## Technical Reference

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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

#### Ball Screw Drive

$T_L = \left( \frac{F_A + m \cdot g}{2} \right) \frac{\mu \cdot F_0}{2} \frac{1}{i} \quad [N\cdot m] \quad \text{---}(1)$

$F = F_0 + m \cdot g ( \sin \theta + \mu \cdot \cos \theta) \quad [N] \quad \text{---}(2)$

#### Pulley Drive

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

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

$T_L = \left( \frac{F}{2} \right) \frac{\pi \cdot D}{i^2} = \left( \frac{F \cdot D}{2} \right) \eta \quad [N\cdot m] \quad \text{---}(4)$

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

#### Actual Measurement Method

$T_L = \frac{F_A \cdot D}{2} \quad [N\cdot m] \quad \text{---}(6)$

---

**Symbols and Units**

- $F$: Force of moving direction [N]
- $F_0$: Preload [N] ($\approx 1/3F$)
- $\mu_0$: Internal friction coefficient of preload nut (0.1~0.3)
- $\eta$: Efficiency (0.85~0.95)
- $i$: 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] ($F_B = \text{Spring balance value [kg]} \times g$ [m/s²])
- $m$: Total mass of table and load [kg]
- $\mu$: Friction coefficient of sliding surface
- $\theta$: Inclination angle [°]
- $D$: Final pulley diameter [m]
- $g$: Gravitational acceleration [m/s²] (9.807)
Selection Calculations/Motors

Formula for the Inertia $J$ [kg·m$^2$]

- **Calculate the Moment of Inertia**

  - **Inertia of a Cylinder**
    \[
    J_x = \frac{1}{2} m \cdot D_r^2 = \frac{\pi}{32} \rho \cdot L \cdot D_r^4 \quad \text{[kg·m$^2$]} \quad \text{②}
    \]
    \[
    J_y = \frac{1}{4} m \left( \frac{D_r^4}{4} + \frac{L^2}{3} \right) \quad \text{[kg·m$^2$]} \quad \text{③}
    \]

  - **Inertia of a Hollow Cylinder**
    \[
    J_x = \frac{1}{12} m (D_1^4 + D_2^4) = \frac{\pi}{32} \rho \cdot L \left( D_1^4 - D_2^4 \right) \quad \text{[kg·m$^2$]} \quad \text{⑤}
    \]
    \[
    J_y = \frac{1}{4} m \left( \frac{D_1^4 + D_2^4}{4} + \frac{L^2}{3} \right) \quad \text{[kg·m$^2$]} \quad \text{⑥}
    \]

  - **Inertia on Off-Center Axis**
    \[
    J_x = J_{xx} + m \cdot l^2 = \frac{1}{12} m (A^4 + B^4 + 12 \cdot I^4) \quad \text{[kg·m$^2$]} \quad \text{⑤}
    \]
    \text{m: Distance between $x$ and $x_0$ axes [m]}

  - **Inertia of a Rectangular Pillar**
    \[
    J_x = \frac{1}{12} m (A^4 + B^4) = \frac{\rho}{12} A \cdot B \cdot C (A^4 + B^4) \quad \text{[kg·m$^2$]} \quad \text{⑤}
    \]
    \[
    J_y = \frac{1}{12} m (B^4 + C^4) = \frac{\rho}{12} A \cdot B \cdot C (B^4 + C^4) \quad \text{[kg·m$^2$]} \quad \text{⑤}
    \]

  - **Inertia of an Object in Linear Motion**
    \[
    J = m \left( \frac{A}{2 \pi} \right)^2 \quad \text{[kg·m$^2$]} \quad \text{⑤}
    \]
    \text{A: Unit movement [m/rev]}

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

\[
J_m = \frac{1}{i} J_L
\]

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/m$^3$]
- Iron $\rho = 7.9 \times 10^3$ [kg/m$^3$]
- Aluminum $\rho = 2.8 \times 10^3$ [kg/m$^3$]
- Brass $\rho = 8.5 \times 10^3$ [kg/m$^3$]
- Nylon $\rho = 1.1 \times 10^3$ [kg/m$^3$]

$J_x$ : Inertia on $x$-axis [kg·m$^2$]

$J_y$ : Inertia on $y$-axis [kg·m$^2$]

$J_{x0}$: Inertia on $x_0$-axis (axis passing through center of gravity) [kg·m$^2$]

$m$ : Mass [kg]

$D_1$ : Outer diameter [m]

$D_2$ : Inner diameter [m]

$\rho$ : Density [kg/m$^3$]

$L$ : 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.

- **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.

  \[
  A = \frac{l}{\text{rev}} \times \frac{360^\circ}{\theta} 
  \]

  \( l \) : Traveling amount between the point A to point B [m]
  \( \text{rev} \) : 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.

  \( f_2 = \frac{A - f_1 \times t_1}{t_1 - t_0} \)

- **Formula for the Acceleration/Deceleration Rate \( T_a \) [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.

  \[
  T_a = \frac{t_1}{f_2 - f_1} \]

- **Formula for the Required Torque \( T_a \) [N·m]**
  The required torque is calculated by multiplying the sum of load torque and acceleration torque by the safety factor.

  \[
  T_a = (T_0 + T_1) S_i
  \]

  \( T_0 \): Load torque [N·m]
  \( T_1 \): Acceleration torque [N·m]
  \( S_i \): Safety factor

- **Calculate the Load Torque**
  Refer to formulas on page H-3.

- **Formula for the Acceleration Torque \( T_a \) [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.

  \[
  T_a = \left( J_1 \cdot f_2^2 + J_2 \right) \cdot \frac{\pi \cdot 60}{180} \cdot \frac{f_2 - f_1}{t_1}
  \]

  \( J_1 \): Rotor inertia [kg·m²]
  \( J_2 \): Total load inertia [kg·m²]
  \( f_1 \): Operating speed [r/min]
  \( f_2 \): Acceleration (deceleration) time [s]
  \( t_1 \): Gear Ratio

  \[
  T_a = \left( J_1 \cdot f_2^2 + J_2 \right) \cdot \frac{\pi \cdot 60}{180} \cdot f_2^2 \cdot n \cdot 3.6^i \cdot (60 - i)
  \]

- **Formula for the Effective Load Torque \( T_{\text{me}} \) [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.

  \[
  T_{\text{me}} = \left( T_0 + T_1 T_2 + T_3 + T_4 \right) \cdot \frac{1}{t_1}
  \]
Selection Calculations/Motors

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 $N_{s1}$ ($f_s$) and the required torque $T_{s1}$) falls within the pullout torque curve.

     **Safety Factor: $S_f$ (Reference Value)**

     | Product              | Safety Factor (Reference Value) |
     |----------------------|---------------------------------|
     | 2-/5-Phase Stepping Motors | 2                              |
     |                      | **$\alpha_{STEP}$** = 1.5—2     |

     ![Torque Diagram]

     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 insulation 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 $N_{s1}$ and the required torque $T_{s1}$) 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/decleration 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/decleration. 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 $\theta_s$ (Reference Value) |
     |----------------------|------------|---------------------------------------------------------------|
     | 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                                                   |

     \[
     \theta_s = \frac{T_{s1}}{T_{s1} \cdot \theta_s} \cdot \theta_s
     \]

     **Coefficient**

     | Product              | $\alpha_{STEP}$ |
     |----------------------|-----------------|
     | 5-Phase Stepping Motors | 0.72            |
     | 2-Phase Stepping Motors | 1.8             |

     4. **Check the inertia ratio**
     Calculate the inertia ratio using the following equation:

     \[
     \text{Inertia Ratio} = \frac{J_s}{J_{s1}}
     \]

     For Geared Motors

     \[
     \text{Inertia Ratio} = \frac{J_s}{J_{s1} \cdot i}
     \]

     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    |
     |                      | 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.

<table>
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<th>Product</th>
<th>Permissible Load Inertia</th>
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</table>
   | NX Series | 50 times 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.

   \[
   \text{Rated Torque} \geq 1.5 \rightarrow 2
   \]

3. Maximum Instantaneous Torque
   Check that the required torque is less than the maximum instantaneous torque of the servo motor. (Keep the safety factor of required torque $S_f$ 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
<table>
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<tr>
<th>Product</th>
<th>Operating Time</th>
<th>Maximum Instantaneous Torque</th>
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<tr>
<td>NX Series</td>
<td>Approx. within 0.5 second</td>
<td>At 3 times the rated torque (at rated speed)</td>
</tr>
</tbody>
</table>

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 a servo motor, is 1.5 to 2 or more.

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

5. Setting Time
   There is a time lag between a position command by pulse signal and a servo motor’s real operation. This is called the setting 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 setting time for NX Series is 60 to 70 ms. However, the setting 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: $V = 12 \pm 2$ [mm/s]
   - External force: $F_A = 0$ [N]
   - Ball screw tilt angle: $\theta = 90^\circ$
   - Overall length of ball screw: $L_A = 800$ [mm]
   - Ball screw shaft diameter: $D_A = 20$ [mm]
   - Ball screw lead: $P_S = 5$ [mm]
   - The traveling distance moved for one rotation of ball screw: $A = 5$ [mm]
   - Ball screw efficiency: $\eta = 0.9$
   - Material of ball screw: Iron (Density $\rho = 7.9 \times 10^3$ [kg/m$^3$])
   - Internal friction coefficient of preload nut: $\mu_B = 0.3$
   - Friction coefficient of sliding surface: $\mu = 0.05$
   - 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.

   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.

   Gearhead Gear Ratio $i = \frac{1200 - 1300}{V} = \frac{1200 - 1300}{144 - 24} = 7.1 - 10.8$

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

2. Determine the Gear Ratio of Gearhead
   Gearhead Output Shaft Speed $N_C = \frac{V \cdot 60}{A} = \frac{(12 \pm 2) \times 60}{5} = 144 \pm 24$ [r/min]

3. Calculate the required torque $T_L$ [N-m]
   Force of moving direction $F = F_A + m \cdot g \cdot (\sin \theta + \mu \cdot \cos \theta) = 0 + 45 \times 9.807 (\sin 90^\circ + 0.05 \cos 90^\circ) = 441$ [N]

   Ball screw preload $F_L = \frac{F}{2 \cdot \eta} = 147$ [N]

   Load Torque $T_L = \frac{F \cdot P_S}{2 \cdot \eta} + \frac{\mu \cdot F \cdot P_S}{2 \eta} = 441 \times 5 \times 10^{-3} + \frac{0.3 \times 147 \times 5 \times 10^{-3}}{2 \eta} = 0.426$ [N-m]

   Consider the safety factor $S_f = 2$.

   $T_L = T_L \cdot S_f = 0.426 \times 2 = 0.856$ [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: 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 $T_M$.

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

(Gearhead 4GN9KF Transmission Efficiency $\eta = 0.81$)

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 $T_M$ is

$$T_M = \frac{T_M}{i} = \frac{0.86}{9} = 0.0956 \text{ [mN-m]} = 96.5 \text{ [mN-m]}$$

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

$$J_s = \frac{\pi}{32} \cdot \rho \cdot L_s \cdot D_s^4$$

$$= \frac{\pi}{32} \times 7.9 \times 10^8 \times 800 \times 10^{-6} \times (20 \times 10^{-3})^4$$

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

Inertia of table and load $J_\text{total} = J_s + J = \frac{A^2}{2r^2} + \frac{5}{2} \times 10^{-3} \text{ [kg·m²]}$

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

Calculate the load inertia for the gearhead output shaft $J$.

$$J = J_s + J_\text{total} = 0.993 + 0.286$$

$$= 1.28 \times 10^{-4} \text{ [kg·m²]}$$

For the permissible load inertia $J_\text{max}$ for gearhead 4GN9KF with a gear ratio of 9, use the formula below (refer to page A-15).

$$J_\text{max} = 0.31 \times 10^{-4} \times 9^4$$

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

Therefore, $J < J_\text{max}$ 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).

$$V = \frac{N_\text{motor} \cdot P_m}{60 \times \pi} = \frac{1470 \times 5}{60 \times 3.14} = 13.6 \text{ [mm/s]}$$

$N_\text{motor}$: Motor speed

This confirms that the motor meets the specifications.

So, select motor 4RK25GN-CW2ML1 and gearhead 4GN9KF.
(4) Calculate the required torque $T_r$ [N-m] (Refer to page H-5)

1. Calculate the load torque $T_L$ [N-m]

 Force of moving direction $F = F_\text{m} + m \cdot g \cdot (\sin \theta + \mu \cdot \cos \theta)$

$= 0 + 0 \cdot 9.807 \cdot (\sin 0^\circ + 0.05 \cdot \cos 0^\circ)$

$= 19.6$ [N]

Preload $F_\text{P} = \frac{F}{3} = 6.53$ [N]

Load Torque $T_L = F \cdot \nu + \frac{\mu \cdot F \cdot \nu}{2\pi}$

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

$= 0.0567$ [N-m]

2. Calculate the acceleration torque $T_a$ [N-m]

- Calculate the load inertia $J_L$ [kg-m$^2$]

(Refer to formula on page H-4)

\[
J_L = \frac{\pi}{32} \cdot \rho \cdot L \cdot D^2
\]

\[
= \frac{\pi}{32} \cdot 7.9 \times 10^{-3} \times 600 \times 10^{-3} \times (15 \times 10^{-3})^2
\]

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

Inertia of table and load $J_T = m \left(\frac{F_\text{P}}{2\pi}\right)^2$

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

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

Load inertia $J_R = J_L + J_T$

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

3. Calculate the acceleration torque $T_a$ [N-m]

\[
T_a = \frac{\left(J_R + J_T\right) \cdot N_r}{n}
\]

$= \left(0.236 \times 10^{-4} + 2.52 \times 10^{-4}\right) \times 1200 \times \frac{0.2}{9.55}$

$= 62.8 \times 0.158$ [N-m]

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

\[
T_a = \frac{\left(J_R + J_T\right) \cdot \frac{\nu \cdot 180}{\nu}}{n} = \frac{\left(J_R + J_T\right) \cdot \frac{\pi \cdot 0.72}{180}}{n}
\]

$= \left(0.236 \times 10^{-4} + 2.52 \times 10^{-4}\right) \times \frac{9.55 \times 180}{0.2}$

$= 62.8 \times 0.158$ [N-m]

(5) Select a Motor

1. Tentative motor selection

<table>
<thead>
<tr>
<th>Product Name</th>
<th>Motor Inertia $J_T$ [kg-m$^2$]</th>
<th>Required Torque $T_r$ [N-m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>AR66AC-◇</td>
<td>380×10$^{-4}$</td>
<td>0.48</td>
</tr>
</tbody>
</table>

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

**Selection Calculations/Motors**

- **Controller**
- **Driver**
- **Ball Screw**

**Maximum speed of the table**: \( V_L = 0.2 \) [m/s]

**Resolution**: \( \Delta l = 0.02 \) [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**: \( \mu = 0.04 \)

**Ball screw efficiency**: \( \eta = 0.9 \)

**Internal friction coefficient of preload nut**: \( \mu_0 = 0.3 \)

**Ball screw shaft diameter**: \( D_B = 25 \) [mm]

**Overall length of ball screw**: \( L_B = 1000 \) [mm]

**Material of ball screw**: 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 \( \theta \)

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

\[
\theta = \frac{360 \times \Delta l}{F_s} = \frac{360 \times 0.02}{10} = 0.72^\circ
\]

The resolution of NX Series \( \Delta \theta = 0.36^\circ / \text{pulse} \) satisfies this.

(3) Determine an Operating Pattern

Calculate the motor speed \( N_{V_s} \) from the formula below.

\[
N_{V_s} = \frac{60 \times V_L}{F_s} = \frac{60 \times 0.2}{10 \times 10^{-3}} = 1200 \text{ [r/min]}
\]

Determine the speed pattern using the \( N_{V_s} \), the operating cycle and the acceleration/deceleration time.

\[
\begin{align*}
\text{Speed [r/min]} & \quad 1200 \\
\text{Time [s]} & \quad t_1 = t_3 = 0.1 \\
& \quad t_2 = 0.4 \\
& \quad (1.9) \\
& \quad 2.1 \\
& \quad (2.5)
\end{align*}
\]

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

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

\[
= 29.4 + 100 \times 9.807 \sin 0^\circ + 0.04 \cos 0^\circ
\]

\[
= 68.6 \text{ [N]}
\]

**Load Torque of the Motor Shaft Conversion**

\[
T_L = \frac{F \cdot P_s}{2\pi \cdot \eta} + \frac{\mu_0 \cdot P_r \cdot P_s}{2\pi}
\]

\[
= \frac{68.6 \times 10 \times 10^{-3}}{2\pi \cdot 0.9} + \frac{0.3 \times 22.9 \times 10 \times 10^{-3}}{2\pi}
\]

\[
= 0.13 \text{ [N·m]}
\]

Here, \( P_s = \frac{1}{3} \) \( F \) represents the ball screw preload.

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

**Inertia of Ball Screw**

\[
J_B = \frac{\pi}{32} \cdot \rho \cdot D_B \cdot L_B
\]

\[
= \frac{\pi}{32} \times 7.9 \times 10^3 \times 1000 \times 10^{-1} \times (25 \times 10^{-3})^3
\]

\[
= 3.03 \times 10^{-4} \text{ [kg·m²]}
\]

**Inertia of table and load**

\[
J_L = m (\frac{P_s}{2\pi})^2
\]

\[
= 100 \times \left( \frac{10 \times 10^{-3}}{2\pi} \right)^2
\]

\[
= 2.53 \times 10^{-4} \text{ [kg·m²]}
\]

**Load inertia**

\[
J_L = J_B + J_L
\]

\[
= 3.03 \times 10^{-4} + 2.53 \times 10^{-4} = 5.56 \times 10^{-4} \text{ [kg·m²]}
\]

(6) Tentative servo motor selection

**Safety factor** \( S_f = 1.5 \).

**Load torque**

\[
T_L = S_f \cdot T_i = 1.5 \times 0.13 = 0.195 \text{ [N·m]}
\]

**Load inertia**

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

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·m²] or more.

**NX620AC**

- **Rated speed** \( N = 3000 \) [r/min]
- **Rated torque** \( T_M = 0.637 \) [N·m]
- **Rotor inertia** \( J_R = 0.162 \times 10^{-4} \text{ [kg·m²]} \)
- **Permissible load inertia** \( J' = 8.1 \times 10^{-4} \text{ [kg·m²]} \)
- **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.

\[
T_a (= T_d) = \frac{(J_B + J_L) N_{V_s}}{9.55 \cdot t_1}
\]

\[
= \frac{(5.56 \times 10^{-4} + 0.162 \times 10^{-4}) \times 1200}{9.55 \times 0.1}
\]

\[
= 0.72 \text{ [N·m]}
\]

(8) Calculate the required torque \( T' \) [N·m]

\[
T' = T_i + T_L = 0.72 + 0.13 = 0.85 \text{ [N·m]}
\]

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 the operating cycle, acceleration/deceleration torque, load torque and acceleration time.

\[
\begin{align*}
\text{Speed [r/min]} & \quadicone19 \quad t_1 = t_3 = 0.1 \\
& \quad t_2 = 0.4 \\
& \quad (1.9) \\
& \quad 2.1 \\
& \quad (2.5)
\end{align*}
\]

**Torque [N·m]**

\[
\begin{align*}
& \text{Time [s]} \\
& \quad t_1 = 0.19 \\
& \quad t_2 = 0.4 \\
& \quad (1.9) \\
& \quad 2.1 \\
& \quad (2.5)
\end{align*}
\]
(10) Calculate the effective load torque \( T_{\text{fs}} \) [N·m]

Calculate the effective load torque \( T_{\text{fs}} \), using the torque pattern and formula below.

\[
T_{\text{fs}} = \sqrt{\frac{(T_1 - T_2^2) - 0.013^2}{0.013^2}}
\]

\[
= \sqrt{\frac{0.24}{0.013^2}}
\]

\[
= 0.24 \text{ [N·m]}
\]

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, \( t_2 = 2.1 - 0.1 \times 2 = 1.9 \) [s]

The ratio (effective load safety factor) of \( T_{\text{fs}} \) and the rating torque of servo motor \( T_m \) is expressed by the formula below:

\[
\frac{T_m}{T_{\text{fs}}} = \frac{0.637}{0.24} = 2.65
\]

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.

![Belt Conveyor Diagram](image)

- 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], \( \pm 10\% \)
- Motor power supply: Single-phase 220 VAC 50 Hz
- Operating time: Operation for 8 hours a day

(2) Determine the Gear Ratio of Gearhead.

Gearhead Output Shaft Speed \( N_o = \frac{V \cdot 60}{\pi \cdot D} = \frac{(180 \pm 18) \times 60}{\pi \times 90} = 38.2 \pm 3.8 \) [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.

\[
\text{Gearhead Gear Ratio} \quad i = \frac{1200 - 1300}{38.2 - 3.8} = 28.6 - 37.8
\]

Select a gear ratio of \( i = 36 \) from within this range.

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

- Friction coefficient of sliding surface \( F = F_A + m \cdot g \cdot (\sin \theta + \mu \cdot \cos \theta) \)
  \[= 0 + 25 \times 9.807 \cdot (\sin 0° + 0.3 \cos 0°)\]
  \[= 73.6 \text{ [N]}\]

- Load Torque \( T_L = \frac{F \cdot D}{2 \cdot \eta} = \frac{73.6 \times 90 \times 10^{-4}}{2 \times 0.9} = 3.68 \text{ [N·m]}\]

Consider the safety factor \( S_f = 2 \).

\[ T_L = T_r \cdot S_f = 3.68 \times 2 = 7.36 \text{ [N·m]}\]

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 \( T_m \).

\[
T_m = \frac{T_r}{i \cdot \eta} = \frac{7.36}{36 \times 0.73} = 0.280 \text{ [N·m]} = 280 \text{ [mN·m]}
\]

(Gearhead 5GN36KF Transmission Efficiency \( \eta_o = 0.73 \))
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 SMKS100C-A when the belt-drive table shown in Fig. 1 is driven in the operation pattern shown in Fig. 2.
- 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.

\[ V = \frac{\pi \cdot D \cdot N}{60} = \frac{\pi \times 10 \times 60}{60} = 94 \text{ [mm/s]} \]

(3) Calculate the load torque \( T_l \) [N-m]

- Frictional torque due to the friction force
  \[ F = FA + mN \sin \theta + \mu \cdot mN \cos \theta \]
  \[ = 0 + 1.5 \times 9.807 \cdot \sin 0 + 0.04 \cdot \cos 0 \]
  \[ = 0.589 \text{ [N]} \]

- Load Torque
  \[ T_l = \frac{F \cdot D}{2 \cdot \eta} = \frac{0.589 \times 30 \times 10^{-3}}{2 \times 0.9} = 9.82 \times 10^{-4} \text{ [N-m]} \]

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

- Inertia of belt and load
  \[ J_{b+l} = \frac{m_l \cdot D^2}{2} \]
  \[ = 1.5 \times (2 \times 30 \times 10^{-3})^2 \]
  \[ = 3.38 \times 10^{-4} \text{ [kg·m²]} \]

- Inertia of roller
  \[ J_r = \frac{m_r \cdot D^2}{2} \]
  \[ = \frac{1}{8} \times 0.1 \times (30 \times 10^{-3})^2 \]
  \[ = 0.113 \times 10^{-4} \text{ [kg·m²]} \]

- Calculate the moment of load inertia \( J_L \).
  \[ J_L = J_{b+l} + 2J_r = 3.38 \times 10^{-4} + 0.113 \times 10^{-4} \times 2 = 3.5 \times 10^{-4} \text{ [kg·m²]} \]

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

Calculate the start acceleration torque.

\[ T_a = (J_r + J_L) \cdot \frac{\pi \cdot \theta_s}{180} \cdot \eta = (J_r + J_L \cdot 3.5 \times 10^{-4}) \times \frac{\pi \times 7.2}{180 \times 0.3} \times 50 \]
\[ = 628 J_r + 0.22 \text{ [N-m]} \]

\[ \theta_s=7.2, f=50 \text{ Hz}, \eta=3.67/\theta_s=0.5 \]

\[ J_r \text{ Rotor Inertia} \]
(6) Calculate the required torque \( T_M \) [N·m] (Safety factor \( S_f = 2 \))

Required operating torque \( T_M = (T_r + T_L) S_f \)
\[
= (9.82 \times 10^{-3} + 628 J_0 + 0.22) \times 2
\]
\[
= 1256 J_0 + 0.46 \text{ [N·m]}
\]

(7) Select a Motor
Select a motor that satisfies both the required operating torque and the permissible load inertia.

<table>
<thead>
<tr>
<th>Product Name</th>
<th>Rotor Inertia ([\text{kg·m}^2])</th>
<th>Permissible Load Inertia ([\text{kg·m}^2])</th>
<th>Output Torque ([\text{N·m}])</th>
</tr>
</thead>
<tbody>
<tr>
<td>SMK5100C-A</td>
<td>1.4 \times 10^{-4}</td>
<td>7 \times 10^{-4}</td>
<td>1.12</td>
</tr>
</tbody>
</table>

When the required torque is calculated by substituting the rotor inertia, \( T_M = 0.636 \text{ [N·m]} \) 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:

![Diagram](image)

Belt speed \( \nu_c = 0.05 \sim 1 \text{ [m/s]} \)
Motor power supply \( \text{Single-Phase} 220 \text{ VAC} \)
Belt conveyor drive
Roller diameter \( D = 0.1 \text{ [m]} \)
Roller mass \( m_2 = 1 \text{ [kg]} \)
Total mass of belt and load \( m_1 = 7 \text{ [kg]} \)
External force \( F_A = 0 \text{ [N]} \)
Friction coefficient of sliding surface \( \mu = 0.3 \)
Belt and roller efficiency \( \eta = 0.9 \)

(2) Calculate the Speed Range Used

\[
N_0 = \frac{60 \cdot \nu_c}{\pi \cdot D}
\]

Calculate the speed of the rollers from the belt speed.

\[
\text{Minimum speed} = \frac{60 \times 0.05}{\pi \times 0.1} = 9.55 \text{ [t/min]}
\]

\[
\text{Maximum speed} = \frac{60 \times 1}{\pi \times 0.1} = 191 \text{ [t/min]}
\]

For the gear ratio of gearhead, select "15" (Speed Range: 6.7 \sim 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 \( J_L \) [kg·m²]

Inertia of belt and load \( J_{ml} = \frac{m_1 \cdot D^2}{2 \pi} \)
\[
= 7 \times \frac{\pi \times 0.1^2}{2 \pi}
= 175 \times 10^{-4} \text{ [kg·m²]}
\]

Inertia of roller \( J_{ml} = \frac{1}{8} \cdot m_1 \cdot D^2 \)
\[
= \frac{1}{8} \times 1 \times 0.1^2 = 12.5 \times 10^{-4} \text{ [kg·m²]}
\]

Calculate the moment of load inertia \( J_L \).
Take into account that there are two rollers \( (J_{ml})_2 \).
\[
J_L = J_{ml} + 2J_{ml} = 175 \times 10^{-4} + 12.5 \times 10^{-4} \times 2 = 200 \times 10^{-4} \text{ [kg·m²]}
\]

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

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

Friction coefficient of sliding surface \( F_s = F_A + m \cdot g \cdot (\sin \theta + \mu \cdot \cos \theta) \)
\[
= 0 + 7 \times 9.807 \times (0.3 \times \cos 0^\circ) = 20.6 \text{ [N]}
\]

Load Torque \( T_L = \frac{F_s \cdot D}{2 \cdot \eta} \)
\[
= \frac{20.6 \times 0.1}{2 \times 0.9} = 1.15 \text{ [N·m]}
\]

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

Permissible torque is 5.4 [N·m], so safety factor is \( T_M / T_L = 5.4 / 1.15 = 4.6 \).
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 \(D_r = 300 \text{ [mm]}\)
Thickness of table \(D_w = 40 \text{ [mm]}\)
Material of table \(\text{Aluminum (Density } \rho = 2.8 \times 10^3 \text{ [kg/m}^3\text{]}\)\)
Load diameter \(L_r = 5 \text{ [mm]}\)
Load thickness \(L_w = 30 \text{ [mm]}\)
Number of loads \(n = 10\) (One at every 36˚)
Materials of load \(\text{Aluminum (Density } \rho = 2.8 \times 10^3 \text{ [kg/m}^3\text{]}\)\)
Distance from center of table to center of load \(l = 120 \text{ [mm]}\)
Positioning angle \(\theta = 36^\circ\)
Positioning time \(t_0 = 0.25 \text{ seconds}\)

2. 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 inerital drive.

Gear Ratio = i = 10
Resolution/Pulse = \(\theta_B = 0.072^\circ\)

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

1. Formula for the number of operating pulses \(A\) [Pulse]

\[
A = \frac{\theta_B}{\theta_A} = \frac{36^\circ}{0.072^\circ} = 500 \text{ [Pulse]}
\]

3. 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 speed \(f_2\) [Hz].

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

2. Calculate the operating speed \(N_{\text{ref}}\) [r/min]

\[
N_{\text{ref}} = \frac{\theta_B}{360^\circ} f_2 \times 60
\]

\[
= \frac{0.072^\circ}{360^\circ} \times 3334 \times 60
\]

\[
\approx 40 \text{ [r/min]}
\]

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]

(Refer to formula on page H-4)

Inertia of table \(J_T = \frac{\pi^2}{32} \rho \cdot L_r \cdot Dr^4\)

\[
= \frac{\pi^2}{32} \times 2.8 \times 10^3 \times (5 \times 10^{-7}) \times (300 \times 10^{-3})^4
\]

\[
= 1.11 \times 10^{-2} \text{ [kg-m}^2\text{]}
\]

Inertia of load \(J_{L1}\) (Around center of load rotation)

\[
= \frac{\pi^2}{32} \times 2.8 \times 10^3 \times (30 \times 10^{-7}) \times (40 \times 10^{-3})^4
\]

\[
= 0.211 \times 10^{-4} \text{ [kg-m}^2\text{]}
\]

Load mass \(m_L = \frac{G}{c} \cdot L_r \cdot Dv^2\)

\[
= \frac{G}{c} \times 2.8 \times 10^3 \times (30 \times 10^{-7}) \times (40 \times 10^{-3})^2
\]

\[
= 0.106 \text{ [kg]}
\]

Inertia of load \(J_m\) [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 \(m_L\) [kg], and inertia of load around the center of load \(J_{L1}\) [kg-m²].

Since, the number of loads, \(n = 10\) (pieces),

Inertia of load \(J_m\) (Around center of table rotation)

\[
= n \left( J_{L1} + m_L \cdot c^2 \right)
\]

\[
= 10 \times \left( 0.211 \times 10^{-4} + 0.106 \times (120 \times 10^{-3})^2 \right)
\]

\[
= 1.55 \times 10^{-2} \text{ [kg-m}^2\text{]}
\]

Load inertia \(J_L = J_{L1} + J_m\)

\[
= (1.11 + 1.55) \times 10^{-2}
\]

\[
= 2.66 \times 10^{-2} \text{ [kg-m}^2\text{]}
\]

The maximum driving torque is \(T_m\) [N-m] and the maximum driving speed is \(N_{\text{ref}}\) [r/min].
②-2 Calculate the acceleration torque \( T_a \) [N·m]

Calculate the acceleration torque of the output gear shaft.

\[
T_a = \frac{(J_s \cdot \omega_2^2 + J_i)}{9.55} \cdot \frac{Nv}{n} = \frac{(J_s \times 10^2 + 2.66 \times 10^{-2})}{10.1} \cdot 40 = 4.19 \times 10^4 J_s + 1.11 \text{ [N·m]}
\]

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

\[
T_a = \left( J_s \cdot \frac{\pi \cdot \omega_2}{180} - J_i \right) \times \frac{3334 - 0}{0.1} = 4.19 \times 10^4 J_s + 1.11 \text{ [N·m]}
\]

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

Calculate safety factor \( S_f = 2 \).

\[
T_m = (T_a + T_v) S_f = (4.19 \times 10^4 J_s + 1.11) \times 2 = 8.38 \times 10^4 J_s + 2.22 \text{ [N·m]}
\]

(4) Select a Motor

① Tentative motor selection

<table>
<thead>
<tr>
<th>Product Name</th>
<th>Motor Inertia [kg·m²]</th>
<th>Required Torque [N·m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>RK566ACE-PS10</td>
<td>280 \times 10^{-7}</td>
<td>2.45</td>
</tr>
</tbody>
</table>

② Determine the motor by speed - torque characteristics

![Graph of Motor Torque and Speed Characteristics]

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 \textbf{RK566ACE-PS10} has a gear ratio of 10, therefore, the inertia ratio is calculated as follows.

\[
\frac{J_v}{J_0} = \frac{2.66 \times 10^{-4}}{280 \times 10^{-3} \times 10^3} = 9.5
\]

\textbf{RK566ACE-PS10} motor is the equivalent of the \textbf{RK566ACE} motor.
Since 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 \( T_a \) are [ms/kHz].

\[
T_a = \frac{f_2 - f_1}{0.1} \times \frac{3334 \text{ [Hz]} - 0 \text{ [Hz]}}{100 \text{ [ms]}} = \frac{3.334 \text{ [kHz]} - 0 \text{ [kHz]}}{30 \text{ [ms/kHz]}}
\]

The \textbf{RK566ACE-PS10} motor is the equivalent of the \textbf{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.
Selection Calculations/Motors

- **Winding Mechanism**

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

![Diagram of Winding Mechanism](image)

(1) **Specifications and Operating Conditions of the Drive Mechanism**

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Winding Roller Diameter (D)</td>
<td>(D_1 = 15 \text{ mm} = 0.015 \text{ m})</td>
</tr>
<tr>
<td></td>
<td>(D_2 = 30 \text{ mm} = 0.03 \text{ m})</td>
</tr>
<tr>
<td>Tensioning Roller Diameter (D)</td>
<td>(D_3 = 20 \text{ mm} = 0.02 \text{ m})</td>
</tr>
<tr>
<td>Winding Speed (V)</td>
<td>(V = 47 \text{ m/min}) (Constant)</td>
</tr>
<tr>
<td>Tension (F)</td>
<td>(F = 4 \text{ N}) (Constant)</td>
</tr>
<tr>
<td>Power Supply</td>
<td>Single-phase 220 VAC, 50 Hz</td>
</tr>
<tr>
<td>Running time</td>
<td>Continuous</td>
</tr>
</tbody>
</table>

(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.

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

Calculate the speed \(N_2\) required at the end of winding.

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

**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 \(N_1 = 1000 \text{ [r/min]}, \) Torque \(T_1 = 0.03 \text{ [N·m]}\)
- End of Winding: Speed \(N_2 = 500 \text{ [r/min]}, \) Torque \(T_2 = 0.06 \text{ [N·m]}\)

**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**

<table>
<thead>
<tr>
<th>Speed [r/min]</th>
<th>Torque Setting Voltage [V DC]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.00</td>
</tr>
<tr>
<td>500</td>
<td>1.0</td>
</tr>
<tr>
<td>1000</td>
<td>1.6</td>
</tr>
<tr>
<td>1500</td>
<td>2.0</td>
</tr>
<tr>
<td>2000</td>
<td>2.0</td>
</tr>
<tr>
<td>2500</td>
<td>3.0</td>
</tr>
<tr>
<td>3000</td>
<td>3.0</td>
</tr>
<tr>
<td>3500</td>
<td>4.0</td>
</tr>
<tr>
<td>4000</td>
<td>5.0</td>
</tr>
</tbody>
</table>

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 \( N_3 \)

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

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)**

<table>
<thead>
<tr>
<th>Torque Setting Voltage</th>
<th>Brake Torque [N·m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.0 VDC</td>
<td>0.35</td>
</tr>
<tr>
<td>4.0 VDC</td>
<td>0.30</td>
</tr>
<tr>
<td>3.0 VDC</td>
<td>0.25</td>
</tr>
<tr>
<td>2.0 VDC</td>
<td>0.20</td>
</tr>
<tr>
<td>1.6 VDC</td>
<td>0.15</td>
</tr>
<tr>
<td>1.0 VDC</td>
<td>0.10</td>
</tr>
<tr>
<td>0.8 VDC</td>
<td>0.05</td>
</tr>
</tbody>
</table>

**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.