H

Technical Reference

Selection Calculations

Motors

Linear & Rotary Actuators

Cooling Fans

Service Life

Stepper Motors

Servo Motors

Standard AC Motors

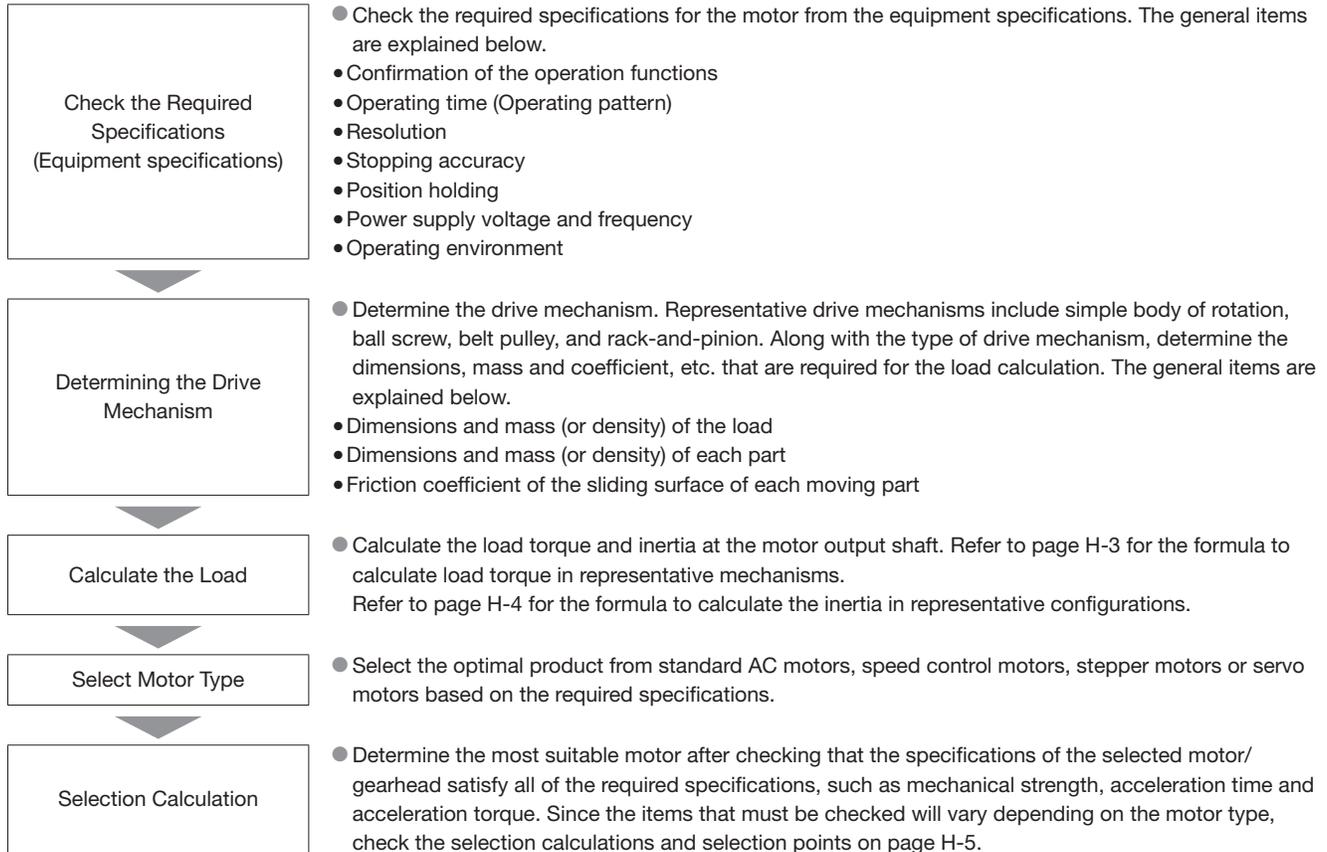Brushless Motors/AC Speed Control Motors

Gearheads

Cooling Fans

Selection Calculations For Motors

Selecting a motor that satisfies the specifications required by your equipment is an important key to ensuring the desired reliability and economic efficiency of the equipment.
This section introduces the procedure to select the ideal motor, selection calculations, key points of selection and selection examples.

■Selection Procedure

An overview of the selection procedure is explained below.

Check the Required Specifications (Equipment specifications)	● Check the required specifications for the motor from the equipment specifications. The general items are explained below. ● Confirmation of the operation functions ● Operating time (Operating pattern) ● Resolution ● Stopping accuracy ● Position holding ● Power supply voltage and frequency ● Operating environment
Determining the Drive Mechanism	● Determine the drive mechanism. Representative drive mechanisms include simple body of rotation, ball screw, belt pulley, and rack-and-pinion. Along with the type of drive mechanism, determine the dimensions, mass and coefficient, etc. that are required for the load calculation. The general items are explained below. ● Dimensions and mass (or density) of the load ● Dimensions and mass (or density) of each part ● Friction coefficient of the sliding surface of each moving part
Calculate the Load	● Calculate the load torque and inertia at the motor output shaft. Refer to page H-3 for the formula to calculate load torque in representative mechanisms. Refer to page H-4 for the formula to calculate the inertia in representative configurations.
Select Motor Type	● Select the optimal product from standard AC motors, speed control motors, stepper motors or servo motors based on the required specifications.
Selection Calculation	● Determine the most suitable motor after checking that the specifications of the selected motor/gearhead satisfy all of the required specifications, such as mechanical strength, acceleration time and acceleration torque. Since the items that must be checked will vary depending on the motor type, check the selection calculations and selection points on page H-5.

Sizing and Selection Service

We provide sizing and selection services for motor section from your application specification requirements.

● **Phone**
Requests for sizing and section can be made online by contacting our technical support team at:
USA/Canada: TEL: 800-468-3982
Mexico: TEL: 01-800-681-5309

● **Website**
Requests for sizing and section can be made online by contacting our technical support team at techsupport@orientalmotor.com.

Use our online Motor Sizing Tool to calculate the necessary torque, speed, stopping accuracy and the system inertia that is important to consider when selecting a proper motor for the application.
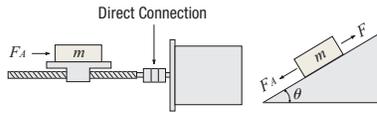
■ Formula for Load Torque T_L [N·m] for Each Drive Mechanism
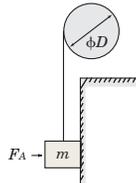
● Formula for Load Torque
◇ Ball Screw Drive

$$T_L = \left(\frac{F \cdot P_B}{2\pi \cdot \eta} + \frac{\mu_0 \cdot F_0 \cdot P_B}{2\pi}\right)\frac{1}{i} \text{ [N·m]} \quad \text{①}$$

$$F = F_A + m \cdot g(\sin\theta + \mu \cdot \cos\theta) \text{ [N]} \quad \text{②}$$

Direct Connection

◇ Pulley Drive

$$T_L = \frac{\mu \cdot F_A + m \cdot g}{2\pi} \cdot \frac{\pi \cdot D}{i}$$
$$= \frac{(\mu \cdot F_A + m \cdot g)D}{2 \cdot i} \text{ [N·m]} \quad \text{③}$$

◇ Wire and Belt Drive, Rack-and-Pinion Drive

$$T_L = \frac{F}{2\pi \cdot \eta} \cdot \frac{\pi \cdot D}{i} = \frac{F \cdot D}{2 \cdot \eta \cdot i} \text{ [N·m]} \quad \text{④}$$

$$F = F_A + m \cdot g(\sin\theta + \mu \cdot \cos\theta) \text{ [N]} \quad \text{⑤}$$
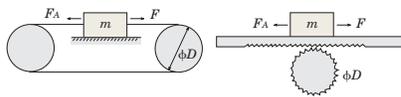
◇ Actual Measurement Method

$$T_L = \frac{F_B \cdot D}{2} \text{ [N·m]} \quad \text{⑥}$$

Spring Balance

Equipment

Pulley
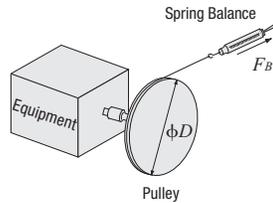
F : Force of moving direction [N]

F_0 : Preload [N] $\left(\doteqdot \frac{1}{3}F\right)$

μ_0 : Internal friction coefficient of preload nut $(0.1\sim0.3)$

η : Efficiency $(0.85\sim0.95)$

i : Gear ratio (This is the gear ratio of the mechanism -and not the gear ratio of an Oriental Motor's gearhead.)

P_B : Ball screw lead [m/rev]

F_A : External force [N]

F_B : Force when main shaft begins to rotate [N] ($F_B =$ Spring balance value [kg]×g [m/s²])

m : Total mass of table and load [kg]

μ : Friction coefficient of sliding surface

θ : Inclination angle [˚]

D : Final pulley diameter [m]

g : Gravitational acceleration [m/s²] (9.807)

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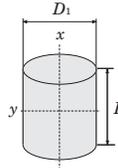# ■Formula for Inertia J [kg·m²]

●Formula for the Inertia
◇Inertia of a Cylinder

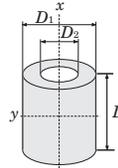$$Jx = \frac{1}{8} m \cdot D_1{}^2 = \frac{\pi}{32} \rho \cdot L \cdot D_1{}^4 \ [\text{kg·m}^2] \ \text{--------} \ ⑦$$

$$Jy = \frac{1}{4} m \left(\frac{D_1{}^2}{4} + \frac{L^2}{3} \right) \ [\text{kg·m}^2] \ \text{--------} \ ⑧$$

◇Inertia of a Hollow Cylinder

$$Jx = \frac{1}{8} m (D_1{}^2 + D_2{}^2) = \frac{\pi}{32} \rho \cdot L (D_1{}^4 - D_2{}^4) [\text{kg·m}^2] \ \text{----} \ ⑨$$
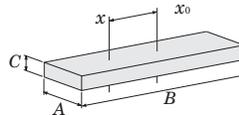
$$Jy = \frac{1}{4} m \left(\frac{D_1{}^2 + D_2{}^2}{4} + \frac{L^2}{3} \right) [\text{kg·m}^2] \ \text{--------} \ ⑩$$

◇Inertia on Off-Center Axis

$$Jx = Jx_0 + m \cdot l^2 = \frac{1}{12} m (A^2 + B^2 + 12 \cdot l^2) \ [\text{kg·m}^2] \ \text{-----} \ ⑪$$
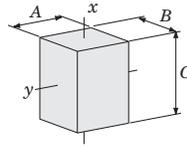
l: Distance Between x and x_0 Axes [m]

◇Inertia of a Rectangular Pillar

$$Jx = \frac{1}{12} m (A^2 + B^2) = \frac{1}{12} \rho \cdot A \cdot B \cdot C (A^2 + B^2) \ [\text{kg·m}^2] \ \text{--------} \ ⑫$$

$$Jy = \frac{1}{12} m (B^2 + C^2) = \frac{1}{12} \rho \cdot A \cdot B \cdot C (B^2 + C^2) \ [\text{kg·m}^2] \ \text{--------} \ ⑬$$

◇Inertia of an Object in Linear Motion

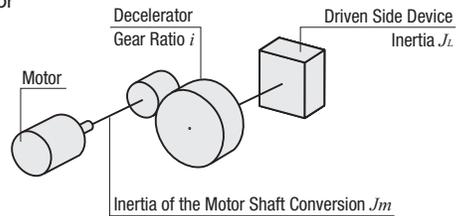$$J = m \left(\frac{A}{2\pi} \right)^2 \ [\text{kg·m}^2] \ \text{--------------------} \ ⑭$$

A: Unit Movement [m/rev]

Conversion formula for the inertia of the motor shaft when using a decelerator

$$Jm = \frac{1}{i^2} J_L$$

Decelerator
Gear Ratio i
Driven Side Device
Inertia J_L
Motor

Formula for the relation between J and GD^2

$$J = \frac{1}{4} GD^2$$

Inertia of the Motor Shaft Conversion Jm

Density

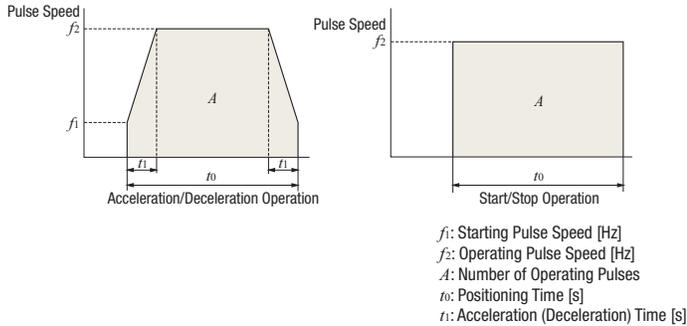|	
Iron	$\rho = 7.9 \times 10^3$ [kg/m³]
Stainless steel (SUS304)	$\rho = 8.0 \times 10^3$ [kg/m³]
Aluminum	$\rho = 2.8 \times 10^3$ [kg/m³]
Brass	$\rho = 8.5 \times 10^3$ [kg/m³]
Nylon	$\rho = 1.1 \times 10^3$ [kg/m³]

J_x : Inertia on x-axis [kg·m²]
J_y : Inertia on y-axis [kg·m²]
J_{x0}: Inertia on x_0-axis (centered axis) [kg·m²]
m : Mass [kg]
D_1 : Outer diameter [m]
D_2 : Inner diameter [m]
ρ : Density [kg/m³]
L : Length [m]

■Motor Selection Calculations

The following explains the required formulas for controlling a stepper motor or servo motor based on pulse signal.

●Operating Pattern

For stepper motors, the pattern for acceleration/deceleration operation in the figure on the left is commonly used as operating patterns on pulse speed. The pattern for start/stop operation in the figure on the right can be used when the operating speeds are low and the load inertia is small.

Acceleration/Deceleration Operation   Start/Stop Operation

f_1: Starting Pulse Speed [Hz]
f_2: Operating Pulse Speed [Hz]
A: Number of Operating Pulses
t_0: Positioning Time [s]
t_1: Acceleration (Deceleration) Time [s]

●Formula for the Number of Operating Pulses A [Pulse]

The number of operating pulses is expressed as the number of pulse signals that add up to the angle that the motor must rotate to get the load from point A to point B.

$$A = \frac{l}{l\text{rev}} \cdot \frac{360°}{\theta s}$$

l : Traveling Amount from point A to point B [m]
l_{rev} : Traveling Amount per Motor Rotation [m/rev]
θ_S : Step Angle [°]

●Formula for the Operating Pulse Speed f_2 [Hz]

The operating pulse speed can be obtained from the number of operating pulses, the positioning time and the acceleration (deceleration) time.

① For Acceleration/Deceleration Operation

The level of acceleration (deceleration) time is an important point in the selection. The acceleration (deceleration) time cannot be set easily, because it correlates with the acceleration torque and acceleration/deceleration rate.

Initially, as a reference, calculate the acceleration (deceleration) time at roughly 25% of the positioning time. (The calculation must be adjusted before the final decision can be made.)

$$t_1 = t_0 \times 0.25$$

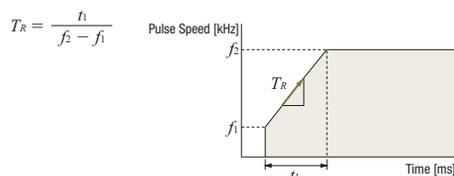$$f_2 = \frac{A - f_1 \cdot t_1}{t_0 - t_1}$$

② For Start/Stop Operation

$$f_2 = \frac{A}{t_0}$$

●Formula for the Acceleration/Deceleration Rate T_R [ms/kHz]

The acceleration/deceleration rates are the setting values used for the Oriental Motor's controllers.

The acceleration/deceleration rate indicates the degree of acceleration of pulse speed and is calculated using the formula shown below.

$$T_R = \frac{t_1}{f_2 - f_1}$$

- Calculate the pulse speed in full step conversion.
- For this formula, the unit for speed is [kHz] and the unit for time is [ms].

●Conversion Formula for the Operating Speed N_M [r/min] from the Operating Pulse Speed f_2 [Hz]

$$N_M = f_2 \cdot \frac{\theta s}{360} \cdot 60$$
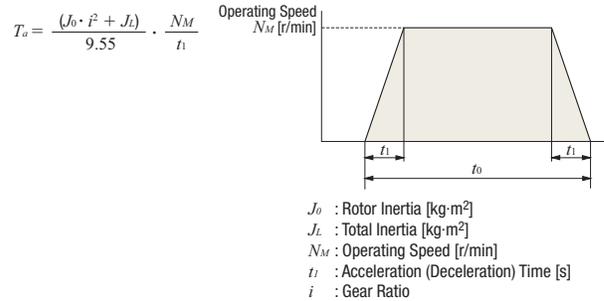
●Calculate the Load Torque

Refer to formulas on page H-3.

●Formula for the Acceleration Torque Ta [N·m]

If the motor speed is varied, the acceleration torque or deceleration torque must always be set.

The basic formula is the same for all motors. However, use the formulas below when calculating the acceleration torque for stepper motors on the basis of pulse speed.

<Common Basic Formula for All Motors>

$$T_a = \frac{(J_0 \cdot i^2 + J_L)}{9.55} \cdot \frac{N_M}{t_1}$$

J_0 : Rotor Inertia [kg·m²]
J_L : Total Inertia [kg·m²]
N_M : Operating Speed [r/min]
t_1 : Acceleration (Deceleration) Time [s]
i : Gear Ratio

<When Calculating the Acceleration Torque for Stepper Motors on the Basis of Pulse Speed>

① For Acceleration/Deceleration Operation

$$T_a = (J_0 \cdot i^2 + J_L) \cdot \frac{\pi \cdot \theta s}{180} \cdot \frac{f_2 - f_1}{t_1}$$

② For Start/Stop Operation

$$T_a = (J_0 \cdot i^2 + J_L) \cdot \frac{\pi \cdot \theta s}{180 \cdot n} \cdot f_2^2 \qquad n : 3.6° / (\theta s \cdot i)$$

●Formula for the Required Torque T_M [N·m]

The required torque is calculated by multiplying the sum of load torque and acceleration torque by the safety factor.

$$T_M = (T_L + T_a) \, S_f$$

T_M : Required Torque [N·m]
T_L : Load Torque [N·m]
T_a : Acceleration Torque [N·m]
S_f : Safety Factor

●Formula for the Effective Load Torque T_{rms} [N·m]

Calculate the effective load torque when selecting the servo motors and **BXⅡ** Series brushless motors.

When the required torque for the motor varies over time, determine if the motor can be used by calculating the effective load torque.

The effective load torque becomes particularly important for operating patterns such as fast-cycle operations where acceleration/deceleration is frequent.

$$T_{rms} = \sqrt{\frac{(T_a + T_L)^2 \cdot t_1 + T_L{}^2 \cdot t_2 + (T_d - T_L)^2 \cdot t_3}{t_f}}$$
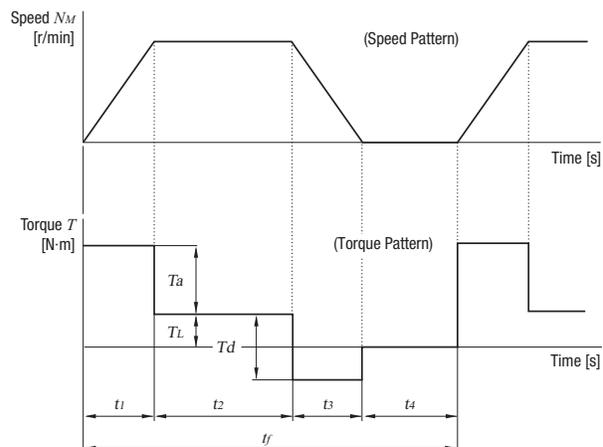
■Selection Points

Since there are differences in characteristics between standard AC motors, brushless motors, stepper motors and servo motors, there will also be differences in points (check items) when selecting a motor.

●Standard AC Motors

① Speed Variation by Load
The actual speed of standard AC motors is 2~20% lower than its synchronous speed under the influence of the load torque.
When selecting a standard AC motor, the selection should take this decrease in speed into account.

② Time Rating
There are differences in continuous rating and short time rating depending on the motor type, even for motors with the same output power. Motor selection should be based on the operating time (pattern).

③ Permissible Load Inertia of the Gearhead
If instantaneous stop (with brake pack, etc.), frequent intermittent operations or instantaneous bi-directional operation will be performed using a motor with a gearhead, an excessive load inertia may damage the gearhead. Selections must be made for these values, so that the load inertia does not exceed the permissible load inertia of the gearhead. (Refer to Page C-16)

●Brushless Motors

① Permissible Torque
Brushless motor combination types with a dedicated gearhead installed are listed on the permissible torque table based on the output gear shaft. Select products in which the load torque does not exceed the permissible torque.

② Permissible Inertia
A permissible inertia is specified for the brushless motor for avoiding alarms using regenerative power during deceleration and for stable speed control. Select products in which the inertia does not exceed the permissible value. For the combination type, there is a permissible inertia combination type. Select products with values that do not exceed the values of the combination types.

③ Effective Load Torque
When operating the **BXⅡ** Series with frequent starts and stops, make sure the effective load torque does not exceed the rated torque. If the rated torque is exceeded, the overload protective function activates and stops the motor.
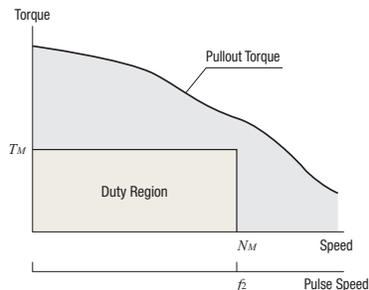
●Stepper Motors

① Check the Required Torque
For stepper motors, select motors whose duty region (operating speed N_M (f_2) and the required torque T_M) falls within the pullout torque curve.

Safety Factor: Sf (Reference Value)

Product	Safety Factor (Reference Value)
α**STEP**	1.5~2
Stepper Motors	2

② Considering Temperature Rise

The stepper motor will have an increase in temperature if operated continuously over a long period of time. Exceeding the temperature of heat-resistant class 130 (B) inside the motor may deteriorate its insulating performance. Temperature rise will vary based on the operating speed, load conditions and installation conditions. The stepper motor should be used at an operating duty of 50% or less. If the operating duty exceeds 50%, choose a motor with a sufficient margin of torque or use methods to lower the running current.

$$\text{Operating Duty} = \frac{\text{Running time}}{\text{Running + Stopping Time}} \times 100$$

③ Check the Acceleration/Deceleration Rate
If the duty region (operating speed N_M and the required torque T_M) of the stepper motor falls within the pullout torque curve, the specified equipment can be operated. Controllers, when set for acceleration/deceleration, adjust the pulse speed in steps using output pulse signals. Sudden acceleration/declaration causes the pulse speed step to become large. Therefore, if large inertias are present in this condition, there is a possibility that the motor cannot be driven even when sudden acceleration/deceleration direction is given. Check that the reference values are equal to or higher than the acceleration/deceleration rates shown in the table so that the selected motor can be operated more reliably.

Acceleration/Deceleration Rate
(Combination reference values with **EMP** Series)

Product	Frame Size	Acceleration/Deceleration Rate T_{RS} [ms/kHz]
α**STEP**	28 (30), 42, 60, 85 (90)	0.5 or more✱
0.36°/0.72° Stepper Motors	20, 28, 42, 60	20 or more
	85 (90)	30 or more
0.9°/1.8° Stepper Motors	20, 28 (30), 35, 42, 50, 56.4, 60	50 or more
	85 (90)	75 or more

✱When using α**STEP**, this item does not need to be checked. The values in the table represent the lower limit of settings for the **EMP** Series.
Also for the geared type, the acceleration/deceleration rates are equal to the values shown above. However, when using a half step or microstep motor, the conversion below is required.

$$T_{RS} \cdot \frac{\theta_S}{\theta_B} \cdot i$$

T_{RS} : Acceleration/Deceleration Rate [ms/kHz]
θ_S : Step Angle [°]
θ_B : Refer to Table Below
i : Gear Ratio of Geared Type

Coefficient

Product	θ_B
α**STEP**	0.36°
0.72° Stepper Motors	0.72°
1.8° Stepper Motors	1.8°

④ Check the Inertia Ratio
Calculate the inertia ratio using the following formula:

$$\text{Inertia Ratio} = \frac{J_L}{J_0}$$

For Geared Motors

$$\text{Inertia Ratio} = \frac{J_L}{J_0 \cdot i^2}$$ i: Gear Ratio

Large inertia ratios in stepper motors cause large overshooting and undershooting during starting and stopping, which can affect rise times and settling times. Controllers, when set for acceleration/deceleration, adjust the pulse speed in steps using output pulse signals. Sudden acceleration/deceleration causes the pulse speed step to become large. Therefore, if the inertia ratio is large, operation may not be possible. Check that the reference values are less than or equal to inertia ratios shown in the table so that the selected motor can be operated more reliably.

Inertia Ratio (Reference values)

Product	Frame Size	Inertia Ratio
α**STEP**	28, 42, 60, 85	30 or less
Stepper Motors	20, 28, 35	5 or less
	42, 50, 56.4, 60, 85	10 or less

When the values in the table are exceeded, we recommend a geared type motor.

●Servo Motors

① Permissible Inertia

A permissible inertia is specified for the servo motor for stable control. The inertia of the servo motor must be lower than the permissible value.

Product	Permissible Load Inertia
NX Series	50 times the rotor inertia or less✱

✱Automatic tuning allows operation up to 50 times the rotor inertia; manual tuning allows operation up to 100 times the rotor inertia.

② Rated Torque

The motor can be driven when the ratio of load torque T_L and rated torque of the servo motor is 1.5~2 or more.

$$\frac{\text{Rated Torque}}{\text{Load Torque}} \geqq 1.5\sim2$$

③ Maximum Instantaneous Torque

Check that the required torque is less than the maximum instantaneous torque of the servo motor. (Ensure that the safety factor of required torque Sf is at 1.5~2 or more.)
Note that the time that max. instantaneous torque can be used for varies depending on the motor.

Maximum Instantaneous Torque and Operating Time

| Product	Operating Time	Maximum Instantaneous Torque
NX Series	Within approx. 0.5 seconds	At 3 times the rated torque (at rated speed)

④ Effective Load Torque

The motor can be driven when the effective load safety factor, which is the ratio of an effective load torque and a rated torque of servo motor, is 1.5~2 or more.

$$\text{Effective Load Safety Factor} = \frac{\text{Rated Torque}}{\text{Effective Load Torque}}$$

⑤ Settling Time

There is a time lag between a position command sent by pulse signal and the servo motor's actual operation. This difference is called the settling time.
Therefore, the real positioning time is the sum of the positioning time calculated from the operating pattern and the settling time.
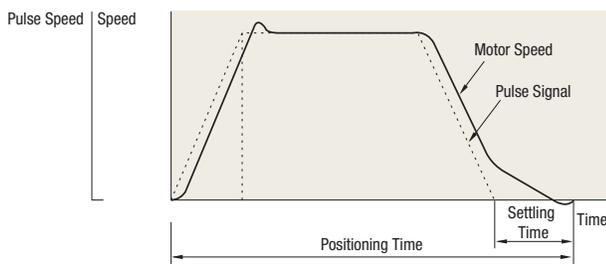
● The factory setting for settling time on the **NX** Series is 60~70 ms. However, the settling time varies when the gain parameter is changed by the mechanical rigidity setting switch.
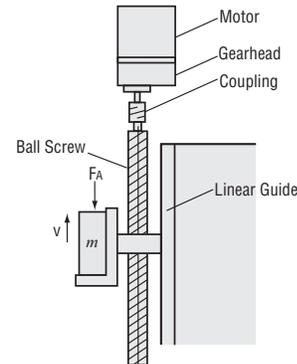
■Selection Examples

●Ball Screw Mechanism

Using Standard AC Motors

(1) Specifications and Operating Conditions of the Drive Mechanism

This selection example demonstrates an electromagnetic brake motor for use on a table moving vertically on a ball screw.
In this case, a motor must be selected that meets the following required specifications.

Total mass of the table and load $\cdots\cdots m = 45$ [kg]
Table speed $\cdots\cdots V = 15\pm2$ [mm/s]
External force $\cdots\cdots F_A = 0$ [N]
Ball screw tilt angle $\cdots\cdots \theta = 90$ [°]
Total length of ball screw $\cdots\cdots L_B = 800$ [mm]
Ball screw shaft diameter $\cdots\cdots D_B = 20$ [mm]
Ball screw lead $\cdots\cdots P_B = 5$ [mm]
Distance moved for one rotation of ball screw $\cdots\cdots A = 5$ [mm]
Ball screw efficiency $\cdots\cdots \eta = 0.9$
Ball screw material $\cdots\cdots$ Iron (Density $\rho = 7.9 \times 10^3$ [kg/m³])
Internal friction coefficient of preload nut $\cdots\cdots \mu_0 = 0.3$
Friction coefficient of sliding surface $\cdots\cdots \mu = 0.05$
Motor power supply $\cdots\cdots$ Three-Phase 230 VAC 60 Hz
Operating time $\cdots\cdots$ Intermittent operation, 5 hours/day
    Load with repeated starts and stops
    Required load holding

(2) Determine the Gear Ratio

Speed at the gearhead output shaft $N_G = \dfrac{V \cdot 60}{A} = \dfrac{(15 \pm 2) \times 60}{5}$
$$= 180 \pm 24 \text{ [r/min]}$$

Because the rated speed for a 4-pole motor at 60 Hz is 1450 to 1550 [r/min], the gear ratio is calculated as follows:

Gear ratio $i = \dfrac{1450\sim1550}{N_G} = \dfrac{1450\sim1550}{180 \pm 24} = 7.1\sim9.9$

This gives us a gear ratio of $i = 9$.

(3) Calculate the Required Torque T_M [N·m]

Force of moving direction $F = F_A + m \cdot g \, (\sin\theta + \mu \cdot \cos\theta)$
$$= 0 + 45 \times 9.807 \, (\sin 90° + 0.05 \cos 90°)$$
$$= 441 \text{ [N]}$$

Ball screw preload $F_0 = \dfrac{F}{3} = 147$ [N]

Load torque $T'_L = \dfrac{F \cdot P_B}{2\pi \cdot \eta} + \dfrac{\mu_0 \cdot F_0 \cdot P_B}{2\pi}$
$$= \frac{441 \times 5 \times 10^{-3}}{2\pi \times 0.9} + \frac{0.3 \times 147 \times 5 \times 10^{-3}}{2\pi}$$
$$= 0.426 \text{ [N·m]}$$

Consider the safety factor $Sf = 2$.

$$T_L = T'_L \cdot Sf = 0.426 \times 2 = 0.86 \text{ [N·m]}$$

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Select an electromagnetic brake motor and gearhead satisfying the permissible torque of gearhead based on the calculation results (gear ratio $i = 9$, load torque $T_L = 0.86$ [N·m]) obtained so far. Here, **4IK25GN-SW2M** and **4GN9SA** are tentatively selected as the motor and gearhead respectively, by referring to the "Gearmotor – Torque Table" on page C-73.

Next, convert this load torque to a value on the motor output shaft to obtain the required torque T_M, as follows:

$$T_M = \frac{T_L}{i \cdot \eta_G} = \frac{0.86}{9 \times 0.81} = 0.118 \text{ [N·m]} = 118 \text{ [mN·m]}$$

(Gearhead efficiency $\eta_G = 0.81$)

The starting torque of the **4IK25GN-SW2M** motor selected earlier is 160 [mN·m]. Since this is greater than the required torque of 118 [mN·m], this motor can start the mechanism in question.
Next, check if the gravitational load acting upon the mechanism in standstill state can be held with the electromagnetic brake. Here, the load equivalent to the load torque obtained earlier is assumed to act.
Torque T'_M required for load holding on the motor output shaft:

$$T'_M = \frac{T_L}{i} = \frac{0.86}{9} = 0.0956 \text{ [N·m]} = 95.6 \text{ [mN·m]}$$

The static friction torque generated by the electromagnetic brake of the **4IK25GN-SW2M** motor selected earlier is 100 [mN·m], which is greater than 95.6 [mN·m] required for the load holding.

(4) Check the Moment of Inertia J [kg·m²]

Inertia of ball screw $J_B = \dfrac{\pi}{32} \cdot \rho \cdot L_B \cdot D_B{}^4$

$$= \frac{\pi}{32} \times 7.9 \times 10^3 \times 800 \times 10^{-3} \times (20 \times 10^{-3})^4$$

$$= 0.993 \times 10^{-4} \text{ [kg·m²]}$$

Inertia of table and load $J_m = m \left(\dfrac{A}{2\pi}\right)^2$

$$= 45 \left(\frac{5 \times 10^{-3}}{2\pi}\right)^2$$

$$= 0.286 \times 10^{-4} \text{ [kg·m²]}$$

Inertia at the gearhead shaft J is calculated as follows:

$$J = J_B + J_m = 0.993 \times 10^{-4} + 0.286 \times 10^{-4}$$
$$= 1.28 \times 10^{-4} \text{ [kg·m²]}$$

Here, permissible inertia of gearhead **4GN9SA** (gear ratio $i = 9$) J_G is (Refer to page C-16):

$$J_G = 0.31 \times 10^{-4} \times 9^2$$
$$= 25.1 \times 10^{-4} \text{ [kg·m²]}$$

Therefore, $J < J_G$, the inertia is less than the permissible value, so there is no problem. There is margin for the torque, so the traveling speed is checked with the speed under no load (approximately 1750 r/min).

$$V = \frac{N_M \cdot P_B}{60 \cdot i} = \frac{1750 \times 5}{60 \times 9} = 16.2 \text{ [mm/s]}$$

N_M: Motor speed

This confirms that the motor meets the specifications.
Based on the above, **4IK25GN-SW2M** and **4GN9SA** are selected as the motor and gearhead, respectively.

Using Stepper Motors

(1) Specifications and Operating Conditions of the Drive Mechanism
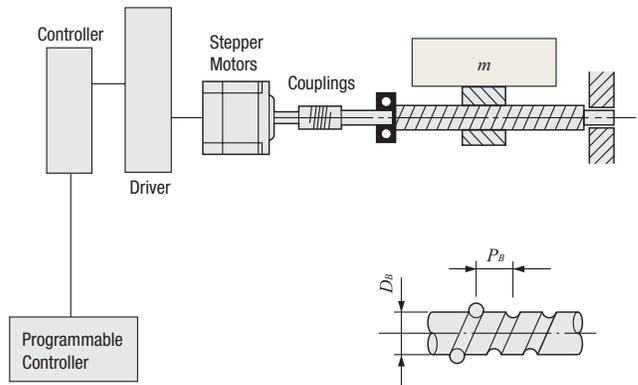
Total mass of table and load ································· $m = 40$ [kg]
Friction coefficient of sliding surface ················· $\mu = 0.05$
Ball screw efficiency ······································· $\eta = 0.9$
Internal friction coefficient of preload nut ·········· $\mu_0 = 0.3$
Shaft diameter of ball screw ···························· $D_B = 15$ [mm]
Overall length of ball screw ···························· $L_B = 600$ [mm]
Ball screw material ·············· Iron (Density $\rho = 7.9 \times 10^3$ [kg/m³])
Ball screw lead ·· $P_B = 15$ [mm]
Required resolution ·· $\Delta l = 0.03$ [mm/step]
(Feed per pulse)
Feed ·· $l = 180$ [mm]
Positioning time ·· $t_0 = 0.8$ seconds max.
Inclination angle ·· $\theta = 0$ [°]

(2) Calculate the Required Resolution θ_S

$$\theta_S = \frac{360° \cdot \Delta l}{P_B}$$

$$= \frac{360° \times 0.03}{15} = 0.72°$$

AR Series stepper motor and driver package can be used.
Changing or specifying the resolution is possible.
The factory setting resolution can be changed from 0.36°/pulse → 0.72°/pulse.

(3) Determine an Operating Pattern
(Refer to formula on page H-5)
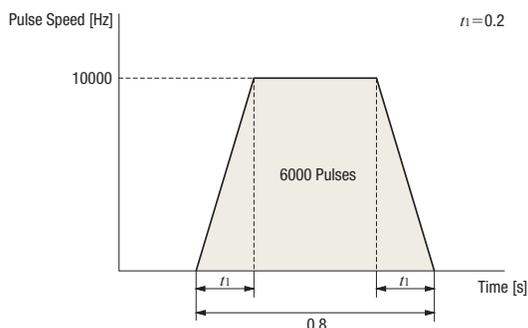① Formula for the number of operating pulses A [Pulse]

$$A = \frac{l}{P_B} \cdot \frac{360°}{\theta_S}$$

$$= \frac{180}{15} \times \frac{360°}{0.72°} = 6000 \text{ [Pulse]}$$

② Determine the acceleration (deceleration) time t_1 [s]
An acceleration (deceleration) time which is 25% of the positioning time is ideal.

$$t_1 = 0.8 \times 0.25 = 0.2 \text{ [s]}$$

③ Calculate the operating pulse speed f_2 [Hz].

$$f_2 = \frac{A - f_1 \cdot t_1}{t_0 - t_1}$$

$$= \frac{6000 - 0}{0.8 - 0.2} = 10000 \text{ [Hz]}$$

④ Calculate the operating speed N_M [r/min]

$$N_M = \frac{\theta s}{360°} f_2 \cdot 60$$

$$= \frac{0.72°}{360°} \times 10000 \times 60$$

$$= 1200 \,[\text{r/min}]$$

(4) Calculate the Required Torque T_M [N·m] (Refer to page H-5)

① Calculate the load torque T_L [N·m]

Force of Moving Direction $F = F_A + m \cdot g \,(\sin\theta + \mu\cos\theta)$

$$= 0 + 40 \times 9.807 \,(\sin 0° + 0.05 \cos 0°)$$

$$= 19.6 \,[\text{N}]$$

Preload $F_0 = \dfrac{F}{3} = \dfrac{19.6}{3} = 6.53 \,[\text{N}]$

Load Torque $T_L = \dfrac{F \cdot P_B}{2\pi \cdot \eta} + \dfrac{\mu_0 \cdot F_0 \cdot P_B}{2\pi}$

$$= \frac{19.6 \times 15 \times 10^{-3}}{2\pi \times 0.9} + \frac{0.3 \times 6.53 \times 15 \times 10^{-3}}{2\pi}$$

$$= 0.0567 \,[\text{N·m}]$$

② Calculate the acceleration torque T_a [N·m]

②-1 Calculate the inertia J_L [kg·m^2]
(Refer to the formula on page H-4)

Inertia of Ball Screw

$$J_B = \frac{\pi}{32} \cdot \rho \cdot L_B \cdot D_B{}^4$$

$$= \frac{\pi}{32} \times 7.9 \times 10^3 \times 600 \times 10^{-3} \times (15 \times 10^{-3})^4$$

$$= 0.236 \times 10^{-4} \,[\text{kg·m}^2]$$

Inertia of Table and Load $J_T = m \left(\dfrac{P_B}{2\pi}\right)^2$

$$= 40 \times \left(\frac{15 \times 10^{-3}}{2\pi}\right)^2$$

$$= 2.28 \times 10^{-4} \,[\text{kg·m}^2]$$

Inertia $J_L = J_B + J_T$

$$= 0.236 \times 10^{-4} + 2.28 \times 10^{-4} = 2.52 \times 10^{-4} \,[\text{kg·m}^2]$$

②-2 Calculate the acceleration torque T_a [N·m]

$$T_a = \frac{(J_0 + J_L)}{9.55} \cdot \frac{N_M}{t_1}$$

$$= \frac{(J_0 + 2.52 \times 10^{-4})}{9.55} \times \frac{1200}{0.2}$$

$$= 628 \, J_0 + 0.158 \,[\text{N·m}]$$

The formula for calculating acceleration torque with pulse speed is shown below. Calculation results are the same.

$$T_a = (J_0 + J_L) \cdot \frac{\pi \cdot \theta s}{180°} \cdot \frac{f_2 - f_1}{t_1}$$

$$= (J_0 + 2.52 \times 10^{-4}) \times \frac{\pi \times 0.72°}{180°} \times \frac{10000 - 0}{0.2}$$

$$= 628 \, J_0 + 0.158 \,[\text{N·m}]$$

③ Calculate the required torque T_M [N·m]
Safety factor $Sf = 2$.

$$T_M = (T_L + T_a) \, Sf$$

$$= \{0.0567 + (628 \, J_0 + 0.158)\} \times 2$$

$$= 1256 \, J_0 + 0.429 \,[\text{N·m}]$$

(5) Select a Motor

① Tentative motor selection

Product Name	Rotor Inertia [kg·m^2]	Required Torque [N·m]
AR66AA-3	380×10^{-7}	0.48

② Determine the motor from the speed – torque characteristics
AR66AA-3
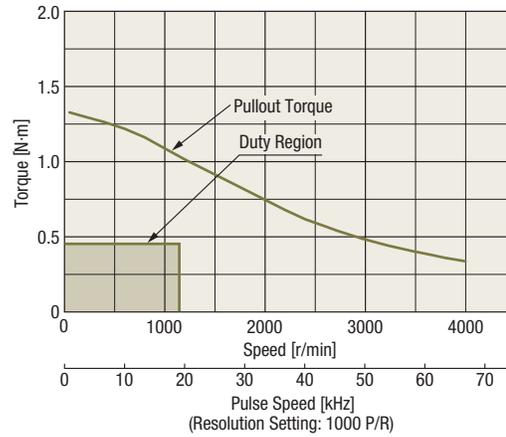
(Resolution Setting: 1000 P/R)

Since the duty region of the motor (operating speed and required torque) falls within the pullout torque of the speed – torque characteristics, the motor can be used.

(6) Check the Inertia Ratio (Refer to page H-6)

$$\frac{J_L}{J_0} = \frac{2.52 \times 10^{-4}}{380 \times 10^{-7}} \doteqdot 6.6$$

Since the inertia ratio of **AR66AA-3** is 30 or less, if the calculated inertia ratio is 6.6, then operation of that motor is possible.
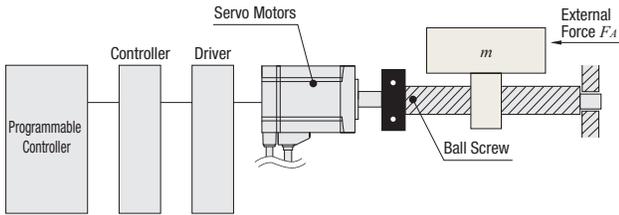
Using Servo Motors

(1) Specifications and Operating Conditions of the Drive Mechanism

The following is an example of how to select a servo motor to drive a single axis table:

Max. table speed	$V_L = 0.2$ [m/s]
Resolution	$\Delta l = 0.02$ [mm]
Motor power supply	Single-Phase 115 VAC
Total mass of table and load	$m = 100$ [kg]
External	$F_A = 29.4$ [N]
Friction coefficient of sliding surface	$\mu = 0.04$
Ball screw efficiency	$\eta = 0.9$
Internal friction coefficient of preload nut	$\mu_0 = 0.3$
Shaft diameter of ball screw	$D_B = 25$ [mm]
Overall length of ball screw	$L_B = 1000$ [mm]
Ball screw lead	$P_B = 10$ [mm]
Ball screw material	Iron (Density $\rho = 7.9 \times 10^3$ [kg/m³])
Operating cycle	Operation for 2.1 seconds/stopped for 0.4 seconds (repeated)
Acceleration/deceleration time	$t_1 = t_3 = 0.1$ [s]

(2) Calculate the Required Resolution θ

Calculate the motor resolution from the resolution required for the table drive.

$$\theta = \frac{360° \cdot \Delta l}{P_B} = \frac{360° \times 0.02}{10} = 0.72°$$
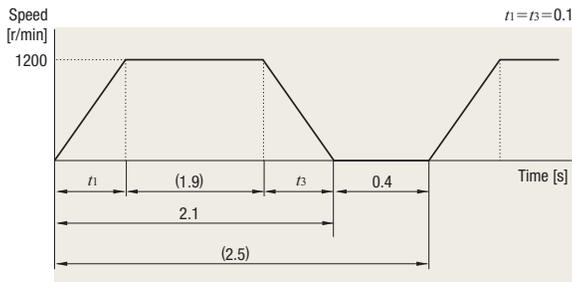
The resolution of the **NX** Series, $\theta_M = 0.36°$/pulse (factory setting) satisfies this requirement.

(3) Determine an Operating Pattern

Calculate the motor speed N_M from the formula below.

$$N_M = \frac{60 \cdot V_L}{P_B} = \frac{60 \times 0.2}{10 \times 10^{-3}} = 1200 \, [\text{r/min}]$$

Determine the speed pattern using N_M, the operating cycle and the acceleration/deceleration time.

(4) Calculate the Load Torque T_L [N·m]

Operation direction load $F = F_A + m \cdot g (\sin\theta + \mu \cdot \cos\theta)$
$$= 29.4 + 100 \times 9.807 \, (\sin 0° + 0.04 \cos 0°)$$
$$= 68.6 \, [\text{N}]$$

Load Torque of the Motor Shaft Conversion

$$T_L = \frac{F \cdot P_B}{2\pi \cdot \eta} + \frac{\mu_0 \cdot F_0 \cdot P_B}{2\pi}$$
$$= \frac{68.6 \times 10 \times 10^{-3}}{2\pi \times 0.9} + \frac{0.3 \times 22.9 \times 10 \times 10^{-3}}{2\pi}$$
$$\doteqdot 0.13 \, [\text{N·m}]$$

Here $F_0 = \frac{1}{3} F$ represents the ball screw preload.

(5) Calculate the Inertia J_L [kg·m²]

Inertia of Ball Screw

$$J_B = \frac{\pi}{32} \cdot \rho \cdot L_B \cdot D_B{}^4$$
$$= \frac{\pi}{32} \times 7.9 \times 10^3 \times 1000 \times 10^{-3} \times (25 \times 10^{-3})^4$$
$$\doteqdot 3.03 \times 10^{-4} \, [\text{kg·m²}]$$

Inertia of Table and Load $J_m = m \left(\frac{P_B}{2\pi}\right)^2$
$$= 100 \times \left(\frac{10 \times 10^{-3}}{2\pi}\right)^2$$
$$\doteqdot 2.53 \times 10^{-4} \, [\text{kg·m²}]$$

Inertia $J_L = J_B + J_m$
$$= 3.03 \times 10^{-4} + 2.53 \times 10^{-4} = 5.56 \times 10^{-4} \, [\text{kg·m²}]$$

(6) Tentative Servo Motor Selection

Safety factor $Sf = 1.5$.

Load torque $T'_L = Sf \cdot T_L$
$$= 1.5 \times 0.13 = 0.195 \, [\text{N·m}]$$

Inertia $J_L = 5.56 \times 10^{-4}$ [kg·m²]

Therefore, select the servo motor which has a speed of 1200 [r/min], outputs the rated torque 0.195 [N·m] or more and whose permissible inertia is 5.56×10^{-4} [kg·m²] or more.

→ NX620AA-3

Rated speed $N = 3000$ [r/min]
Rated torque $T_M = 0.637$ [N·m]
Rotor inertia $J_0 = 0.162 \times 10^{-4}$ [kg·m²]
Permissible inertia $J = 8.1 \times 10^{-4}$ [kg·m²]
Max. instantaneous torque $T_{MAX} = 1.91$ [N·m]
is ideal.

(7) Calculate the Acceleration Torque T_a [N·m] and Deceleration Torque T_d [N·m]

Calculate the acceleration/deceleration torque using the formula below.

$$T_a \, (= T_d) = \frac{(J_L + J_0) \, N_M}{9.55 \, t_1}$$
$$= \frac{(5.56 \times 10^{-4} + 0.162 \times 10^{-4}) \times 1200}{9.55 \times 0.1} \doteqdot 0.72 \, [\text{N·m}]$$

(8) Calculate the Required Torque T [N·m]

$$T = T_a + T_L$$
$$= 0.72 + 0.13 = 0.85 \, [\text{N·m}]$$

The required torque is less than the max. instantaneous torque of **NX620AA-3** of 1.91 [N·m], so the **NX620AA-3** can be used.

(9) Determine a Torque Pattern

Determine a torque pattern using operating cycle, acceleration/deceleration torque, load torque and acceleration time.
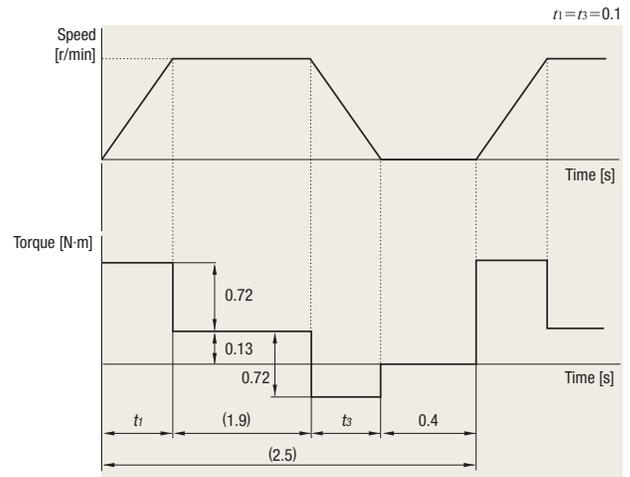
(10) Calculate the Effective Load Torque T_{rms} [N·m]

Calculate the effective load torque T_{rms} using the torque pattern and formula below.

$$T_{rms} = \sqrt{\frac{(T_a + T_L)^2 \cdot t_1 + T_L^2 \cdot t_2 + (T_d - T_L)^2 \cdot t_3}{t_f}}$$

$$= \sqrt{\frac{(0.72 + 0.13)^2 \times 0.1 + 0.13^2 \times 1.9 + (0.72 - 0.13)^2 \times 0.1}{2.5}}$$

$$\fallingdotseq 0.24 \,[\text{N·m}]$$

Here, $t_1 + t_2 + t_3 = 2.1$ [s] from the operating cycle and $t_1 = t_3 = 0.1$ for acceleration and deceleration time. Therefore, $t_2 = 2.1 - 0.1 \times 2 = 1.9$ [s]

The ratio (effective load safety factor) of T_{rms} and the rating torque of servo motor T_M is expressed by the formula below.

$$\frac{T_M}{T_{rms}} = \frac{0.637}{0.24} = 2.65$$

Generally a motor can operate at an effective load safety factor of 1.5~2 or more.
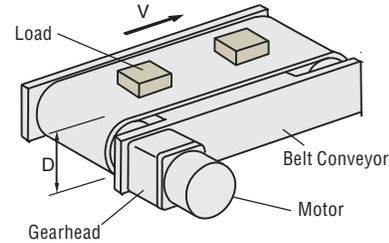
●Belt and Pulley Mechanism

| When Using AC Motor |

(1) Specifications and Operating Conditions of the Drive Mechanism

The following is an example of how to select an induction motor to drive a belt conveyor:

A motor that meets the following required specifications is selected.

Total mass of belt and load $\cdots\cdots\cdots\cdots\cdots\cdots\cdots m_1 = 25$ [kg]
External force $\cdots\cdots\cdots\cdots\cdots\cdots\cdots F_A = 0$ [N]
Friction coefficient of sliding surface $\cdots\cdots\cdots\cdots \mu = 0.3$
Roller diameter $\cdots\cdots\cdots\cdots\cdots\cdots D = 90$ [mm]
Roller mass $\cdots\cdots\cdots\cdots\cdots\cdots m_2 = 1$ [kg]
Belt and roller efficiency $\cdots\cdots\cdots\cdots\cdots \eta = 0.9$
Belt Speed $\cdots\cdots\cdots\cdots\cdots V = 150$ [mm/s]±10%
Motor power supply $\cdots\cdots\cdots\cdots$Single-Phase 115 VAC, 60 Hz
Operating time $\cdots\cdots\cdots\cdots$8 hours operation per day

(2) Determine the Gear Ratio of Gearhead

$$\text{Gearhead Output Shaft Speed } N_G = \frac{V \cdot 60}{\pi \cdot D} = \frac{(150 \pm 15) \times 60}{\pi \times 90}$$

$$= 31.8 \pm 3.2 \,[\text{r/min}]$$

Since the rated speed for an induction motor (4-pole) at 60 Hz is 1450~1550 [r/min], select a gearhead gear ratio within this range.

$$\text{Gearhead Gear Ratio } i = \frac{1450 \sim 1550}{N_G} = \frac{1450 \sim 1550}{31.8 \pm 3.2} = 41.4 \sim 54.2$$

Select a gear ratio of $i = 50$ from within this range.

(3) Calculate the Required Torque T_M [N·m]

$$\text{Friction Coefficient of Sliding Surface } F = F_A + m \cdot g\,(\sin\theta + \mu \cdot \cos\theta)$$

$$= 0 + 25 \times 9.807\,(\sin 0° + 0.3\cos 0°)$$

$$= 73.6 \,[\text{N}]$$

$$\text{Load Torque } T'_L = \frac{F \cdot D}{2 \cdot \eta} = \frac{73.6 \times 90 \times 10^{-3}}{2 \times 0.9} = 3.68 \,[\text{N·m}]$$

Consider the safety factor $Sf = 2$.

$$T_L = T'_L \cdot Sf = 3.68 \times 2 = 7.36 \,[\text{N·m}]$$

Select the motor that satisfies the rated torque based on the calculation results so far (Gear ratio $i = 50$, load torque $T_L = 7.36$ [N·m]).

At this time, refer to the specifications table on page C-126 and tentatively select motor **5IK40UA-50A**.

(4) Check the Inertia J [kg·m²]

Inertia of Belt and Load $J_{m1} = m_1 \left(\dfrac{\pi \cdot D}{2\pi} \right)^2$

$$= 25 \times \left(\dfrac{\pi \times 90 \times 10^{-3}}{2\pi} \right)^2$$

$$= 507 \times 10^{-4} \text{ [kg·m²]}$$

Inertia of Roller $J_{m2} = \dfrac{1}{8} \cdot m_2 \cdot D^2$

$$= \dfrac{1}{8} \times 1 \times (90 \times 10^{-3})^2$$

$$= 10.2 \times 10^{-4} \text{ [kg·m²]}$$

Calculate the load inertia for the gearhead output shaft J.
Take into account that there are 2 rollers (J_{m2}).

$$J = J_{m1} + 2J_{m2}$$
$$= 507 \times 10^{-4} + 10.2 \times 10^{-4} \times 2$$
$$= 528 \times 10^{-4} \text{ [kg·m²]}$$

The value of the permissible inertia J_G for the **5IK40UA-50A** can be found on the specifications table on page C-18.

$$J_G = 2750 \times 10^{-4} \text{ [kg·m²] (During instantaneous stop)}$$

Therefore, since $J < J_G$, the inertia is less than the permissible value, so there is no problem. Since the motor selected has a rated torque of 11.2 [N·m], which is larger than the actual load torque, the motor will operate at a higher speed than the rated speed.
Therefore, use the speed that is without load (approx. 1750 r/min) to calculate belt speed, and check whether the selected product meets the required specifications.

$$V = \dfrac{N_M \cdot \pi \cdot D}{60 \cdot i} = \dfrac{1750 \times \pi \times 90}{60 \times 50} = 165 \text{ [mm/s]} \qquad N_M : \text{Motor Speed}$$

This confirms that the motor meets the specifications.
Therefore, the **5IK40UA-50A** motor is selected.

Using Low-Speed Synchronous Motors (**SMK** Series)

(1) Specifications and Operating Conditions of the Drive Mechanism

The mass of load is selected that can be driven with **SMK5100A-AA** when the belt-drive table shown in Fig. 1 is driven in the operation pattern shown in Fig. 2.
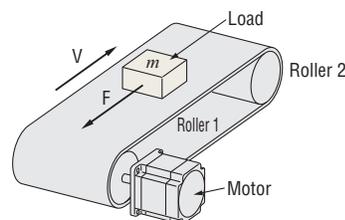

Fig. 1 Example of Belt Drive

Total mass of belt and load ··· $m_1 = 1.5$ [kg]
Roller diameter ··· $D = 30$ [mm]
Mass of roller ··· $m_2 = 0.1$ [kg]
Frictional coefficient of sliding surfaces ···························· $\mu = 0.04$
Belt and pulley efficiency ·· $\eta = 0.9$
Frequency of power supply ··················· 60 Hz (Motor speed: 72 r/min)
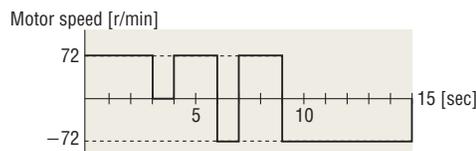

Fig. 2 Operating Pattern

Low-speed synchronous motors share the same basic operating principle with 1.8° stepper motors. Accordingly, the torque for a low-speed synchronous motor is calculated in the same manner as for a 1.8° stepper motor.

(2) Belt Speed V [mm/s]
Check the belt (load) speed

$$V = \dfrac{\pi \cdot D \cdot N}{60} = \dfrac{\pi \times 30 \times 72}{60} = 113 \text{ [mm/s]}$$

(3) Calculate the Required Torque T_L [N·m]

Frictional coefficient of sliding surfaces $F = F_A + m_1 \cdot g (\sin \theta + \mu \cdot \cos \theta)$
$$= 0 + 1.5 \times 9.807 (\sin 0° + 0.04 \cos 0°)$$
$$= 0.589 \text{ [N]}$$

Load Torque $T_L = \dfrac{F \cdot D}{2 \cdot \eta} = \dfrac{0.589 \times 30 \times 10^{-3}}{2 \times 0.9} = 9.82 \times 10^{-3}$ [N·m]

(4) Calculate the Moment of Inertia J_G [kg·m²]

Inertia of belt and load $J_{m1} = m_1 \left(\dfrac{\pi \cdot D}{2\pi} \right)^2$

$$= 1.5 \times \left(\dfrac{\pi \times 30 \times 10^{-3}}{2\pi} \right)^2$$

$$= 3.38 \times 10^{-4} \text{ [kg·m²]}$$

Inertia of Roller $J_{m2} = \dfrac{1}{8} m_2 \cdot D^2$

$$= \dfrac{1}{8} \times 0.1 \times (30 \times 10^{-3})^2$$

$$= 0.113 \times 10^{-4} \text{ [kg·m²]}$$

The inertia J_L is calculated as follows:
Take into account that there are two rollers (J_{m2}).
$$J_L = J_{m1} + 2 J_{m2} = 3.38 \times 10^{-4} + 0.113 \times 10^{-4} \times 2 = 3.5 \times 10^{-4} \text{ [kg·m²]}$$

(5) Calculate the Acceleration Torque T_a [N·m]

Calculate the start acceleration torque.

$$T_a = (J_0 + J_L) \cdot \frac{\pi \cdot \theta s}{180 \cdot n} \cdot f^2 = (J_0 + 3.5 \times 10^{-4}) \times \frac{\pi \times 7.2}{180 \times 0.5} \times 60^2$$

$$= 905 J_0 + 0.32 \text{ [N·m]}$$

Here, $\theta s = 7.2°$, $f = 60$ Hz, $n = 3.6°/\theta s = 0.5$

J_0: Rotor Inertia

(6) Calculate the Required Torque T_M [N·m] (Safety factor Sf = 2.)

Required Torque $T_M = (T_L + T_a) Sf$

$$= (9.82 \times 10^{-3} + 905 J_0 + 0.32) \times 2$$

$$= 1810 J_0 + 0.66 \text{ [N·m]}$$

(7) Select a Motor

Select a motor that satisfies both the required torque and the permissible inertia.

| Motor	Rotor Inertia [kg·m^2]	Permissible Inertia [kg·m^2]	Output Torque [N·m]
SMK5100A-AA	1.4×10^{-4}	7×10^{-4}	1.12

When the required torque is calculated by substituting the rotor inertia, T_M is obtained as 0.914 [N·m], which is below the output torque. Next, check the permissible inertia. Since the inertia calculated in (4) is also below the permissible inertia, **SMK5100A-AA** can be used in this application.

Using Brushless Motors

(1) Specifications and Operating Conditions of the Drive Mechanism

Here is an example of how to select a brushless motor to drive a belt conveyor.
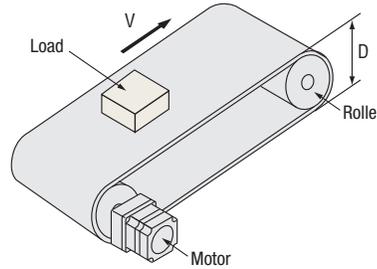
Belt speed ·· $V = 0.05 \sim 1$ [m/s]
Motor power supply ·· Single-Phase 115 VAC
Belt conveyor drive
Roller diameter ··· $D = 0.1$ [m]
Roller mass ·· $m_2 = 1$ [kg]
Total mass of belt and load ··· $m_1 = 7$ [kg]
External force ·· $F_A = 0$ [N]
Friction coefficient of sliding surface ··· $\mu = 0.3$
Belt and roller efficiency ·· $\eta = 0.9$

(2) Find the Required Speed Range

For the gear ratio, select 15:1 (speed range: 5.3~200) from the "Gearmotor – Torque Table of Combination Type" on page D-28 so that the minimum/maximum speed falls within the speed range.

$$N_G = \frac{60 \cdot V_L}{\pi \cdot D} \qquad N_G: \text{Speed at the gearhead shaft}$$

Belt speed 0.015 [m/s] ········ $\frac{60 \times 0.05}{\pi \times 0.1} = 9.55$ [r/min] (Minimum speed)

1 [m/s] ············· $\frac{60 \times 1}{\pi \times 0.1} = 191$ [r/min] (Maximum speed)

(3) Calculate the Moment of Inertia J_G [kg·m^2]

Inertia of belt and load $Jm_1 = m_1 \left(\frac{\pi \cdot D}{2\pi} \right)^2 = 7 \times \left(\frac{\pi \times 0.1}{2\pi} \right)^2$

$$= 175 \times 10^{-4} \text{ [kg·m}^2\text{]}$$

Inertia of roller $Jm_2 = \frac{1}{8} \cdot m_2 \cdot D^2$

$$= \frac{1}{8} \times 1 \times 0.1^2 = 12.5 \times 10^{-4} \text{ [kg·m}^2\text{]}$$

The inertia J_G is calculated as follows:
Take into account that there are two rollers (Jm_2).

$J_G = Jm_1 + 2 Jm_2 = 175 \times 10^{-4} + 12.5 \times 10^{-4} \times 2$

$$= 200 \times 10^{-4} \text{ [kg·m}^2\text{]}$$

From the specifications on page D-29, the permissible load inertia of **BMU5120A-15A-3** is 225×10^{-4} [kg·m^2].

(4) Calculate the Load Torque T_L [N·m]

Friction coefficient of sliding surface $F = F_A + m \cdot g (\sin \theta + \mu \cdot \cos \theta)$

$$= 0 + 7 \times 9.807 (\sin 0° + 0.3 \times \cos 0°)$$

$$= 20.6 \text{ [N]}$$

Load torque $T_L = \frac{F \cdot D}{2 \cdot \eta} = \frac{20.6 \times 0.1}{2 \times 0.9} = 1.15$ [N·m]

Select **BMU5120A-15A-3** from the "Gearmotor – Torque Table of Combination Type" on page D-28.
Since the permissible torque is 5.2 [N·m], the safety factor is $T_M / T_L = 5.2 / 1.15 \doteqdot 4.5$.
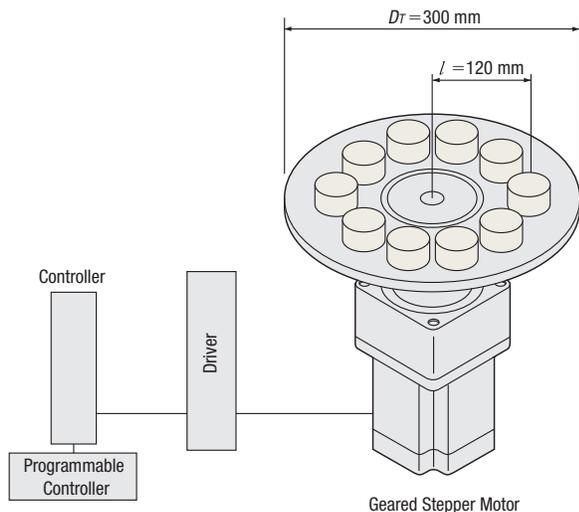Usually, a motor can operate at the safety factor of 1.5~2 or more.

● Index Mechanism
(1) Specifications and Operating Conditions of the Drive Mechanism
Geared stepper motors are ideal for systems with big inertia, such as index tables.

Controller

Driver

Programmable Controller

Geared Stepper Motor

Table diameter ··· $D_T = 300$ [mm]
Table thickness ··· $L_T = 5$ [mm]
Table material ························· Aluminum (Density $\rho = 2.8 \times 10^3$ [kg/m³])
Load diameter ··· $D_W = 40$ [mm]
Load thickness ··· $L_W = 30$ [mm]
Number of loads ·· 10 (1 every 36°)
Load material ························· Aluminum (Density $\rho = 2.8 \times 10^3$ [kg/m³])
Distance from central axis of table to central axis of load ·············· $l = 120$ [mm]
Positioning angle ··· $\theta = 36°$
Positioning time ··· $t_0 = 0.25$ seconds

The **RKⅡ** Series **PS** geared type (Gear ratio 10, resolution/pulse = 0.072°) can be used.
The **PS** geared type can be used at the maximum starting/stopping torque in the inertial drive.
Gear ratio ··· $i = 10$
Resolution/pulse ·· $\theta_S = 0.072°$

(2) Determine the Operating Pattern (Refer to formula on page H-5)
① Calculate the number of operating pulses A [Pulse]

$$A = \frac{\theta}{\theta_S}$$
$$= \frac{36°}{0.072°}$$
$$= 500 \text{ [Pulse]}$$

② Determine the acceleration (deceleration) time t_1 [s]
An acceleration (deceleration) time of 25% of the positioning time is appropriate.
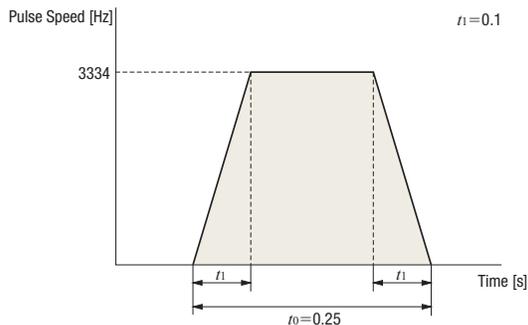Here, we shall let
$t_1 = 0.1$ [s].

③ Calculate the operating pulse speed f_2 [Hz].

$$f_2 = \frac{A}{t_0 - t_1} = \frac{500}{0.25 - 0.1}$$
$$\fallingdotseq 3334 \text{ [Hz]}$$

④ Calculate the operating speed N_M [r/min].

$$N_M = \frac{\theta_S}{360°} f_2 \cdot 60$$
$$= \frac{0.072°}{360°} \times 3334 \times 60$$
$$\fallingdotseq 40 \text{ [r/min]}$$

The permissible speed range for the **PS** geared motor with a gear ratio of 10 is $0 \sim 300$ [r/min].

Pulse Speed [Hz]

$t_1 = 0.1$

3334

t_1 t_1 Time [s]

$t_0 = 0.25$

(3) Calculate the Required Torque T_M [N·m] (Refer to page H-5)
① Calculate the load torque T_L [N·m]
Friction load is negligible and therefore omitted. Load torque is assumed as 0.

$$T_L = 0 \text{ [N·m]}$$

② Calculate the acceleration torque T_a [N·m]
②-1 Calculate the inertia J_L [kg·m²]
(Refer to page H-4 for the formula)

Inertia of Table $J_T = \dfrac{\pi}{32} \rho \cdot L_T \cdot D_T^4$

$$= \frac{\pi}{32} \times 2.8 \times 10^3 \times (5 \times 10^{-3}) \times (300 \times 10^{-3})^4$$
$$= 1.11 \times 10^{-2} \text{ [kg·m²]}$$

Inertia of Load J_{W1}
(Around Center of Load Rotation)
$$= \frac{\pi}{32} \rho \cdot L_W \cdot D_W^4$$
$$= \frac{\pi}{32} \times 2.8 \times 10^3 \times (30 \times 10^{-3}) \times (40 \times 10^{-3})^4$$
$$= 0.211 \times 10^{-4} \text{ [kg·m²]}$$

Load Mass $m_W = \dfrac{\pi}{4} \rho \cdot L_W \cdot D_W^2$

$$= \frac{\pi}{4} \times 2.8 \times 10^3 \times (30 \times 10^{-3}) \times (40 \times 10^{-3})^2$$
$$= 0.106 \text{ [kg]}$$

Inertia of load J_W [kg·m²] relative to the center of rotation can be calculated from distance l [mm] between the center of load and center of table rotation, mass of load m_W [kg], and inertia of load around the center of load J_{W1} [kg·m²].

Since the number of loads, $n = 10$ [pcs],

Inertia of Load J_W
(Around Center of Table Rotation)
$$= n (J_{W1} + m_W \cdot l^2)$$
$$= 10 \times \{(0.211 \times 10^{-4}) + 0.106 \times (120 \times 10^{-3})^2\}$$
$$= 1.55 \times 10^{-2} \text{ [kg·m²]}$$

Inertia $J_L = J_T + J_W$
$$= (1.11 + 1.55) \times 10^{-2}$$
$$= 2.66 \times 10^{-2} \text{ [kg·m²]}$$

②-2 Calculate the acceleration torque T_a [N·m]
Calculate the acceleration torque of the output gear shaft.

$$T_a = \frac{(J_0 \cdot i^2 + J_L)}{9.55} \cdot \frac{N_M}{t_1}$$
$$= \frac{(J_0 \times 10^2 + 2.66 \times 10^{-2})}{9.55} \cdot \frac{40}{0.1}$$
$$= 4.19 \times 10^3 J_0 + 1.11 \,[\text{N·m}]$$

The formula for calculating acceleration torque with pulse speed is shown below. Calculation results are the same.

$$T_a = (J_0 \cdot i^2 + J_L) \frac{\pi \cdot \theta s}{180°} \cdot \frac{f_2 - f_1}{t_1}$$
$$= (J_0 \times 10^2 + 2.66 \times 10^{-2}) \times \frac{\pi \times 0.072°}{180°} \times \frac{3334 - 0}{0.1}$$
$$= 4.19 \times 10^3 J_0 + 1.11 \,[\text{N·m}]$$

③ Calculate the required torque T_M [N·m]
Calculate safety factor $S_f = 2$.

$$T_M = (T_L + T_a) S_f$$
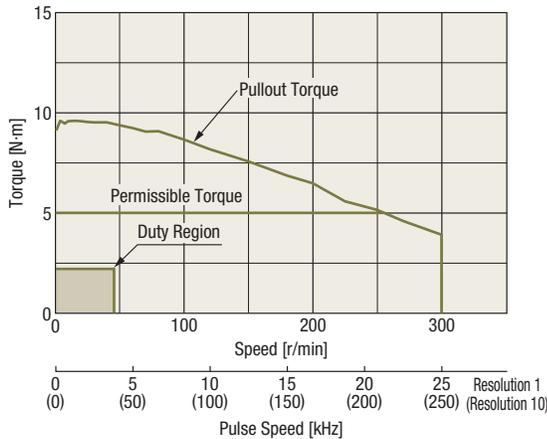$$= \{0 + (4.19 \times 10^3 J_0 + 1.11)\} \times 2$$
$$= 8.38 \times 10^3 J_0 + 2.22 \,[\text{N·m}]$$

(4) Select a Motor
①Tentative motor selection

Product Name	Rotor Inertia [kg·m^2]	Required Torque [N·m]
RKS566AAD-PS10-3	270×10^{-7}	2.45

② Determine the motor from the speed – torque characteristics
RKS566AAD-PS10-3

The **PS** geared type can use acceleration torque up to the maximum torque range to start and stop inertia loads.
Since the duty region of the motor (operating speed and required torque) falls within the pullout torque of the speed – torque characteristics, the motor can be used.
Check the inertia ratio and acceleration/deceleration rate to ensure that the selection is correct.

(5) Check the Inertia Ratio (Refer to page H-6)
The **RKS566AAD-PS10-3** has a gear ratio of 10, therefore, the inertia ratio is calculated as follows.

$$\frac{J_L}{J_0 \cdot i^2} = \frac{2.66 \times 10^{-2}}{270 \times 10^{-7} \times 10^2}$$
$$\fallingdotseq 9.85$$

RKS566AAD-PS10-3 motor is the equivalent of the **RKS566AAD-3** motor. Since the inertia ratio is 10 or less, if the inertia ratio is 9.85, motor operation is deemed to be possible.

(6) Check the Acceleration/Deceleration Rate (Refer to page H-5)
Note when calculating that the units for acceleration/deceleration rate T_R are [ms/kHz].

$$T_R = \frac{t_1}{f_2 - f_1} = \frac{0.1\,[\text{s}]}{3334\,[\text{Hz}] - 0\,[\text{Hz}]}$$
$$= \frac{100\,[\text{ms}]}{3.334\,[\text{kHz}] - 0\,[\text{kHz}]}$$
$$\fallingdotseq 30\,[\text{ms/kHz}]$$

The **RKS566AAD-PS10-3** motor is the equivalent of the **RKS566AAD-3** and it has an acceleration/deceleration rate of 20 [ms/kHz] or more. Since the acceleration/deceleration rate is 30 [ms/kHz] the operation of the motor is possible.

● **Winding Mechanism**
This example demonstrates how to select winding equipment when a torque motor is used.

Tensioning Motor

Winding Motor
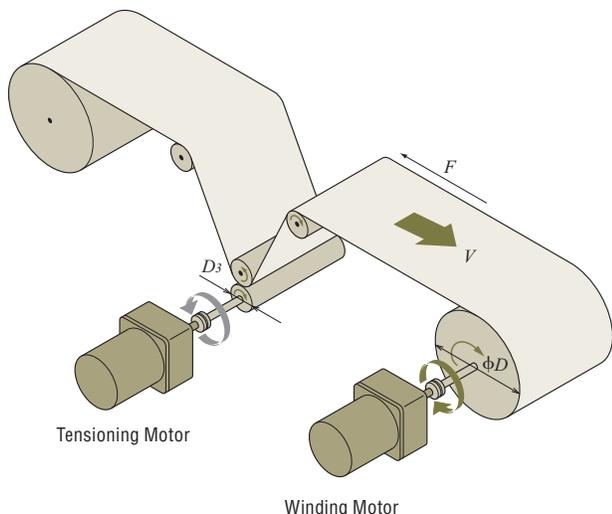
(1) Specifications and Operating Conditions of the Drive Mechanism
Winding roller diameter ϕD
   Diameter at start of winding ....$D_1 = 15$ [mm] $= 0.015$ [m]
   Diameter at end of winding ....$D_2 = 30$ [mm] $= 0.03$ [m]
Tensioning roller diameter ....$D_3 = 20$ [mm] $= 0.02$ [m]
Winding speed .... $V = 47$ [m/min] (constant)
Tension ....$F = 4$ [N] (constant)
Power ....Single-phase 115 VAC
Operating time ....Continuous

(2) Select a Winding Motor
In general, a winding motor must satisfy the following conditions:
- Able to provide a constant winding speed
- Able to apply a constant tension to prevent slackening of material

To meet the above conditions, the following points must be given consideration when selecting a motor:
- Since the winding diameter is different between the start and end of winding, the motor speed must be varied according to the winding diameter to keep the winding speed constant.
- If the tension is constant, the required motor torque is different between the start and end of winding. Accordingly, the torque must be varied according to the winding diameter.

Torque motors have ideal characteristics to meet these conditions.

① Calculate the Required Speed
Calculate the speed N_1 required at the start of winding.

$$N_1 = \frac{V}{\pi \cdot D_1} = \frac{47}{\pi \times 0.015} = 997.9 \text{ [r/min]} \doteqdot 1000 \text{ [r/min]}$$

Calculate the speed N_2 required at the end of winding.

$$N_2 = \frac{V}{\pi \cdot D_2} = \frac{47}{\pi \times 0.03} = 498.9 \text{ [r/min]} \doteqdot 500 \text{ [r/min]}$$

② Calculate the Required Torque
Calculate the torque T_1 required at the start of winding.

$$T_1 = \frac{F \cdot D_1}{2} = \frac{4 \times 0.015}{2} = 0.03 \text{ [N·m]}$$

Calculate the torque T_2 required at the end of winding.

$$T_2 = \frac{F \cdot D_2}{2} = \frac{4 \times 0.03}{2} = 0.06 \text{ [N·m]}$$

This winding motor must meet the following conditions:
   Start of Winding:
      Speed $N_1 = 1000$ [r/min], Torque $T_1 = 0.03$ [N·m]
   End of Winding:
   Speed $N_2 = 500$ [r/min], Torque $T_2 = 0.06$ [N·m]

③ Select a Motor
Check the Speed – Torque Characteristics
Select a motor that meets the required conditions specified above. If the required conditions are plotted on the Speed – Torque Characteristics for **4TK10A-AW2U**, it is clear that the conditions roughly correspond to the characteristics at a torque setting voltage of 60 VAC.

Speed – Torque Characteristics
4TK10A-AW2U
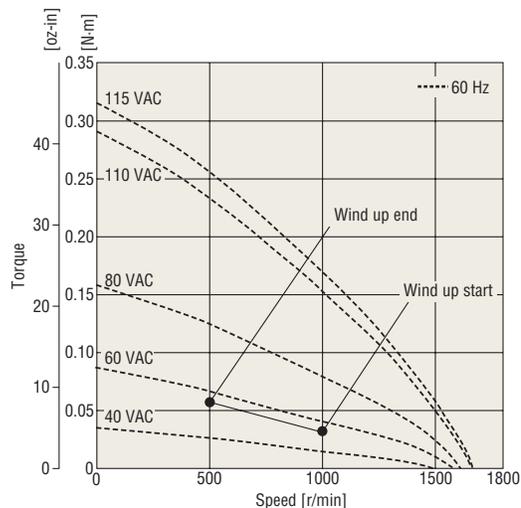
Check the Operation Time
4TK10A-AW2U has a five-minute rating when the voltage is 115 VAC and a continuous rating when it is 60 VAC. Under the conditions given here, the voltage is 60 VAC max., meaning that the motor can be operated continuously.

Note
● If a torque motor is operated continuously in a winding application, select conditions where the service rating of the torque motor remains continuous.

(3) Select a Tensioning Motor

If tension is not applied, the material slackens as it is wound and cannot be wound neatly. Torque motors also have reverse-phase brake characteristics and can be used as tensioning motors. How to select a tensioning motor suitable for the winding equipment shown on page H-16 is explained below.

① Calculate the Required Speed N_3

$$N_3 = \frac{V}{\pi \cdot D_3} = \frac{47}{\pi \times 0.02} = 748.4 \text{ [r/min]} \doteqdot 750 \text{ [r/min]}$$

② Calculate the Required Torque T_3

$$T_3 = \frac{F \cdot D_3}{2} = \frac{4 \times 0.02}{2} = 0.04 \text{ [N·m]}$$

③ Select a Motor

Select a motor that meets the required conditions specified above. If the required conditions are plotted on the speed – brake torque characteristics* for the **4TK10A-AW2U** reverse-phase brake, it is clear that the conditions roughly correspond to the characteristics at a torque setting voltage of 40 VAC.

Speed – Brake Torque Characteristics with Reverse-Phase Brake
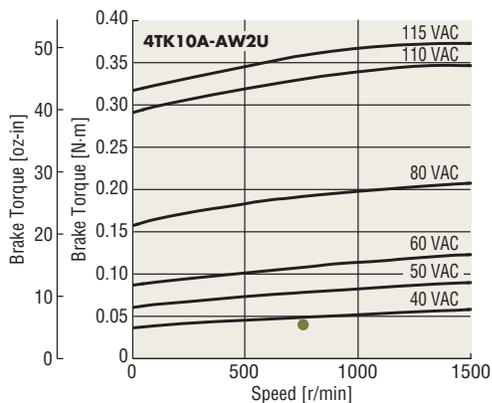
Note
● If a torque motor is operated continuously in a brake application, how much the motor temperature rises varies depending on the applicable speed and torque setting voltage. Be sure to keep the temperature of the motor case at 90°C max.

From the above checks, the **4TK10A-AW2U** can be used both as a winding motor and tensioning motor.

∗ Please contact the nearest Oriental Motor sales office or customer support center for information on the speed – brake torque characteristics of each product.

Selection Calculations

Motors

Linear & Rotary Actuators

Cooling Fans

Service Life

Stepper Motors

Servo Motors

Standard AC Motors

Brushless Motors/AC Speed Control Motors

Gearheads

Cooling Fans