The criterion of the preload to ball screw

Nut rigidity increases by a larger preload volume. But excessive preload shortens life, and generates heat. Set the maximum preload about at 0.1 C_a (0.05 for *P* Preload). Table 6.1 shows the criteria for preload for different application.

Table 6.1 Criteria of preload

Ball screw application	Preload (relative to dynamic load rating C_a)
Robots,material handling systems, etc.	Axial play or under 0.01 C_a
Semiconductor manufacturing systems, etc. That require highly accurate positioning	0.01 C_a – 0.04 C_a
Medium- high-speed machine tools for cutting	0.03 C_a – 0.07 C_a
Low to medium-speed systems that require especially high rigidity	0.07 C_a – 0.1 C_a

(4) Axial rigidity of support bearing: K_B

Rigidity of the combined thrust angular contact ball bearings which is widely used as a support bearing of the ball screw for high-precision equipment can be obtained by the following formula.

$$K_B \fallingdotseq \frac{3F_{a0}}{\delta_{a0}} \ (\text{N}/\mu\text{m}) \qquad (\text{II-24})$$

In this formula:

K_B : Rigidity of the combined thrust angular contact ball bearings (N/µm)

F_{ao} : Preload of the bearings (N)

δ_{ao} : Axial elastic deformation by preload (µm)

$$\delta_{a0} \fallingdotseq \frac{0.44}{\sin\alpha}\left(\frac{Q^2}{D_w}\right)^{1/3} (\mu\text{m}) \qquad (\text{II-25})$$

$$Q = \frac{F_{a0}}{Z} \cdot \sin\alpha$$

α : Contact angle

D_w : Ball diameter (mm)

Z : Number of balls

Refer to Page B457 for data regarding thrust angular contact ball bearings which support high-precision ball screws (TAC Series).

(5) Axial rigidity of the ball nut and bearing mounting section: K_H

The effect of rigidity of mounting section on positioning accuracy is big, we recommend incorporating high rigidity of the mounting sections of ball nut and support bearings into the design at the early stage of designing the machine.

(a) Torsional rigidity of the feed screw system

Major torsion factors in the rotating system that bring about error in positioning accuracy are given three points below.

- Torsional deformation of the screw shaft
- Torsional deformation of the joint section
- Torsional deformation of the motor

The value of the effect of torsional strain to positioning accuracy is smaller than axial deformation. However, check the effect when designing equipment that requires high positioning accuracy.

(b) Suppress thermal error

It is necessary to minimize the thermal error for ever increasing demand for positioning accuracy give three points below.

- Suppress heat
- Forced cooling
- Avoid effect of temperature rise

Refer to "Measures against thermal expansion" on Page B44.

B-2-7 Friction Torque and Drive Torque

Operations that use ball screw drives require a motor torque which is equivalent to the total of two:

- Friction torque, i.e. the friction of the ball screw itself
- Drive torque which is required for operation

B-2-7.1 Friction Torque

(1) Starting friction torque (Break away torque)

A large torque is necessary to start ball screw. This is called "starting friction torque" or "brakeaway torque." This torque is 2 to 2.5 times larger than preloaded dynamic (friction) torque which is described below. Starting friction torque quickly diminishes once the ball screw begins to move.

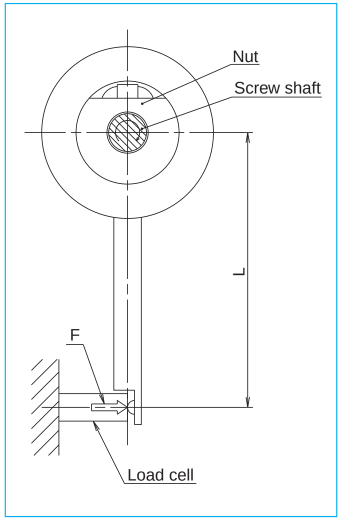

Fig. 7.2 Preload dynamic torque measuring method

(2) Dynamic preloaded drag torque (preloaded dynamic friction torque)

When the ball screw is moving, two types of torque generate: 1. Dynamic friction torque by preload; 2. Friction torque associated with ball recirculation. JIS B1192 sets standard of dynamic preloaded torque, which is the total of these two torque types. They are defined in Fig. 7.1.

The preload dynamic friction torque is calculated by following formula. When screw shaft is rotated as Fig. 7.2 in following measure condition, measuring the nut stop power *F* and the distance from action line and right angle direction to the measured screw shaft multiple by it's power value *F*.

$$T_p = F \cdot L \qquad (\text{II-26})$$

- Measuring rotational speed 100 min^{-1}
- Viscosity of lubrication is prescribed in JIS K 2001 ISO VG 68
- Without measurement Seal

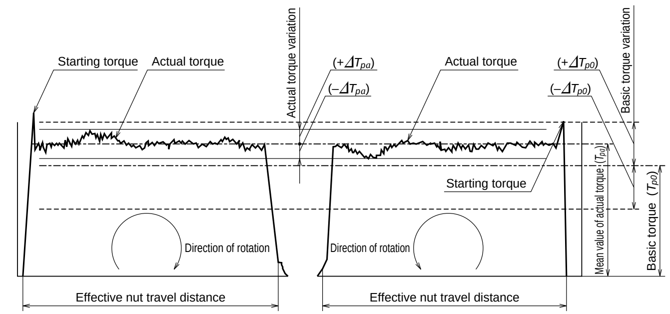

Fig. 7.1 Definitions of dynamic preloaded drag torque

(3) Calculation of basic torque

Basic torque of preloaded ball screw T_{p0} can be obtained by the following formula.

$$T_{p0} = K \frac{F_{a0} \bullet l}{2\pi} \fallingdotseq 0.014 F_{a0} \sqrt{dm \bullet l} \quad (\text{N} \cdot \text{cm}) \qquad (\text{II-27})$$

In this formula:

F_{a0} : Preload (N)

l : Lead (cm)

K : Torque coefficient of ball screw

$$K = \frac{0.05}{\sqrt{tan\beta}}$$

β : Lead angle (deg.)

d_m : Ball pitch circle diameter (cm)

Allowable values of torque variation rate relative to basic torque are regulated as shown in Table 7.1.

B-2-7.2 Drive Torque

(1) Operating torque of the ball screw

① Normal drive

The torque when converting rotational motion to linear motion (normal operation) is obtained by the following formula.

$$T_a = \frac{F_a \bullet l}{2\pi \bullet \eta_1} \quad (\text{N} \cdot \text{cm}) \qquad (\text{II-28})$$

In this formula:

T_a : Normal operation torque (N · cm)

F_a : Axial load (N)

l : Lead (cm)

η_1 : Normal efficiency ($\eta_1 = 0.9 – 0.95$)

② Back-drive operation

The torque when converting linear motion to rotational motion (back-drive operation) is obtained by the following formula.

$$T_b = \frac{F_a \bullet l \bullet \eta_2}{2\pi} \quad (\text{N} \cdot \text{cm}) \qquad (\text{II-29})$$

In this formula:

T_b : Reverse operation torque (N · cm)

η_2 : Reverse efficiency ($\eta_2 = 0.9$ - 0.95)

③ Dynamic drag torque of the preloaded ball screw

Operation torque of preloaded ball screw can be obtained by Formula Ⅱ-27.

Table 7.1 Range of allowable values of torque variation rates (Source: JIS B 1192)

Basic torque (N · cm)		Effective length of the screw thread (mm)										
		4000 or under								Over 4000 and 10000 or under		
		Slenderness ratio[1]: 40 or less				Slenderness ratio[1]: More than 40 and 60 or less				—		
		Accuracy grade				Accuracy grade				Accuracy grade		
Over	Incl.	C0	C1	C2, 3	C5	C0	C1	C2, 3	C5	C1	C2, 3	C5
20	40	±30%	±35%	±40%	±50%	±40%	±40%	±50%	±60%	—	—	—
40	60	±25%	±30%	±35%	±40%	±35%	±35%	±40%	±45%	—	—	—
60	100	±20%	±25%	±30%	±35%	±30%	±30%	±35%	±40%	—	±40%	±45%
100	250	±15%	±20%	±25%	±30%	±25%	±25%	±30%	±35%	—	±35%	±40%
250	630	±10%	±15%	±20%	±25%	±20%	±20%	±25%	±30%	—	±30%	±35%
630	1000	—	±15%	±15%	±20%	—	—	±20%	±25%	—	±25%	±30%

Remarks 1. Slenderness ratio: The value obtained by dividing the length of the screw thread section of screw shaft (mm) by diameter of the screw shaft (mm).
2. NSK independently sets torque standards which are under 20 N · cm.

(2) Drive torque of the motor

① Drive torque at constant speed

Torque which is necessary to drive a ball screw at constant speed resisting to external loads can be obtained by the following formula.

$$T_1 = (T_a + T_{pmax} + T_u) \times \frac{N_1}{N_2} \qquad (\text{II-30})$$

In this formula:

T_a : Drive torque at constant speed

$$T_a = \frac{F_a \bullet l}{2\pi \bullet \eta_1} \qquad (\text{II-28})$$

F_a : Axial load (N)

The value of F_a in Fig. 7.3 is:

$F_a = F + \mu \bullet m \bullet g$

F : Such as cutting force to axial direction (N)

μ : Friction coefficient of the guide way

m : Volume of the traveling section (table mass plus work mass kg)

g : Gravitational acceleration (9.80665 m/s²)

T_{pmax} : Upper limit of the dynamic friction torque of ball screw (N · cm)

T_u : Friction torque of the support bearing (N · cm)

N_1 : Number of teeth in Gear 1

N_2 : Number of teeth in Gear 2

Generally, though it depends on the type of motor, T_1 shall be kept under 30% of the motor rating torque.

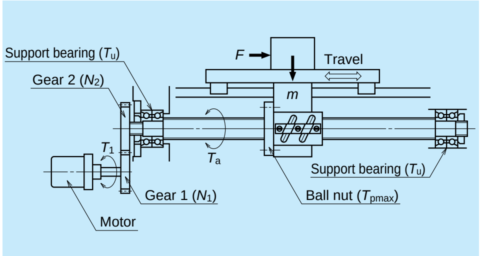

Fig. 7.3 Driving mechanism of ball screw

② Drive torque at acceleration

Accelerating the ball screw resisting axial load requires maximum torque. Drive torque necessary for this occasion can be obtained by the following formula.

$$T_2 = T_1 + J \bullet \dot{\omega} \qquad (\text{II-31})$$

$$J = J_M + J_{G1} \left(\frac{N_1}{N_2}\right)^2 \left[J_{G2} + J_S + m \left(\frac{l}{2\pi}\right)^2 \right] \quad (\text{kg} \cdot \text{m}^2) \qquad (\text{II-32})$$

In this formula:

T_2 : Maximum drive torque at time of acceleration (N · m)

$\dot{\omega}$: Motor's angular acceleration (rad/s²)

J : Moment of inertia applied to the motor (kg · m²)

J_M : Moment of inertia of the motor (kg · m²)

J_{G1} : Moment of inertia of Gear 1 (kg · m²)

J_{G2} : Moment of inertia of Gear 2 (kg · m²)

J_S : Moment of inertia of the screw shaft (kg · m²)

When selecting a motor, it is necessary to examine the maximum torque of the motor relative to maximum drive torque T_2 at time of acceleration of ball screw.

Calculation of the moment of inertia of a cylindrical object (ball screw, gear, etc.), please refer to below.

Formula for the moment of inertia of a cylindrical object

$$J = \frac{\pi \bullet \gamma}{32} D^4 \bullet L \quad (\text{kg} \cdot \text{cm}^2) \qquad (\text{II-33})$$

In this formula:

γ : Material density (kg/cm³)

D : Diameter of the cylindrical object (cm)

L : Length of the cylindrical object (cm)