern, obtain approximate value of the mean load F_m by the formula below.

When the sine curve is Fig. (a)

$$F_m \fallingdotseq 0.65\, F_{max} \quad \cdots (\text{II-14})$$

When the sine curve is Fig. (b)

$$F_m \fallingdotseq 0.75\, F_{max} \quad \cdots (\text{II-15})$$

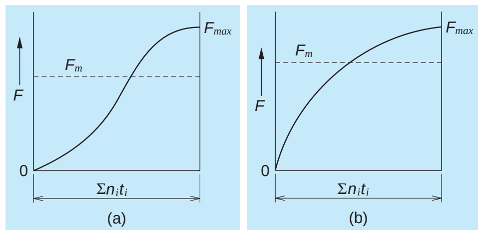


Fig. 5.3 Load changes in sinusoidal pattern

(4) Affect of mounting misalignment

If moment load or radial load is applied to the ball screw, it adversely affects ball screw function, and shortens life. Watch for eccentric load that induces moment or radial load.

Fig. 5.4 shows a calculation example of fatigue life when moment load is applied to the ball screw. In this figure, the value of the rigidity of mounting ball screw sections (screw shaft, support bearing, guide, etc.) is set at infinity. In actual use, deformation is absorbing the moment load in various areas, and the moment load that generates between the screw shaft and nut is abated.

In general, the following values are recommended as control values for precision grade.

Misalignment in inclination	··1/2000 or less
Eccentricity	·························20 μm or less

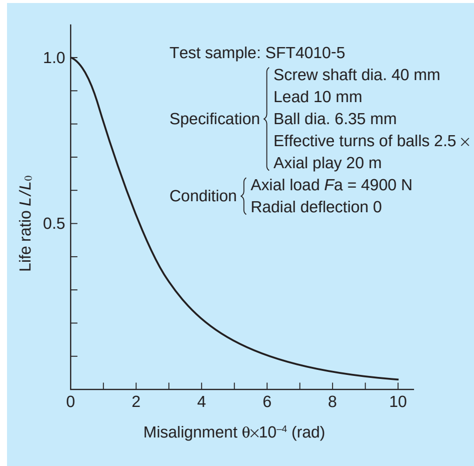


Fig. 5.4 Affects of misalignment

(5) Effects of heavy load and short stroke

If the ball screw is used under heavy load and short strokes, such as for drive of plastic injection molding machine and of press machines, the fatigue life may become significantly shorter than the rated fatigue life which is calculated in B-2-5.2.
This decreased life occurs because the heavy load generates large stress (surface pressure) in the contact point of balls and ball grooves of the screw shaft and the nut, adversely affecting the life. In such case, the life calculation should take into account the size of the surface pressure as well as the size of the stroke.

The axial load F_{amax} *1 during operation and the size of strokes, which affect fatigue life, can be obtained by the following formula.
In such case, the life calculation should take into account the size of the surface pressure as well as the size of the stroke. Please consult with NSK.

$$F_{amax} \geq 0.10C_{0a} \qquad \cdots (\text{Ⅱ-16})$$
$$S \leq 4$$

In this formula:

F_{amax} : Maximum load to axial direction during drive (N)
C_{0a} : Basic static load rating (N)
S : Stroke (rev)

$$S = \frac{L_s}{l}$$

L_s : Stroke distance (mm)
l : Lead (mm)

* Axial load : The load is applied to the axial direction when screw shaft and the nut of ball screw are rotating relatively each other. The rotational speed is irrelevant.

B-2-5.3 Ball screw and Hardness

Table 5.4 indicates NSK standard ball screw and their hardness.

Table 5.4 Ball screw materials and their hardness

Component	Heat treatment method	Hardness (HRC)
Screw shaft	Carburizing	58 or over
	Induction hardening	58 or over
Nut	Carburizing	58 or over

* NSK manufactures special material ball screws for special environments (stainless steel: SUS440C, SUS630). NSK also furnishes surface treatment (Refer to Page D5). Please consult NSK for such request.

B-2-5.4 Wear Life

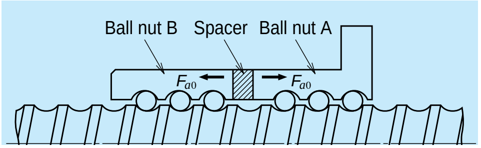
Wear of materials, as is the case for other mechanical components, is significantly affected by use conditions, lubrication conditions and other factors. It is difficult to estimate its volume, and measuring requires various tests and field data.
NSK has data of wear accumulated through abundant experience. Please contact NSK for inquiry pertaining to the wear.

B-2-6 Preload and Rigidity

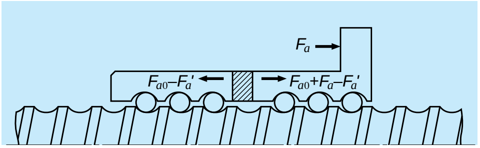
B-2-6.1 Elastic Deformation of the Preloaded Ball Screw

(1) Position preload (D, Z, P preloads)

Double nut preload ball screw shown in Fig. 6.1.



(a) Extemal load : 0



(b) Extemal load : F_a

Fig. 6.1 Position preload (double-nut)

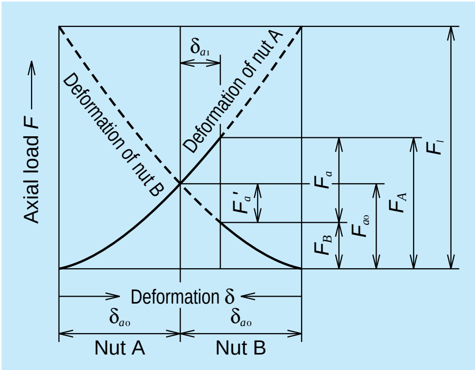


Fig. 6.2 Deformation of A and B nut (position preload)

Elastic deformation of Nut A and B is already given at time of assembly by the amount of δao by preload F_{ao}. When the external load F_a is added to Nut A, the elastic deformation δ_a and δ_b of each Nut A and B change as shown in Fig. 6.2,

$$\delta_a = \delta_{ao} + \delta_{a1} \qquad \delta_b = \delta_{ao} - \delta_{a1}$$

At this time, the load to each Nut A and B are:

$$F_A = F_{ao} + F_a - F_a'$$
$$F_B = F_{ao} - F_a'$$

It shows that the load applied to Nut A is affected by Nut B and reduced by the amount of F_a'. Thereby, the elastic deformation of Nut A becomes smaller. This effect continues until the elastic deformation by the external load becomes δ_{ao}, and the preload by Nut B disappears.
Assuming that the load when the preload is absorbed is F_l, the relationship between the axial load and the elastic deformation is as follows. (Fig. 6.2)

$$\delta_{ao} = K \cdot F_{ao}^{2/3} \qquad 2\delta_{ao} = K \cdot F_l^{2/3}$$

(K : Invariable number)

$$\left[\frac{F_l}{F_{ao}}\right]^{2/3} = \frac{2\delta_{ao}}{\delta_{ao}} = 2$$

$$F_l = 2^{3/2} \times F_{ao} \fallingdotseq 3F_{ao}$$

For this reason, the preload should be about 1/3 of the maximum axial load. Please note that the preload of about 1/3 of the maximum axial load increases heat, and shortens life if it exceeds 10% of C_a. The criterion for the maximum preload is 0.1 C_a.

Fig. 6.3 shows two types of elastic deformation curves: one is by the ball screw with preload, the other without preload. When an axial load which is about three times as large as the preload is applied, the deformation of the preloaded ball screw is 1/2 of the deformation of the ball screw without preload.

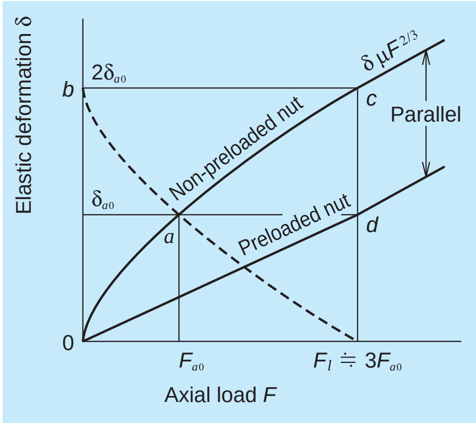


Fig. 6.3 Deformation of preloaded ball nut (position preload)