

## DRIVING TORQUE

Frictional characteristics of ball screw and selection of driving motor.

### •FRICTION AND EFFICIENCY

The efficiency “η” of a ball screw obtained by the analysis of a mechanical model of screw can be expressed as follows, assuming that the coefficient of friction =μ and the screw lead angle =β.

•When converting the rotational force into the axial force (normal operation):

$$\eta = \frac{1 - \mu \tan \beta}{1 + \mu / \tan \beta} \dots\dots\dots (32)$$

•When converting the axial force into the rotational force (reverse operation):

$$\eta' = \frac{1 - \mu / \tan \beta}{1 + \mu \tan \beta} \dots\dots\dots (33)$$

### •LOAD TORQUE

The load torque (constant-speed driving torque) required for designing a driving unit (motor etc.) can be worked out as follows.

#### •Normal operation

When converting the rotational force into the axial force

$$T = \frac{PL}{2\pi\eta} \quad (\text{N}\cdot\text{cm}) \dots\dots\dots (34)$$

Where,

T:Load torque(N•cm)  
 P:Axial external load(N)  
 L:Lead of ball screw(cm)  
 η:Efficiency of ball screw(0.9)

#### •Reverse operation

When converting the axial force into the rotational force

$$P = \frac{2\pi T}{\eta' L} \quad (\text{N}) \dots\dots\dots (35)$$

Where,

P:Axial external load(N)  
 T:Load torque(N•cm)  
 L:Lead of ball screw(cm)  
 η':Efficiency of ball screw(0.9)

#### •Friction torque caused by preload

A torque produced by preloading. According as the external load increases, the preload applied to the preload nut is gradually released and consequently, the friction torque caused by preload is reduced.

In case of no-load:

$$T_P = K \frac{P_L L}{2\pi} \quad (\text{N}\cdot\text{cm}) \dots\dots\dots (36)$$

$$K = 0.05(\tan \beta)^{\frac{1}{2}}$$

Where,

- P<sub>L</sub>:Preload (N)
- L:Lead of ball screw (cm)
- K:Coefficient of internal friction
- β:Lead angle

$$\beta = \tan^{-1} \left( \frac{L}{\pi D} \right)$$

D:Outside diameter of screw shaft (cm)

### •SELECTION OF A DRIVING MOTOR

Select a motor which meets the following conditions.

1. The motor should be able to sufficiently bear the load torque applied to the output shaft.
2. The motor should be able to start and stop at the required pulse speed when the moment of inertia is applied to the output shaft.
3. The required acceleration constant and deceleration constant can be obtained when the moment of inertia is applied to the output shaft.

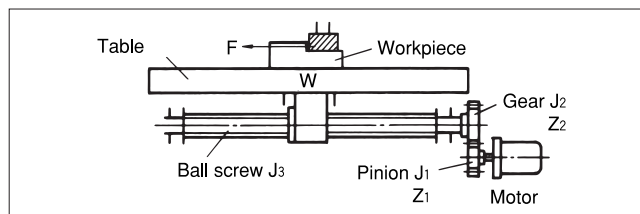


Fig. 21

#### •Torque applied to the output shaft of a motor

A torque required for driving at a constant speed against external load.

$$T_1 = \left( \frac{PL}{2\pi\eta} + T_P \frac{(3P_L - P)}{3P_L} \right) \frac{Z_1}{Z_2} \quad (\text{N}\cdot\text{cm}) \dots\dots (37)$$

Where, P ≤ 3P<sub>L</sub>

T<sub>1</sub>:Driving torque at constant speed (N•cm)

P:Axial external load (N)

$$P = F + \mu Mg$$

F:Anti-thrust repulsive force by cutting force (N)

M:Weight of table and work (kg)

μ:Coefficient of friction of sliding surface

g:Acceleration of gravity (9.8m/s<sup>2</sup>)

L:Lead of ball screw (cm)

η:Mechanical efficiency of motor including ball screw and gear

T<sub>P</sub>:Friction torque caused by preload (N•cm) Refer to formula 36.

P<sub>L</sub>:Preload (N)

Z<sub>1</sub>:Number of teeth of pinion

Z<sub>2</sub>:Number of teeth of gear

# TECHNICAL DATA OF BALL SCREWS

•Acceleration torque applied to the shaft of a motor  
A torque required for accelerative driving against external load.

$$T_2 = J_M \omega = J_M \times \frac{2\pi N}{60t} \times 10^{-3} \quad (\text{N}\cdot\text{cm}) \dots\dots ⑳$$

$$J_M = J_1 + J_4 + \left(\frac{Z_1}{Z_2}\right)^2 \left\{ (J_2 + J_3) + M \left(\frac{L}{2\pi}\right)^2 \right\} \quad (\text{kg}\cdot\text{cm}^2) \dots\dots ㉑$$

Where,

- $T_2$  :Driving torque at the time of acceleration (N•cm)
- $\omega$  :Angular acceleration of motor shaft (rad/S<sup>2</sup>)
- $N$  :Number of revolutions of motor shaft (min<sup>-1</sup>)
- $t$  :Acceleration time (s)
- $J_M$  :Moment of inertia applied to motor (kg•cm<sup>2</sup>)
- $J_1$  :Moment of inertia of pinion (kg•cm<sup>2</sup>)
- $J_2$  :Moment of inertia of gear (kg•cm<sup>2</sup>)
- $J_3$  :Moment of inertia of ball screw (kg•cm<sup>2</sup>)
- $J_4$  :Moment of inertia of motor rotor (kg•cm<sup>2</sup>)
- $M$  :Mass of table and work (kg)
- $L$  :Lead of ball screw (cm)

Moment of inertia of cylinders such as ball screw and gear (Calculation of  $J_1$ - $J_4$ )

$$J = \frac{\pi\gamma}{32} D^4 \ell \quad (\text{kg}\cdot\text{cm}^2) \dots\dots ㉒$$

Where,

- $D$ :Outside diameter of cylinder (cm)
- $\ell$  :Length of cylinder (cm)
- $\gamma$ :Specific gravity of material
- $\gamma = 7.8 \times 10^{-3} (\text{kg}/\text{cm}^3)$

•Total torque applied to the shaft of a motor  
The total torque can be calculated by adding the value of formula ㉑, to that of formula ㉒.

$$T_M = T_1 + T_2 = \left( \frac{PL}{2\pi\eta} + T_P \frac{(3P_L - P)}{3P_L} \right) \frac{Z_1}{Z_2} + J_M \frac{2\pi N}{60t} \times 10^{-3} \quad (\text{N}\cdot\text{cm}) \dots\dots ㉓$$

Where,

- $T_M$ :Total torque applied to output shaft of motor (N•cm)
- $T_1$ :Driving torque at constant speed (N•cm)
- $T_2$ :Driving torque at the time of acceleration (N•cm)

After temporarily selecting a motor, check the motor for the following items. At this time, the motor should satisfactorily meet the prescribed conditions of the respective.

Effective torque value

Acceleration constant

Over-load characteristics and tolerance to overheat of motor at the time of repetitional starting and stopping