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 following 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 high torque is necessary to start a ball screw. This is called "starting friction torque" or "brakeaway torque." This torque is 2 to 2.5 times larger than the dynamic (friction) torque due to preload which is described below. The starting friction torque quickly diminishes once the ball screw begins to move.

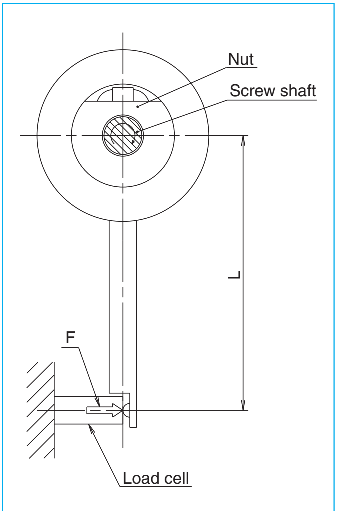

Fig. 7.1 Preload dynamic torque measuring method

(2) Dynamic friction torque (dynamic friction torque due to preload)

When a ball screw is moving, two types of torque generate: the dynamic friction torque due to preload and the friction torque associated with ball recirculation. JIS B1192 sets the standard of dynamic friction torque due to preload, which is the total of these two torque types. They are defined in **Fig. 7.2**.

The dynamic friction torque due to preload is calculated by the following formula. When the screw shaft is rotated as **Fig. 7.1** in the following measuring conditions, measure the nut holding power *F* and then multiple the distance of action line *L* which is perpendicular to the direction of the power *F*.

$$T_p = F \cdot L \qquad \cdots 26)$$

- Measuring rotational speed 100 min^{-1}
- Viscosity of lubrication is ISO VG 68 as prescribed in JIS K 2009.
- Remove Seals.

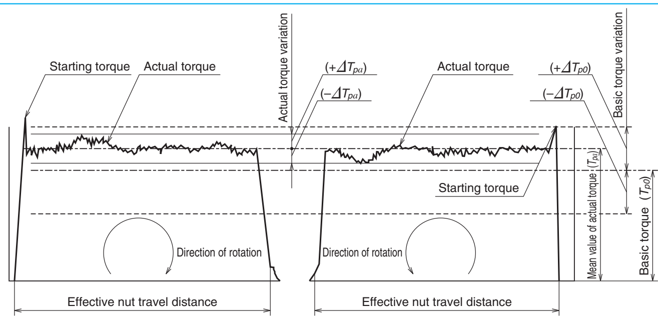

Fig. 7.2 Definitions of dynamic preloaded drag torque

(3) Calculation of basic torque

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

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

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 a ball screw

(a) Normal drive

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

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

In this formula:

T_a : Normal operation torque (N · cm)

F_a : Axial load (N)

l : Lead (cm)

η_1 : Normal efficiency (η_1 = 0.9 to 0.95)

(b) Back-drive operation

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

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

In this formula:

T_b : Reverse operation torque (N · cm)

η_2 : Reverse efficiency (η_2 = 0.9 to 0.95)

(c) Dynamic drag torque of the preloaded ball screw

the operation torque of preloaded ball screw can be obtained by Formula 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)										
		4 000 or under								Over 4 000 and 10 000 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	1 000	—	±15%	±15%	±20%	—	—	±20%	±25%	—	±25%	±30%

Notes: 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

(a) Drive torque at constant speed

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

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

In this formula:

T_a : Drive torque at constant speed

$$T_a = \frac{F_a\cdot l}{2\pi\cdot\eta_1} \qquad \cdots 28)$$

F_a : Axial load (N)

The value of F_a in **Fig. 7.3** is:

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

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.

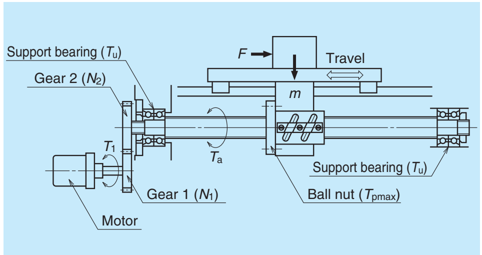

Fig. 7.3 Driving mechanism of ball screw

(b) Drive torque at acceleration

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

$$T_2 = T_1 + J\cdot\dot{\omega} \qquad \cdots 31)$$

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

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 the drive torque T_2 at the time of acceleration of ball screw.

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

Formula for the moment of inertia of a cylindrical object

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

In this formula:

γ : Material density (kg/cm³)

D : Diameter of the cylindrical object (cm)

L : Length of the cylindrical object (cm)