H

Technical Reference

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 procedure is explained below.

Determine the drive mechanism

● First, 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, you must also determine the dimensions, mass and friction coefficient etc. that are required for the load calculation. The general items are explained below.
- Dimensions and mass (or density) of load
- Dimensions and mass (or density) of each part
- Friction coefficient of the sliding surface of each moving part

▼

Check the required specifications (Equipment specifications)

● Check the required specifications for the motor from the equipment specifications. The general items are explained below.
- Operating speed and operating time
- Positioning distance and positioning time
- Resolution
- Stopping accuracy
- Position holding
- Power supply voltage and frequency
- Operating Environment

▼

Calculate the load

● Calculate the load torque and load inertia at the motor output shaft. Refer to page H-3 for the formula of load torque for representative mechanisms.
Refer to page H-4 for formula of the moment of inertia for representative configurations.

▼

Select motor type

● Select the appropriate model from standard AC Motors, Speed Control Motors, Stepping 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 model, check the selection formulas and selection points on page H-5.

Sizing and Selection Service

We offer download service for the easy-to-use selection software. We also offer sizing and selection service for optimal products by dedicated staff members (for free).

Downloading the Selection Software

We provide the dedicated selection software for stepping motors and servo motors from Oriental Motor. All you have to do is enter the value of mechanism or operating conditions to easily select the motor's capacity. The software can be downloaded from our website.

Requesting the Selections

We provide a selection service for motor selections from load calculations that requires time and effort.

●FAX

Product recommendation information sheets are shown from pages I-24 to I-33.
Fill in the necessary information on this sheet and send it to your nearest customer support center.

●Internet

Simple requests for motors can be made using the selection form on our website.

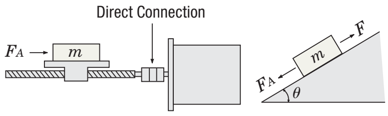
Formula for the Load Torque T_L [N·m] by Drive Mechanism

Formula for the Load Torque

◇Ball Screw Drive

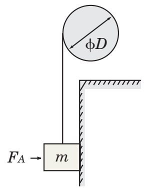
$$T_L = \left(\frac{F \cdot P_B}{2\pi \cdot \eta} + \frac{\mu_0 \cdot F_0 \cdot P_B}{2\pi}\right) \frac{1}{i} \ \text{[N·m]} \quad \text{①}$$

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



◇Pulley Drive

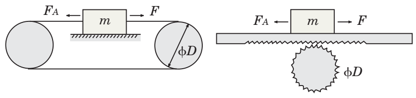
$$T_L = \frac{\mu \cdot F_A + m \cdot g}{2\pi} \cdot \frac{\pi \cdot D}{i} = \frac{(\mu \cdot F_A + m \cdot g)\, D}{2 \cdot i} \ \text{[N·m]} \quad \text{③}$$



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

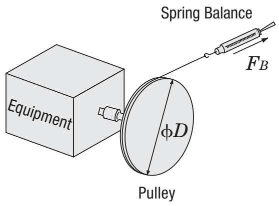
$$T_L = \frac{F}{2\pi \cdot \eta} \cdot \frac{\pi \cdot D}{i} = \frac{F \cdot D}{2 \cdot \eta \cdot i} \ \text{[N·m]} \quad \text{④}$$

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



◇Actual Measurement Method

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



F : Force of moving direction [N]
F_0 : Preload [N] ($\fallingdotseq 1/3F$)
μ_0 : Internal friction coefficient of preload nut ($0.1 \sim 0.3$)
η : Efficiency ($0.85 \sim 0.95$)
i : Gear ratio (This is the gear ratio of the mechanism - 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)

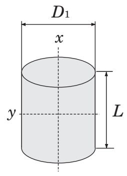
Formula for the Inertia J [kg·m²]

● Calculate the Moment of Inertia

◇ Inertia of a Cylinder

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

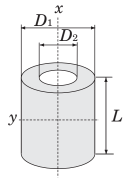
$$J_y = \frac{1}{4} m \left(\frac{D_1^2}{4} + \frac{L^2}{3} \right) \ \text{[kg·m}^2\text{]} \quad (8)$$



◇ Inertia of a Hollow Cylinder

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

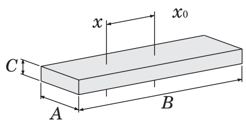
$$J_y = \frac{1}{4} m \left(\frac{D_1^2 + D_2^2}{4} + \frac{L^2}{3} \right) \ \text{[kg·m}^2\text{]} \quad (10)$$



◇ Inertia on Off-Center Axis

$$J_x = J_{x0} + m \cdot l^2 = \frac{1}{12} m \left(A^2 + B^2 + 12 \cdot l^2 \right) \ \text{[kg·m}^2\text{]} \quad (11)$$

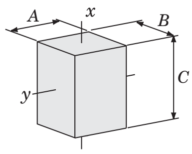
l: Distance between x and x_0 axes [m]



◇ Inertia of a Rectangular Pillar

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

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



◇ Inertia of an Object in Linear Motion

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

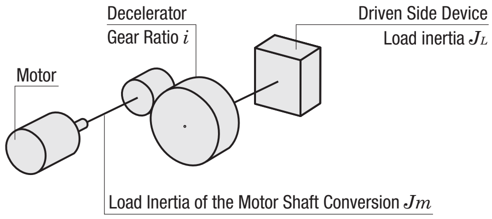
A: Unit movement [m/rev]

Conversion formula for the moment of load inertia of the motor shaft when using a deceleration gear

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

Formula for the relation between J and GD^2

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



Density

- Stainless steel (SUS304) $\rho = 8.0 \times 10^3$ [kg/m³]
- Iron $\rho = 7.9 \times 10^3$ [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]

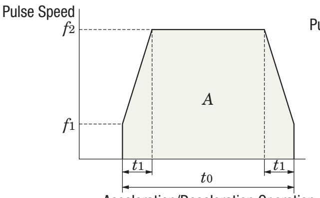
J_x : Inertia on x-axis [kg·m²]
J_y : Inertia on y-axis [kg·m²]
J_{x0}: Inertia on x_0-axis (axis passing through center of gravity) [kg·m²]
m : Mass [kg]
D_1 : Outer diameter [m]
D_2 : Inner diameter [m]
ρ : Density [kg/m³]
L : Length [m]

Motor Selection Calculations

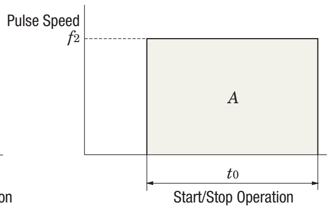
The following explains the required formulas for controlling a stepping motor or servo motor based on pulse signal:

Operating Pattern

For stepping 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 between the point A to point B [m]
$l$rev: Traveling amount per rotation [m/rev]
θs : 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

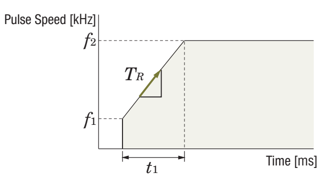
$$f_2 = \frac{A}{t_0}$$

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 speed is in [KHz] and the time in [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.

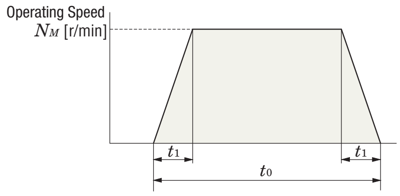
Formula for the Acceleration Torque Ta [N·m]

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 stepping 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 load inertia [kg·m²]
N_M: Operating speed [r/min]
t_1 : Acceleration (deceleration) time [s]
i : Gear Ratio

<When calculating the acceleration torque for stepping 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

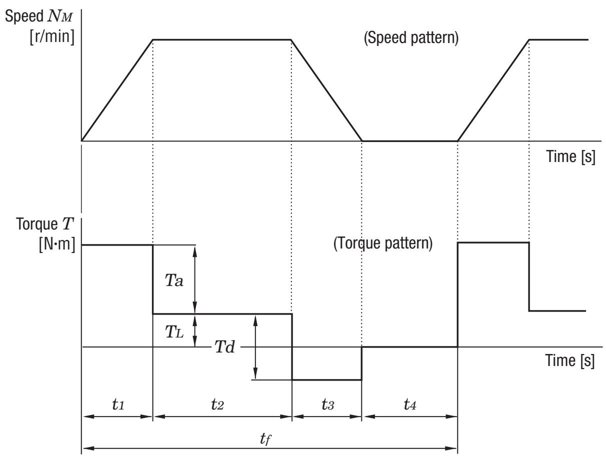
Formula for the Effective Load Torque T_{rms} [N·m]

Calculate the effective load torque when selecting the servo motors and **BX** 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, stepping 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 several percent 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 A-15)

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 load inertia

A permissible load 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 load inertia does not exceed the permissible value. In terms of the combination type, there is the permissible load inertia combination type. Select products with values that do not exceed the values of the combination types.

③ Effective load torque

For the **BX** Series, with its 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.

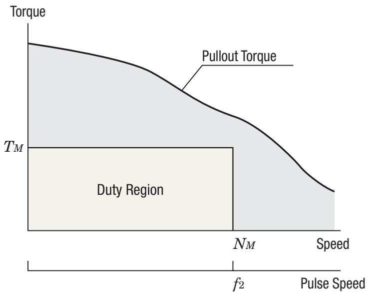
Stepping Motors

① Check the required torque

For stepping 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)
2-/5-Phase Stepping Motors	2
αSTEP	1.5~2



② Consider temperature rise

The stepping 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 stepping 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.

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

③ Check the acceleration/deceleration rate

If the duty region (operating speed N_M and the required torque T_M) of the stepping 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 to be high. Therefore, with large load inertias in this condition, there is a possibility that the motor cannot be driven even with sudden acceleration/deceleration. 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_R [ms/kHz]
5-Phase Stepping Motors	20, 28, 42, 60	20 or more
	85(90)	30 or more
2-Phase Stepping Motors	20, 28(30), 35, 42, 50, 56.4, 60	50 or more
	85(90)	75 or more
αSTEP	28(30), 42, 60, 85(90)	0.5 or more *

*This item need not be checked for αSTEP. 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.

$$T_R \cdot \frac{\theta_S}{\theta_B} \cdot i$$

T_R : Acceleration/Deceleration rate [ms/kHz]
θ_S : Step angle [°]
θ_B : Refer to table below.
i : Gear ratio for geared types

Coefficient

Product	θ_B
5-Phase Stepping Motors	0.72°
2-Phase Stepping Motors	1.8°
αSTEP	0.36°

④ Check the inertia ratio

Calculate the inertia ratio using the following equation:

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

For Geared Motors

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

Large inertia ratios in stepping 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 to be high. 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
2-/5-Phase Stepping Motors	20, 28, 35	5 or less
	42, 50, 56.4, 60, 85	10 or less
αSTEP	28, 42, 60, 85	30 or less

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

Servo Motors

① Permissible Load Inertia

A permissible load inertia is specified for the servo motor for stable control. The load 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 a load torque T_L and a rated torque of servo motor is 1.5 to 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. (Keep the the safety factor of required torque Sf at 1.5 to 2 or more.)

Note that the time that can be used for maximum instantaneous torque varies depending on the motor.

Maximum Instantaneous Torque and Operating Time

Product	Operating Time	Maximum Instantaneous Torque
NX Series	Approx. within 0.5 second	At 3 times the rated torque (at rated speed)

④ Effective Load Torque

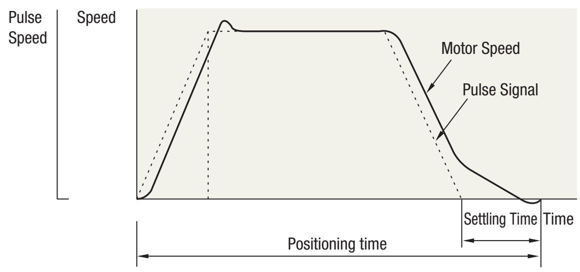
The motor can be driven when the effective load safety factor, which is the ratio of an effective load torque and a rated torque of servo motor, is 1.5 to 2 or more.

$$\text{Effective load safety factor} = \frac{\text{Rated Torque}}{\text{Effective Load Torque}}$$

⑤ Settling Time

There is a time lag between a position command by pulse signal and a servo motor's real operation. This 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 of settling time for **NX** Series is 60 to 70 ms. However, the settling time varies when the gain parameter is changed by the mechanical rigidity setting switch.

Selection Examples

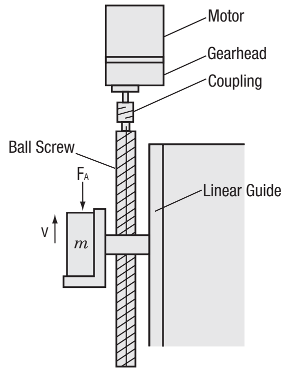
Ball Screw Mechanism

Using Standard AC Motors

(1) Specifications and Operating Conditions of the Drive Mechanism

This is a selection example on how to select an electromagnetic brake type motor for use on a tabletop vertical operation with a ball screw.

A motor that meets the following required specifications is selected.



Total mass of table and load ········ m=45 [kg]
Table speed ········ V=12±2 [mm/s]
External force ········ F_A=0 [N]
Ball screw tilt angle ········ θ=90 [˚]
Overall length of ball screw ········ L_B=800 [mm]
Ball screw shaft diameter ········ D_B=20 [mm]
Ball screw lead ········ P_B=5 [mm]
The traveling distance moved for one rotation of ball screw ········ A=5 [mm]
Ball screw efficiency ········ η=0.9
Material of ball screw ········ Iron (Density ρ =7.9×10^3 [kg/m^3])
Internal friction coefficient of preload nut ········ μ_0=0.3
Friction coefficient of sliding surface ········ μ=0.05
Motor power supply ········ Single-phase 220 VAC 50 Hz
Operating time ········ Intermittent operation for five hours a day
Start and Stop repetition
Load holding during stops is required.

(2) Determine the Gear Ratio of Gearhead

$$\text{Gearhead Output Shaft Speed } N_G = \frac{V\cdot60}{A} = \frac{(12\pm2)\times60}{5}$$
$$= 144\pm24 \text{ [r/min]}$$

Since the rated speed for an electromagnetic brake type motor (4-pole) at 50 Hz is 1200 to 1300 [r/min], select a gearhead gear ratio within this range.

$$\text{Gearhead Gear Ratio } i = \frac{1200\sim1300}{N_G} = \frac{1200\sim1300}{144\pm24} = 7.1\sim10.8$$

Select a gear ratio of i=9 from within this range.

(3) Calculate the required torque T_M [N·m]

$$\text{Force of moving direction } F = F_A + m\cdot g\,(\sin\theta + \mu\cdot\cos\theta)$$
$$= 0 + 45\times9.807\,(\sin90^\circ + 0.05\cos90^\circ)$$
$$= 441 \text{ [N]}$$

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

$$\text{Load Torque } T'_L = \frac{F\cdot P_B}{2\pi\cdot\eta} + \frac{\mu_0\cdot F_0\cdot P_B}{2\pi}$$
$$= \frac{441\times5\times10^{-3}}{2\pi\times0.9} + \frac{0.3\times147\times5\times10^{-3}}{2\pi}$$
$$= 0.426 \text{ [N·m]}$$

Consider the safety factor Sf=2.

$$T_L = T'_L\cdot S_f = 0.426\times2 = 0.86 \text{ [N·m]}$$

Select the gearhead and electromagnetic brake type motor that satisfies the permissible torque of the gearhead based on the calculation results so far (Gear ratio $i=9$, Load torque $T_L=0.86$ [N·m]).
At this time, refer to the "Permissible Torque When Gearhead is Attached" table on page A-105 and temporarily select motor **4RK25GN-CW2ML1** and gearhead **4GN9KF**.
Convert this load torque to the value at the motor output shaft, and calculate the required torque T_M.

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

(Gearhead **4GN9KF** Transmission Efficiency $\eta_G = 0.81$)

Since the preselected starting torque of 160 [mN·m] for **4RK25GN-CW2ML1** satisfies the required torque 118 [mN·m], this mechanism can be started.
Moreover, check whether the working gravitational load can be held with the electromagnetic brake while stopped.
Here, consider a load equivalent to the calculated load torque.
The required torque for load holding at the motor output shaft T'_M

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

Since the preselected static friction torque of the electromagnetic brake of 100 [mN·m] for **4RK25GN-CW2ML1** satisfies the required torque 95.6 [mN·m], this mechanism can be started.

(4) Check the load inertia J [kg·m²]

Inertia of Ball Screw

$$J_B = \frac{\pi}{32} \cdot \rho \cdot L_B \cdot D_B^4$$
$$= \frac{\pi}{32} \times 7.9 \times 10^3 \times 800 \times 10^{-3} \times (20 \times 10^{-3})^4$$
$$= 0.993 \times 10^{-4} \text{ [kg·m}^2\text{]}$$

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

$$= 45 \left(\frac{5 \times 10^{-3}}{2\pi}\right)^2$$
$$= 0.286 \times 10^{-4} \text{ [kg·m}^2\text{]}$$

Calculate the load inertia for the gearhead output shaft J.

$$J = J_B + J_m = 0.993 + 0.286$$
$$= 1.28 \times 10^{-4} \text{ [kg·m}^2\text{]}$$

For the permissible load inertia J_G for gearhead **4GN9KF** with a gear ratio of 9, use the formula below (refer to page A-15).

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

Therefore, $J<J_G$ as the load inertia is less than the permissible value, so there is no problem. Since there is a margin for torque, traveling speed is checked with a speed that is under no load (approx. 1470 r/min).

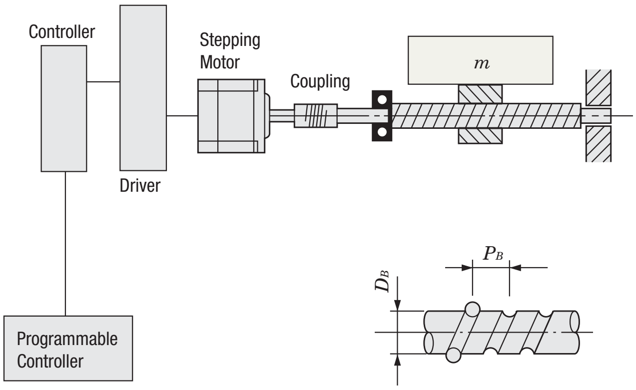
$$V = \frac{N_M \cdot P_B}{60 \cdot i} = \frac{1470 \times 5}{60 \times 9} = 13.6 \text{ [mm/s]}$$

N_M: Motor speed

This confirms that the motor meets the specifications.
So, select motor **4RK25GN-CW2ML1** and gearhead **4GN9KF**.

Using Stepping 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 ········ $\mu_0=0.3$
Ball screw shaft diameter ········ $D_B=15$ [mm]
Overall length of ball screw ········ $L_B=600$ [mm]
Material of ball screw ········ Iron (Density $\rho=7.9\times10^3$ [kg/m³])
Ball screw lead ········ $P_B=15$ [mm]
Desired resolution ········ $\Delta l=0.03$ [mm/step]
(Feed per pulse)
Feed ········ $l=180$ [mm]
Positioning time ········ $t_0=$ within 0.8 second
Tilt angle ········ $\theta=0$ [°]

(2) Calculate the Required Resolution θ_S

$$\theta_S = \frac{360° \cdot \Delta l}{P_B}$$
$$= \frac{360° \times 0.03}{15} = 0.72°$$

Stepping motor and driver package **AR** Series (Resolution 0.72°/pulse) can be used.

(3) Determine an Operating Pattern (Refer to formula on page H-5)

① Formula for the number of operating pulses A [Pulse]

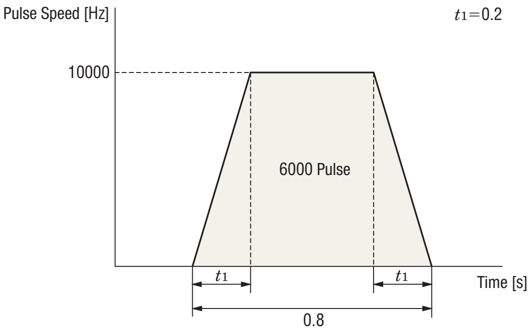
$$A = \frac{l}{P_B} \cdot \frac{360°}{\theta_S}$$
$$= \frac{180}{15} \times \frac{360°}{0.72°} = 6000 \text{ [Pulse]}$$

② Determine the acceleration (deceleration) time t_1 [s]
An acceleration (deceleration) time of 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]

$$N_M = \frac{\theta s}{360^\circ} f_2 \cdot 60$$
$$= \frac{0.72^\circ}{360^\circ} \times 10000 \times 60$$
$$= 1200 \text{ [r/min]}$$

(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 $F = F_A + m \cdot g\,(\sin\theta + \mu \cos\theta)$
$$= 0 + 40 \times 9.807\,(\sin 0^\circ + 0.05 \cos 0^\circ)$$
$$= 19.6 \text{ [N]}$$

Preload $F_0 = \frac{F}{3} = \frac{19.6}{3} = 6.53$ [N]

Load Torque $T_L = \frac{F \cdot P_B}{2\pi \cdot \eta} + \frac{\mu_0 \cdot F_0 \cdot P_B}{2\pi}$
$$= \frac{19.6 \times 15 \times 10^{-3}}{2\pi \times 0.9} + \frac{0.3 \times 6.53 \times 15 \times 10^{-3}}{2\pi}$$
$$= 0.0567 \text{ [N·m]}$$

② Calculate the acceleration torque T_a [N·m]

②-1 Calculate the load inertia J_L [kg·m²]
(Refer to 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 $J_T = m\,(\frac{P_B}{2\pi})^2$
$$= 40 \times (\frac{15 \times 10^{-3}}{2\pi})^2$$
$$= 2.28 \times 10^{-4} \text{ [kg·m}^2]$$

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

$$T_a = (J_0 + J_L) \cdot \frac{\pi \cdot \theta s}{180^\circ} \cdot \frac{f_2 - f_1}{t_1}$$
$$= (J_0 + 2.52 \times 10^{-4}) \times \frac{\pi \times 0.72^\circ}{180^\circ} \times \frac{10000 - 0}{0.2}$$
$$= 628\, J_0 + 0.158 \text{ [N·m]}$$

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

$$T_M = (T_L + T_a)\, Sf$$
$$= \{0.0567 + (628\, J_0 + 0.158)\} \times 2$$
$$= 1256\, J_0 + 0.429 \text{ [N·m]}$$

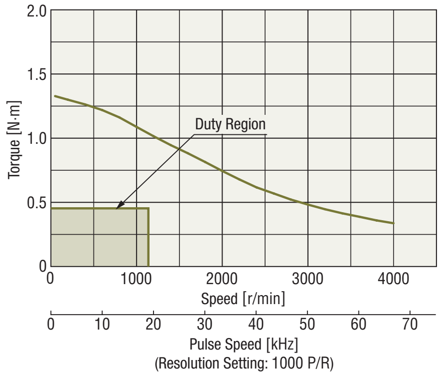
(5) Select a Motor

① Tentative motor selection

Product Name	Rotor Inertia [kg·m²]	Required Torque [N·m]
AR66AC-◇	380×10^{-7}	0.48

② Determine the motor by speed - torque characteristics

AR66AC-◇



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)

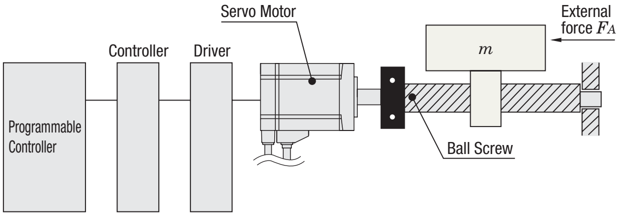
$$\frac{J_L}{J_0} = \frac{2.52 \times 10^{-4}}{380 \times 10^{-7}} \fallingdotseq 6.6$$

Since the inertia ratio of **AR66AC-◇** is 30 or less, you can judge from the calculated inertia ratio of 6.6 that motor operation 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:



Maximum speed of the table .... V_L=0.2 [m/s]
Resolution .... Δl=0.02 [mm]
Motor power supply .... Single-Phase 220 VAC
Total mass of table and load .... m=100 [kg]
External force .... F_A=29.4 [N]
Friction coefficient of sliding surface .... μ=0.04
Ball screw efficiency .... η=0.9
Internal friction coefficient of preload nut .... μ_0=0.3
Ball screw shaft diameter .... D_B=25 [mm]
Overall length of ball screw .... L_B=1000 [mm]
Ball screw lead .... P_B=10 [mm]
Material of ball screw .... Iron (Density ρ =7.9×10^3 [kg/m^3])
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.

$$\theta = \frac{360^\circ \cdot \Delta l}{P_B} = \frac{360^\circ \times 0.02}{10} = 0.72^\circ$$

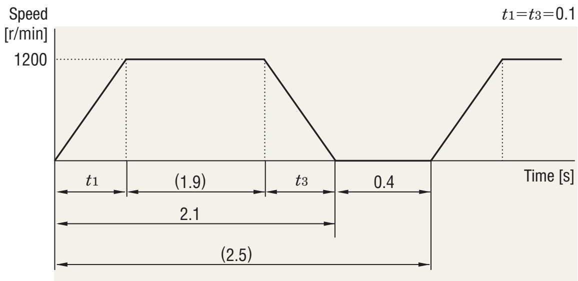
The resolution of **NX** Series θ_M=0.36°/pulse satisfies this.

(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 the N_M, the operating cycle and the acceleration/deceleration time.



(4) Calculate the load torque T_L [N·m]

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

$$= 29.4 + 100 \times 9.807\,(\sin 0^\circ + 0.04 \cos 0^\circ)$$
$$= 68.6 \text{ [N]}$$

Load Torque of the Motor Shaft Conversion

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

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

(5) Calculate the load inertia J_L [kg·m^2]

Inertia of Ball Screw

$$J_B = \frac{\pi}{32} \cdot \rho \cdot L_B \cdot D_B^4$$
$$= \frac{\pi}{32} \times 7.9 \times 10^3 \times 1000 \times 10^{-3} \times (25 \times 10^{-3})^4$$
$$\fallingdotseq 3.03 \times 10^{-4} \text{ [kg·m}^2\text{]}$$

Inertia of table and load $J_m = m\,(\frac{P_B}{2\pi})^2$

$$= 100 \times (\frac{10 \times 10^{-3}}{2\pi})^2$$
$$\fallingdotseq 2.53 \times 10^{-4} \text{ [kg·m}^2\text{]}$$

Load inertia $J_L = J_B + J_m$

$$= 3.03 \times 10^{-4} + 2.53 \times 10^{-4} = 5.56 \times 10^{-4} \text{ [kg·m}^2\text{]}$$

(6) Tentative servo motor selection

Safety factor Sf=1.5.

Load torque $T'_L = Sf \cdot T_L$

$$= 1.5 \times 0.13 = 0.195 \text{ [N·m]}$$

Load Inertia $J_L = 5.56 \times 10^{-4}$ [kg·m^2]

Therefore, select the servo motor whose speed is 1200 [r/min], outputs the rated torque 0.195 [N·m] or more and whose permissible load inertia 5.56×10^{-4} [kg·m^2] or more.

→ **NX620AC-◇**

Rated speed N = 3000 [r/min]
Rated torque T_M = 0.637 [N·m]
Rotor inertia J_0 = 0.162 × 10^{-4} [kg·m^2]
Permissible load inertia J = 8.1 × 10^{-4} [kg·m^2]
Maximum 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.

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

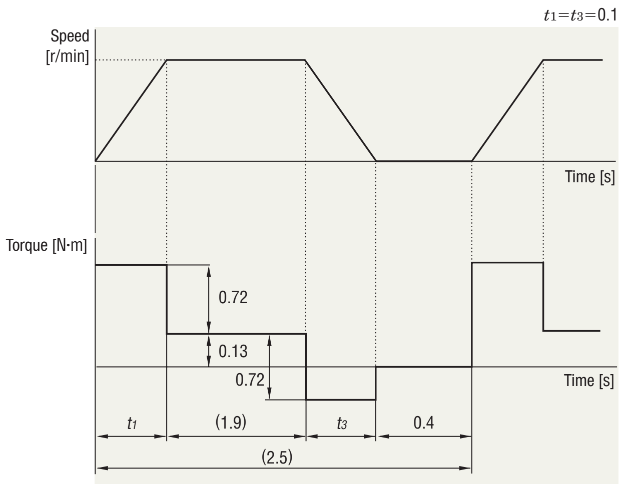
(8) Calculate the required torque T [N·m]

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

The required torque is less than 1.91 [N·m], the maximum instantaneous torque of **NX620AC-◇**, so **NX620AC-◇** 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 $t_1=t_3=0.1$ [s] for acceleration and deceleration time. Therefore, $t_2=2.1-0.1\times2=1.9$ [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:

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

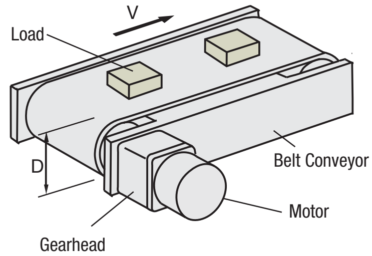
Generally a motor can operate at an effective load safety factor of 1.5 to 2 or more.

Belt and Pulley Mechanism

Using Standard AC Motors

(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 ········· $m_1=25$ [kg]
External force ········· $F_A=0$ [N]
Friction coefficient of sliding surface ········· $\mu=0.3$
Roller diameter ········· $D=90$ [mm]
Roller mass ········· $m_2=1$ [kg]
Belt and roller efficiency ········· $\eta=0.9$
Belt speed ········· $V=180$ [mm/s] $\pm10\%$
Motor power supply ········· Single-phase 220 VAC 50 Hz
Operating time ········· Operation for 8 hours a day

(2) Determine the Gear Ratio of Gearhead.

$$\text{Gearhead Output Shaft Speed } N_G = \frac{V \cdot 60}{\pi \cdot D} = \frac{(180 \pm 18) \times 60}{\pi \times 90}$$

$$= 38.2 \pm 3.8 \text{ [r/min]}$$

Since the rated speed for an induction motor (4-pole) at 50 Hz is 1200 to 1300 [r/min], select a gearhead gear ratio within this range.

$$\text{Gearhead Gear Ratio } i = \frac{1200 \sim 1300}{N_G} = \frac{1200 \sim 1300}{38.2 \pm 3.8} = 28.6 \sim 37.8$$

Select a gear ratio of $i=36$ 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 gearhead and induction motor that satisfies the permissible torque of the gearhead based on the calculation results so far (Gear ratio $i=36$, Load torque $T_L=7.36$ [N·m]).
At this time, refer to the "Permissible Torque When Gearhead is Attached" table on page A-41 and temporarily select motor **5IK40GN-CW2L2** and gearhead **5GN36KF**.
Convert this load torque to the value at the motor output shaft, and calculate the required torque T_M.

$$T_M = \frac{T_L}{i \cdot \eta_G} = \frac{7.36}{36 \times 0.73} = 0.280 \text{ [N·m]} = 280 \text{ [mN·m]}$$

(Gearhead **5GN36KF** Transmission Efficiency $\eta_G = 0.73$)

The preselected starting torque of 200 [mN·m] for **5IK40GN-CW2L2** cannot satisfy the required torque.
Therefore, change the gearhead to **5GE36KBF** and the motor one size to **5IK60GE-CW2L2**. In this case, use the formula below.

$$T_M = \frac{T_L}{i \cdot \eta_G} = \frac{7.36}{36 \times 0.66} = 0.31 \text{ [N·m]} = 310 \text{ [mN·m]}$$

(Gearhead **5GE36KBF** Transmission Efficiency $\eta_G = 0.66$)

The starting torque of 320 [mN·m] for **5IK60GE-CW2L2** satisfies the required torque of 310 [mN·m].

(4) Check the load inertia J [kg·m²]

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

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

$$= 507 \times 10^{-4} \text{ [kg·m}^2\text{]}$$

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

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

$$= 10.2 \times 10^{-4} \text{ [kg·m}^2\text{]}$$

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

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

For the permissible load inertia J_G for gearhead **5GE36KBF** with a gear ratio of 36, use the formula below (refer to page A-15).

$$J_G = 1.1 \times 10^{-4} \times 36^2$$
$$= 1425 \times 10^{-4} \text{ [kg·m}^2\text{]}$$

Therefore, $J < J_G$ as the load inertia is less than the permissible value, so there is no problem. Since the motor selected has a rated torque of 490 [mN·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. 1470 r/min) to calculate belt speed, and check whether the selected product meets the required specifications.

$$V = \frac{N_M \cdot \pi \cdot D}{60 \cdot i} = \frac{1470 \times \pi \times 90}{60 \times 36} = 192 \text{ [mm/s]}$$

N_M: Motor speed

This confirms that the motor meets the specifications.
So, select motor **5IK60GE-CW2L2** and the gearhead **5GE36KBF**.

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 **SMK5100C-A** when the belt-drive table shown in Fig. 1 is driven in the operation pattern shown in Fig. 2.

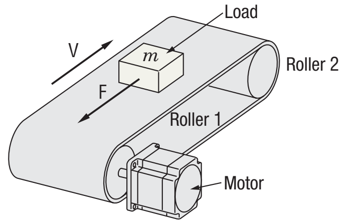


Fig. 1 Example of Belt Drive

Total mass of belt and load ········ m_1=1.5 [kg]
Roller diameter ········ D=30 [mm]
Roller mass ········ m_2=0.1 [kg]
Friction coefficient of sliding surface ········ μ=0.04
Belt and pulley efficiency ········ η=0.9
Power supply frequency ········ 50 Hz (Motor speed: 60 r/min)

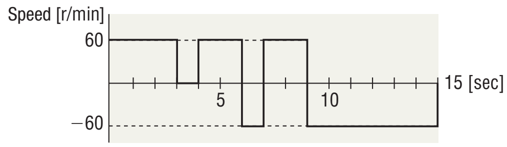


Fig. 2 Operating Pattern

Low-speed synchronous motors share the same basic principles as 2-phase stepping motors. Accordingly, the torque for a low-speed synchronous motor is calculated in the same manner as a 2-phase stepping motor.

(2) Belt Speed V [mm/s]

Check the belt (load) speed.

$$V = \frac{\pi \cdot D \cdot N}{60} = \frac{\pi \times 30 \times 60}{60} = 94 \text{ [mm/s]}$$

(3) Calculate the load torque T_L [N·m]

Frictional coefficient of sliding surfaces $F = F_A + m_1 \cdot g (\sin\theta + \mu \cdot \cos\theta)$

$$= 0 + 1.5 \times 9.807 (\sin 0^\circ + 0.04 \cos 0^\circ)$$
$$= 0.589 \text{ [N]}$$

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

(4) Calculate the load inertia J_L [kg·m²]

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

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

$$= 3.38 \times 10^{-4} \text{ [kg·m}^2\text{]}$$

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

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

$$= 0.113 \times 10^{-4} \text{ [kg·m}^2\text{]}$$

Calculate the moment of load inertia J_L.
Take into account that there are two rollers (J_{m2}).

$$J_L = J_{m1} + 2J_{m2} = 3.38 \times 10^{-4} + 0.113 \times 10^{-4} \times 2 = 3.5 \times 10^{-4} \text{ [kg·m}^2\text{]}$$

(5) Calculate the acceleration torque T_a [N·m]

Calculate the start acceleration torque.

$$T_a = (J_0 + J_L) \cdot \frac{\pi \cdot \theta s}{180^\circ \cdot n} \cdot f^2 = (J_0 + 3.5 \times 10^{-4}) \times \frac{\pi \times 7.2}{180 \times 0.5} \times 50^2$$

$$= 628\, J_0 + 0.22 \text{ [N·m]}$$

θs=7.2°, f=50 Hz, n=3.6°/θs=0.5
J_0: Rotor Inertia

(6) Calculate the required torque T_M [N·m] (Safety factor Sf=2)

Required operating torque $T_M = (T_L + T_a)\, S_f$

$$= (9.82 \times 10^{-3} + 628\, J_0 + 0.22) \times 2$$

$$= 1256\, J_0 + 0.46 \text{ [N·m]}$$

(7) Select a Motor

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

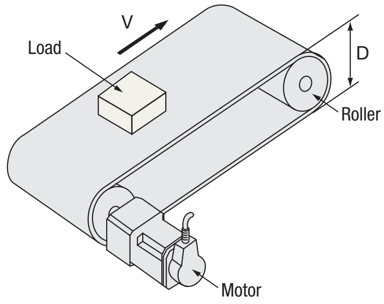
Product Name	Rotor Inertia [kg·m²]	Permissible Load Inertia [kg·m²]	Output Torque [N·m]
SMK5100C-A	1.4×10^{-4}	7×10^{-4}	1.12

When the required torque is calculated by substituting the rotor inertia, T_M=0.636 [N·m] is obtained, which is below the output torque. Next, check the permissible load inertia. Since the moment of load inertia calculated in (4) is also below the permissible load inertia, **SMK5100C-A** can be used.

Using Brushless Motors

(1) Specifications and Operating Conditions of the Drive Mechanism

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



Belt speed ········· V_L=0.05~1 [m/s]
Motor power supply ········· Single-Phase 220 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 ········· μ=0.3
Belt and roller efficiency ········· η=0.9

(2) Calculate the Speed Range Used

$$N_G = \frac{60 \cdot V_L}{\pi \cdot D}$$

N_G: gear shaft speed

Calculate the speed of the rollers from the belt speed.

0.05 [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)

For the gear ratio of gearhead, select "15" (Speed Range: 6.7~200) from the "Permissible Torque of Combination Type" table on page B-34 so that the minimum and maximum speeds fall within the speed range.

(3) Calculate the load inertia J_G [kg·m²]

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

$$= 7 \times \left(\frac{\pi \times 0.1}{2\pi}\right)^2$$

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

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

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

Calculate the moment of load inertia J_G.
Take into account that there are two rollers (J_{m2}).

$$J_G = J_{m1} + 2J_{m2} = 175 \times 10^{-4} + 12.5 \times 10^{-4} \times 2 = 200 \times 10^{-4} \text{ [kg·m}^2\text{]}$$

From the specifications of page B-35, the permissible load inertia for **BLE512C15S□** is 225×10^{-4} [kg·m²].

(4) Calculate the load torque T_L [N·m]

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

$$= 0 + 7 \times 9.807\,(\sin 0^\circ + 0.3 \times \cos 0^\circ) = 20.6 \text{ [N]}$$

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]

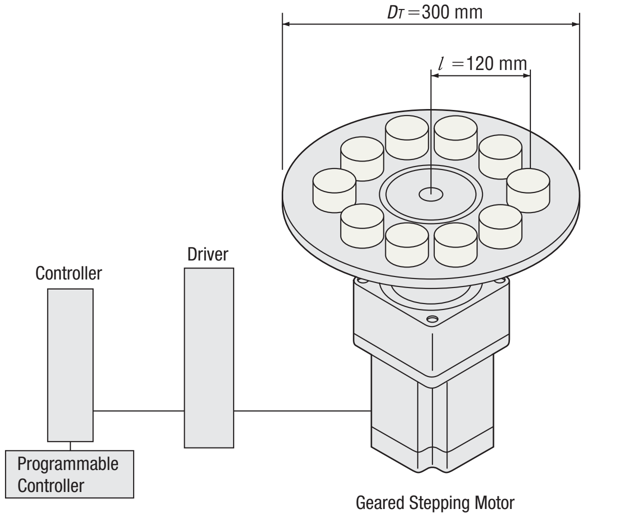
Select **BLE512C15S□** from the "Permissible Torque of Combination Type" on page B-34.

Permissible torque is 5.4 [N·m], so safety factor is $T_M / T_L = 5.4 / 1.15 \fallingdotseq 4.6$.
Generally a motor can operate at a safety factor of 1.5 to 2 or more.

●Index Mechanism

(1) Specifications and Operating Conditions of the Drive Mechanism

Geared stepping motors are ideal for systems with high inertia, such as index tables.



Diameter of table ······ $D_T=300$ [mm]
Thickness of table ······ $L_T=5$ [mm]
Material of table ······ Aluminum (Density $\rho=2.8\times10^3$ [kg/m³])
Load diameter ······ $D_W=40$ [mm]
Load thickness ······ $L_W=30$ [mm]
Number of loads ······ 10 (One at every 36˚)
Materials of load ······ Aluminum (Density $\rho=2.8\times10^3$ [kg/m³])
Distance from center of table to center of load ······ $l=120$ [mm]
Positioning angle ······ $\theta=36^\circ$
Positioning time ······ $t_0=0.25$ seconds

RK 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 ······ $\theta_S=0.072^\circ$

(2) Determine the Operating Pattern (Refer to formula on page H-5)

① Formula for the number of operating pulses A [Pulse]

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

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

$t_1=0.1$ [s].

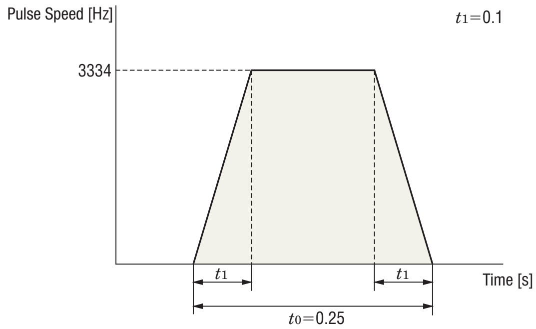
③ Calculate the operating pulse speed f_2 [Hz].

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

④ Calculate the operating speed N_M [r/min]

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

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



(3) Calculate the required torque T_M [N·m] (Refer to page H-5)

① Calculate the load torque T_L [N·m]
Frictional load is small and therefore omitted. The load torque is assumed as 0.

$T_L=0$ [N·m]

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

Inertia of table J_T

$$J_T=\frac{\pi}{32}\rho\cdot L_T\cdot D_T^4=\frac{\pi}{32}\times 2.8\times10^3\times(5\times10^{-3})\times(300\times10^{-3})^4=1.11\times10^{-2}\text{ [kg·m}^2\text{]}$$

Inertia of load J_{W1} (Around center of load rotation)

$$J_{W1}=\frac{\pi}{32}\rho\cdot L_W\cdot D_W^4=\frac{\pi}{32}\times 2.8\times10^3\times(30\times10^{-3})\times(40\times10^{-3})^4=0.211\times10^{-4}\text{ [kg·m}^2\text{]}$$

Load mass m_W

$$m_W=\frac{\pi}{4}\rho\cdot L_W\cdot D_W^2=\frac{\pi}{4}\times 2.8\times10^3\times(30\times10^{-3})\times(40\times10^{-3})^2=0.106\text{ [kg]}$$

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, $n=10$ [pieces],

Inertia of load J_W (Around center of table rotation)

$$J_W=n(J_{W1}+m_W\cdot l^2)=10\times\{(0.211\times10^{-4})+0.106\times(120\times10^{-3})^2\}=1.55\times10^{-2}\text{ [kg·m}^2\text{]}$$

Load inertia J_L

$$J_L=J_T+J_W=(1.11+1.55)\times10^{-2}=2.66\times10^{-2}\text{ [kg·m}^2\text{]}$$

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

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

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

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

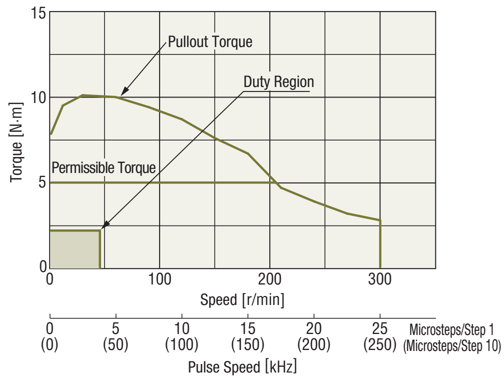
(4) Select a Motor

① Tentative motor selection

Product Name	Rotor Inertia [kg·m^2]	Required Torque [N·m]
RK566ACE-PS10	280×10^{-7}	2.45

② Determine the motor by speed - torque characteristics

RK566ACE-PS10



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 you have the correct selection.

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

The **RK566ACE-PS10** has a gear ratio of 10, therefore, the inertia ratio is calculated as follows.

$$\frac{J_L}{J_0 \cdot i^2} = \frac{2.66 \times 10^{-2}}{280 \times 10^{-7} \times 10^2}$$
$$\fallingdotseq 9.5$$

RK566ACE-PS10 motor is the equivalent of the **RK566ACE** motor.
Since the inertia ratio is 10 or less, if the inertia ratio is 9.5, you can judge that motor operation is possible.

(6) Check the Acceleration/Deceleration Rate (Refer to page H-5)

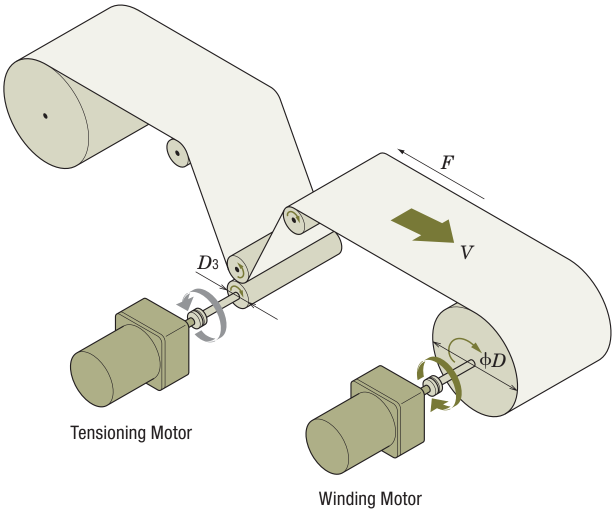
Note when calculating that the units for acceleration/deceleration rate T_R are [ms/kHz].

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

The **RK566ACE-PS10** motor is the equivalent of the **RK566ACE** and it has an acceleration/deceleration rate of 20 [ms/kHz] or more. Therefore, an acceleration/deceleration rate of 30 [ms/kHz] allows you to judge that motor operation is possible.

●Winding Mechanism

This is a selection example on using the torque motor for the winding equipment.



(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 Supply ········· Single-phase 220 VAC, 50 Hz
Running time ········· Continuous

(2) Selection of 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 varies 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 torque to the motor 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 Calculating the Required Speed
Calculate the speed N_1 required at the start of winding.

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

Calculate the speed N_2 required at the end of winding.

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

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

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

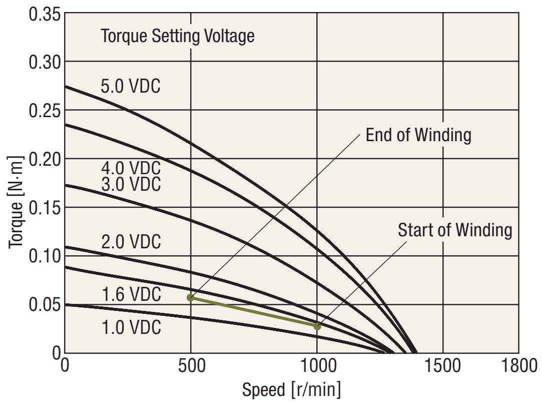
Calculate the torque T_2 required at the end of winding.

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

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 Selection of Motor
Checking the speed – torque characteristics
Select a motor from the **TM** Series torque motor and power controller packages that meets the required conditions specified above. If the required conditions are plotted on the speed – torque characteristics diagram for the **TM410C-AE** type, the conditions roughly correspond to the characteristics at a torque setting voltage of 1.6 VDC.

Speed – Torque Characteristics
TM410C-AE (220VAC 50 Hz)



Checking operation time
The **TM410C-AE** type has a five minute rating when the torque setting voltage is set to 5.0 VDC, and a continuous rating when it is set to 1.6 VDC. Under the conditions given here, the torque setting voltage is 1.6 VDC or less, meaning that this 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 or otherwise the material 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 Calculating the Required Speed N_3

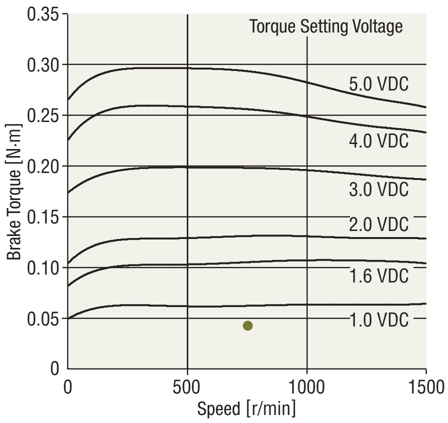
$$N_3 = \frac{V}{\pi \cdot D_3} = \frac{47}{\pi \times 0.02} = 748.4 \text{ [r/min]} \fallingdotseq 750 \text{ [r/min]}$$

② Calculating 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 Selection of Motor
Select a motor from the **TM** Series torque motor and power controller packages that meets the required conditions specified above. If the required conditions are plotted on the speed – brake torque characteristics diagram✻ for the **TM410C-AE** reverse-phase brake, it is clear that the conditions are less than the characteristics at a torque setting voltage of 1.0 VDC.

Speed – Brake Torque Characteristics with a Reverse-Phase Brake
TM410C-AE (220VAC 50 Hz)



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 or less.

From the above checks, the **TM410C-AE** type can be used both as a winding motor and tensioning motor.

✻For the speed – brake torque characteristics of each product, please contact the nearest Oriental Motor sales office.