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Selection Calculations
For Motors

Selecting a motor that satisfies the specifications required by the equipment is an important key to ensuring the desired reliability and economy of the equipment. This section describes the procedure to select the optimum motor for a particular application, as well as the selection calculations, selection points and examples.

**Selection Procedure**

An overview of selection procedure is explained below.

1. **Determine the drive mechanism**
   - First, determine the drive mechanism. Representative drive mechanisms include a simple body of rotation, a ball screw, a belt pulley, and a 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

2. **Check the required specifications** (Equipment specifications)
   - Check 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

3. **Calculate the load**
   - Calculate the values for load torque and load inertia at the motor drive shaft. Refer to the left column on page G-3 for the calculation of load torque for representative mechanisms. Refer to the right column on page G-3 for the calculation of inertia for representative shapes.

4. **Select motor type**
   - Select a motor type from standard AC motors, brushless motors or stepping motors based on the required specifications.

5. **Selection calculation**
   - Make a final determination of the motor after confirming that the specifications of the selected motor and gearhead satisfy all of the requirements, such as mechanical strength, acceleration time and acceleration torque. Since the specific items that must be checked will vary depending on the motor model, refer to the selection calculations and selection points explained on page G-4 and subsequent pages.

**Sizing and Selection Service**

We provide sizing and selection services for motor selection for load calculations that require time and effort.

- **FAX**
  - Product recommendation information sheets are shown from pages H-20 to H-25. Fill in the necessary information on this sheet and send it to the nearest Oriental Motor sales office.

- **Internet**
  - Simple requests for motors can be made using the selection form on our website.
  - www.orientalmotor.com
Calculate the Load Torque of Each Drive Mechanism $T_L$ [N-m]

Calculate the Load Torque

◇ Ball Screw Drive

$T_L = \left( \frac{F_P \times \mu F_P}{2 \pi} + \frac{m F_P}{2 \pi} \right) \times \frac{1}{i} \quad [\text{N-m}] \quad (1)$

$F = F_s + mg (\sin \theta + \mu \cos \theta) \quad [\text{N}] \quad (2)$

◇ Pulley Drive

$T_L = \frac{F_s}{2 \pi} \times \frac{\pi d_D}{i} \quad [\text{N-m}] \quad (3)$

$F = F_s + mg (\sin \theta + \mu \cos \theta) \quad [\text{N}] \quad (4)$

◇ Wire or Belt Drive, Rack and Pinion Drive

$T_L = \frac{F}{2 \pi} \times \frac{\pi d_D}{i} = \frac{FD}{2 \pi} \quad [\text{N-m}] \quad (4)$

$F = F_s + mg (\sin \theta + \mu \cos \theta) \quad [\text{N}] \quad (5)$

◇ By Actual Measurement

$T_L = \frac{F_s d_D}{2} \quad [\text{N-m}] \quad (4)$

$F_s \times \frac{\pi d_D}{2i}$

$F : \text{Force of moving direction} \quad [\text{N}]$

$F_P : \text{Preload} \quad [\text{N}] \quad (\equiv 1/3 F_s)$

$\mu : \text{Internal friction coefficient of preload nut} \quad (0.1 \sim 0.3)$

$i : \text{Efficiency} \quad (0.85 \sim 0.95)$

$\eta : \text{Efficiency} \quad (0.85 \sim 0.95)$

$\mu : \text{Tilt angle} \quad [\text{deg}]$

$D : \text{Final pulley diameter} \quad [\text{m}]$

$g : \text{Gravitational acceleration} \quad [\text{m/s}^2] \quad (9.807)$

Calculate the Moment of Inertia $J$ [kg-m²]

Calculate the Moment of Inertia

◇ Inertia of a Cylinder

$J_X = \frac{1}{8} \pi D l^2 \quad [\text{kg-m}^2] \quad (6)$

$J_Y = \frac{1}{4} \pi m \left( \frac{D^2}{4} + \frac{l^2}{4} \right) \quad [\text{kg-m}^2] \quad (7)$

◇ Inertia of a Hollow Cylinder

$J_X = \frac{1}{8} \pi D l^2 \quad [\text{kg-m}^2] \quad (8)$

$J_Y = \frac{1}{4} \pi m \left( \frac{D_1^2}{4} + \frac{D_2^2}{4} + \frac{l^2}{3} \right) \quad [\text{kg-m}^2] \quad (9)$

◇ Inertia on Off-Center Axis

$J_X = J_{X0} + ml^2 = \frac{1}{12} m (A^2 + B^2 + 12 l^2) \quad [\text{kg-m}^2] \quad (10)$

$J_Y = \frac{1}{12} m (B^2 + C^2) = \frac{1}{12} \pi ABC (B^2 + C^2) \quad [\text{kg-m}^2] \quad (11)$

◇ Inertia of a Rectangular Pillar

$J_X = \frac{1}{12} m (A^2 + B^2) = \frac{1}{12} \pi ABC (A^2 + B^2) \quad [\text{kg-m}^2] \quad (12)$

$J_Y = \frac{1}{12} m (B^2 + C^2) = \frac{1}{12} \pi ABC (B^2 + C^2) \quad [\text{kg-m}^2] \quad (13)$

◇ Inertia of an Object in Linear Motion

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

$A : \text{Unit of movement} \quad [\text{m/rev}]$

Density

- Stainless $\rho = 8.0 \times 10^3 \quad [\text{kg/m}^3]$
- Iron $\rho = 7.9 \times 10^3 \quad [\text{kg/m}^3]$
- Aluminum $\rho = 2.8 \times 10^3 \quad [\text{kg/m}^3]$
- Brass $\rho = 8.5 \times 10^3 \quad [\text{kg/m}^3]$
- Nylon $\rho = 1.1 \times 10^3 \quad [\text{kg/m}^3]$
- $J_X : \text{Inertia on x axis} \quad [\text{kg-m}^2]$
- $J_Y : \text{Inertia on y axis} \quad [\text{kg-m}^2]$
- $J_XO : \text{Inertia on x axis} \quad (\text{passing through center of gravity}) \quad [\text{kg-m}^2]$

$m : \text{Mass} \quad [\text{kg}]$

$D_1 : \text{Outer diameter} \quad [\text{m}]$

$D_2 : \text{Inner diameter} \quad [\text{m}]$

$\rho : \text{Density} \quad [\text{kg/m}^3]$

$L : \text{Length} \quad [\text{m}]$
Motor Selection Calculations

The following explains the calculation for selecting a stepping motor and servo motor based on pulse control:

**Operating Pattern**
There are two basic motion profiles. Acceleration/deceleration operation is the most common. When operating speed is low and load inertia is small, start/stop operation can be used.

![Diagram showing pulse speed and time](image)

**Calculate the Number of Operating Pulses \( A \) [Pulse]**
The number of operating pulses is expressed as the number of pulse signals that adds up to the angle that the motor must move to get the load from point A to B.

\[
A = \frac{l}{\text{rev}} \times \frac{360^\circ}{\theta_s} \times \frac{j}{i}
\]

- \( l \): Movement distance from point A to B [m]
- \( \text{rev} \): Movement distance per motor rotation [m/rev]
- \( \theta_s \): Step angle [deg]

**Calculate the Operating Pulse Speed \( f_2 \) [Hz]**
The operating pulse speed can be found 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 hastily, because it correlates with the acceleration torque and acceleration/deceleration rate.

Initial setting of the acceleration (deceleration) time at roughly 25% of the positioning time. (The setting must be fine-tuned before the final decision can be made.)

\[
\begin{align*}
\varepsilon_i &= \varepsilon_0 \times 0.25 \\
\varepsilon_i &= \frac{A - f_i \cdot \varepsilon}{\varepsilon_0 - \varepsilon}
\end{align*}
\]

2. **For start/stop operation**

\[
\varepsilon_i = \frac{A}{\varepsilon_0}
\]

**Calculate the Acceleration/Deceleration Rate \( T \) [ms/Hz]**
The values represent the specifications of Oriental Motor’s controllers.

The acceleration/deceleration rate indicates the degree of acceleration of pulse speed and is calculated using the following formula:

\[
T = \frac{h}{f_i - f_2}
\]

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

\[
T = (T_i + T_a) \times S_r
\]

- \( T_i \): Load torque [N-m]
- \( T_a \): Acceleration torque [N-m]
- \( S_r \): Safety factor

**Common Basic Formula for All Motors**

\[
T_i = \left( J_i \cdot \varepsilon^2 + J_t \right) \times \frac{\pi \cdot \theta_s}{180} \times \frac{f_i - f_2}{h} 
\]

For start/stop operation

\[
T_i = \left( J_i \cdot \varepsilon^2 + J_t \right) \times \frac{\pi \cdot \theta_s}{180 \cdot m} \times f^2 
\]

\[
\varepsilon: 3.6/(\theta_s \times i)
\]

**Calculate the Operating Speed \( N \) [r/min] from Operating Pulse Speed \( f \) [Hz]**

\[
N = f \times \frac{60}{360} \times 60
\]

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

**Calculate 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.
Formula for the Effective Load Torque $T_{rms} \ [N\cdot m]$

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

$$T_{rms} = \frac{(T_D + T_L) \cdot n \cdot T_1^2 \cdot n + (T_D - T_L) \cdot n}{b}$$

<table>
<thead>
<tr>
<th>Speed [N/\min]</th>
<th>(Speed pattern)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Torque [N\cdot m]</td>
<td>(Torque pattern)</td>
</tr>
<tr>
<td>Time [s]</td>
<td></td>
</tr>
<tr>
<td>Time [s]</td>
<td></td>
</tr>
<tr>
<td>Time [s]</td>
<td></td>
</tr>
<tr>
<td>Time [s]</td>
<td></td>
</tr>
<tr>
<td>y</td>
<td></td>
</tr>
</tbody>
</table>

where:
- $T_D$: Initial Torque
- $T_L$: Load Torque
- $n$: Speed Pattern
- $T_1$: Time
- $b$: Acceleration/Deceleration Pattern
Selection Points

There are differences in characteristics between standard AC motors, brushless motors, stepping motors and servo motors. Shown below are some of the points you should know when selecting a motor.

Standard AC Motors

① Speed variation by load

The speed of induction motors and reversible motors varies by several percent with the load torque. Therefore, when selecting an induction motor or reversible motor, the selection should take into account this possible speed variation by load.

② Time rating

There can be a difference of continuous and short time ratings, due to the difference in motor specifications, even if motors have the same output power. Motor selection should be based on the operating time (operating pattern).

③ Permissible load inertia of gearhead

If instantaneous stop (using a brake pack etc.), frequent intermittent operations or instantaneous bi-directional operations will be performed using a gearhead, an excessive load inertia may damage the gearhead. In these applications, therefore, the selection must be made so the load inertia does not exceed the permissible load inertia of gearhead. (Refer to page C-18)

Brushless Motors

① Permissible torque

Brushless motor combination types with a dedicated gearhead attached 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. Ensure that the load inertia does not exceed the value of the permissible load inertia. For combination types, there are permissible load inertia combination types. 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 triggers and stops the motor.

Stepping Motors

① Check the required torque

Check that the operation range indicated by operating speed \( N_s (\frac{f_s}{f}) \) and required torque \( T_m \) falls within the pullout torque of the speed – torque characteristics.

Safety Factor: \( \gamma \) (Reference value)

<table>
<thead>
<tr>
<th>Product</th>
<th>Safety Factor (Reference value)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \alpha_{\text{Step}} )</td>
<td>1.5~2</td>
</tr>
<tr>
<td>Stepping Motor</td>
<td>2</td>
</tr>
</tbody>
</table>

② Check the duty cycle

A stepping motor is not intended to be run continuously. It is suitable for an application the duty cycle represents rate of running time and stopping time of 50% or less.

\[
\text{Duty cycle} = \frac{\text{Running time}}{\text{Running time} + \text{Stopping time}} \times 100
\]

③ Check the acceleration/deceleration rate

Most controllers, when set for acceleration or deceleration, adjust the pulse speed in steps. For that reason, operation may sometimes not be possible, even though it can be calculated. Calculate the acceleration/deceleration rate from the previous formula and check that the value is at or above the acceleration/deceleration rate shown in the table.

Acceleration/Deceleration Rate (Reference values with EMP Series)

<table>
<thead>
<tr>
<th>Product</th>
<th>Motor Frame Size [mm]</th>
<th>Acceleration/Deceleration Rate ( T_m ) [ms/kHz]</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \alpha_{\text{Step}} )</td>
<td>28 (30), 42, 60, 85 (90)</td>
<td>0.5 Min.*</td>
</tr>
<tr>
<td>0.36°/0.72°</td>
<td>Stepping Motors</td>
<td>20, 28 (30), 42, 60</td>
</tr>
<tr>
<td>Stepping Motors</td>
<td>85 (90)</td>
<td>30 Min.</td>
</tr>
<tr>
<td>0.9°/1.8°</td>
<td>Stepping Motors</td>
<td>20, 28 (30), 35, 42, 50, 56.4, 60</td>
</tr>
<tr>
<td>Stepping Motors</td>
<td>85 (90)</td>
<td>50 Min.</td>
</tr>
</tbody>
</table>
| 0.9°/1.8°     | Stepping Motors       | 85 (90)                                       | 75 Min.

④ Check the inertia ratio

Large inertia ratios cause large overshooting and undershooting during starting and stopping, which can affect starting time and settling time. Depending on the conditions of usage, operation may be impossible. Calculate the inertia ratio with the following formula and check that the value found is at or below the inertia ratios shown in the table.

\[
\text{Inertia ratio} = \frac{J_i}{J_o} = \frac{J_i}{J_o} \cdot \frac{f_o}{f_s}
\]

Inertia Ratio (Reference values)

<table>
<thead>
<tr>
<th>Product</th>
<th>Motor Frame Size [mm]</th>
<th>Inertia Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \alpha_{\text{Step}} )</td>
<td>28, 42, 60, 85</td>
<td>30 Max.</td>
</tr>
<tr>
<td>Stepping Motor</td>
<td>20, 28, 35</td>
<td>5 Max.</td>
</tr>
<tr>
<td>Stepping Motor</td>
<td>42, 50, 56.4, 60, 85</td>
<td>10 Max.</td>
</tr>
</tbody>
</table>

Except for geared types

When the inertia ratio exceeds the values in the table, we recommend a geared type.
- **Servo Motors**
  1. Permissible Load Inertia
     A permissible load inertia is specified to enable stable control of the servo motor. Please select a load inertia that does not exceed this permissible value.

<table>
<thead>
<tr>
<th>Product</th>
<th>Permissible Load Inertia</th>
</tr>
</thead>
<tbody>
<tr>
<td>NX Series</td>
<td>50 times the rotor inertia or less*</td>
</tr>
</tbody>
</table>

*Up to 50 times the rotor inertia can be supported with auto-tuning and up to 100 times with manual tuning.

2. Rated Torque
   The motor can be operated if the ratio between load torque \( T_l \) and the rated torque of the servo motor is 1.5 to 2 or higher.

   \[
   \frac{\text{Rated torque}}{\text{Load torque}} \geq 1.5 - 2
   \]

3. Maximum Instantaneous Torque
   Confirm that the required torque is no higher than the maximum instantaneous torque of the servo motor (the safety factor \( S_f \) of the required torque should be 1.5 to 2).
   Note, the amount of time the maximum instantaneous torque can be used varies depending on the motor.

   Maximum instantaneous torque and operating time

<table>
<thead>
<tr>
<th>Product</th>
<th>Operating Time</th>
<th>Maximum Instantaneous Torque</th>
</tr>
</thead>
<tbody>
<tr>
<td>NX Series</td>
<td>Approximately 0.5 seconds or less</td>
<td>3 times the rated torque (at rated speed)</td>
</tr>
</tbody>
</table>

4. Effective Load Torque
   The motor can be operated if the effective load safety factor, the ratio between effective load torque and the rated torque of the servo motor, is 1.5 to 2 or higher.

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

5. Settling Time
   With servo motors, there is a lag between the position command from the pulse signal and actual operation of the motor. This difference is called the settling time. Therefore, this settling time added to the positioning time calculated from the operation pattern is the actual positioning time.

   \[
   \theta_s = \frac{360 \times \Delta t}{P_s} = \frac{360 \times 0.03}{15} = 0.72^\circ
   \]

   AR Series can be connected directly to the application.

(3) Determine the Operating Pattern (Refer to page G-4 for formula)

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

   \[
   A = \frac{f_1 \times \theta_s}{P_s} = \frac{180 \times 0.72}{15} = 6000 \text{ [Pulse]}
   \]

2. Determine the acceleration (deceleration) time \( t_a \) [s]
   An acceleration (deceleration) time of 25% of the positioning time is appropriate.

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

3. Calculate the operating pulse speed \( f_1 \) [Hz]

   \[
   f_1 = \frac{A - f_1 \times t_a}{t_b - t_a} = \frac{6000 - 0}{0.8 - 0.2} = 10000 \text{ [Hz]}
   \]

   Pulse Speed [Hz]

   ![Pulse speed diagram](https://via.placeholder.com/150)

   The settling time at the time of shipment is 60 to 70 ms in the NX series. However, the settling time changes when the gain parameters are adjusted with the mechanical rigidity setting switch.
Calculate the operating speed $N_u [\text{r/min}]$

$$N_u = f_i \times \frac{\theta_s}{360} \times 60 = 10000 \times \frac{0.72^\circ}{360} \times 60$$

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

(4) Calculate the Required Torque $T_m [\text{N-m}]$ (Refer to page G-4)

1. Calculate the load torque $T_l [\text{N-m}]$

   Force of moving direction $F = F_s + mg \sin \theta + \mu \cos \theta$

   $$= 0 + 40 \times 9.807 \sin 0^\circ + 0.05 \cos 0^\circ$$

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

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

   Load torque $T_l = \frac{F \cdot P_o}{2 \pi} + \frac{\mu \cdot F_s \cdot P_o}{2 \pi}$

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

   $$= 0.0567 \text{ [N-m]}$$

2. Calculate the acceleration torque $T_a [\text{N-m}]$

   - 1 Calculate the moment of load inertia $J_L [\text{kg-m}^2]$
     
     (Refer to page G-3 for formula)

     Inertia of ball screw $J_B = \frac{\pi}{32} \cdot \rho \cdot L_s \cdot D_s^4$

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

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

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

     $$= 40 \times \left( \frac{15 \times 10^{-3}}{2 \pi} \right)^2 = 2.28 \times 10^{-4} \text{ [kg-m}^2\text{]}$$

     Load inertia $J_l = J_s + J_r$

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

   - 2 Calculate the acceleration torque $T_a [\text{N-m}]$

     $$T_a = (J_s + J_r) \times \frac{\pi \cdot \theta_s}{180} \times \frac{f_i - f_t}{f_t}$$

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

     $$= 628.6 + 0.158 \text{ [N-m]}$$

3. Calculate the required torque $T_m [\text{N-m}]$

   Safety factor $S_f = 2$

   $$T_m = (T_s + T_a) S_f$$

   $$= (0.0567 + (628.6 + 0.158)) \times 2$$

   $$= 1256.6 \text{ [N-m]}$$

(5) Select a Motor

1. Tentative motor selection

<table>
<thead>
<tr>
<th>Model</th>
<th>Rotor Inertia [kg·m²]</th>
<th>Required Torque [N·m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>AR66AA-3</td>
<td>380 \times 10^{-7}</td>
<td>0.48</td>
</tr>
</tbody>
</table>

2. Determine the motor from the speed – torque characteristics

   **AR66AA-3**

   Select a motor for which the operating area indicated by operating speed and required torque falls within the pullout torque of the speed – torque characteristics.

(6) Check the Inertia Ratio (Refer to formula on page G-6)

$$\frac{J_s}{J_l} = \frac{2.52 \times 10^{-4}}{380 \times 10^{-7}} \approx 6.6$$

Since the inertia ratio of **AR66AA-3** is 30 or less, if the inertia ratio is 6.6 you can judge whether motor operation is possible.
### Using Servo Motors

1. **Specifications and Operating Conditions of the Drive Mechanism**

   A servo motor for driving a single-axis table is selected, as shown in the figure below.

   ![Diagram of Drive Mechanism]

   Max. speed of table \( F_L = 0.2 \text{ [m/s]} \)
   
   Resolution \( \Delta m = 0.02 \text{ [m/s]} \)
   
   Motor power supply \( \text{Single-Phase 115 VAC} \)
   
   Total mass of table and load \( m = 100 \text{ [kg]} \)
   
   External force \( F_e = 29.4 \text{ [N]} \)
   
   Friction coefficient of sliding surface \( \mu = 0.04 \)
   
   Efficiency of ball screw \( \eta = 0.9 \)
   
   Internal friction coefficient of preload nut \( \mu_0 = 0.3 \)
   
   Ball screw shaft diameter \( D_s = 25 \text{ [mm]} \)
   
   Total length of ball screw \( L_s = 1000 \text{ [mm]} \)
   
   Ball screw lead \( P_s = 10 \text{ [mm]} \)
   
   Ball screw material \( \text{Iron (density } \rho = 7.9 \times 10^3 \text{ [kg/m}^3] \)\)

   Operating cycle ... Operation for 2.1 sec./stopped for 0.4 sec. (repeated)

   Acceleration/deceleration time \( T_i = 0.1 \text{ [s]} \)

2. **Calculation of the Required Resolution \( \theta \)**

   The resolution of the motor is calculated from the resolution required to drive the table.

   \[
   \theta = \frac{360° \cdot \Delta m}{P_s} = \frac{360° \times 0.02}{10} = 0.72°
   \]

   The resolution of the **NX** series, \( \theta_0 = 0.36°/\text{pulse} \), satisfies this condition.

3. **Determination of Operating Pattern**

   The motor speed \( N_u \) is calculated using the following formula.

   \[
   N_u = \frac{60 \cdot F_L}{P_s} = \frac{60 \times 0.2}{10 \times 10^{-3}} = 1200 \text{ [r/min]}
   \]

   A speed pattern is created from this \( N_u \) and operating cycle, as well as the acceleration/deceleration time.

   ![Speed Pattern Diagram]

   \[
   \text{Speed [r/min]} \quad 1200
   \]

   \[
   N_i = \rho = 0.1
   \]

   \[
   T_1 = 0.1
   \]

   \[
   T_2 = 2.1
   \]

   \[
   T_3 = 0.4
   \]

   \[
   T_4 = 0.5
   \]

   \[
   \text{Time [s]} \quad 0.1
   \]

### Calculation of Load Torque \( T_L \) [N·m]

- **Force of moving direction**
  \[
  F = F_L + m \cdot g \cdot (\sin \theta + \mu_0 \cdot \cos \theta)
  \]
  \[
  = 29.4 + 100 \times 9.807 \times (\sin 0° + 0.04 \cos 0°) \]
  \[
  = 68.6 \text{ [N]}
  \]

- **Load torque of motor shaft conversion**
  \[
  T_L = \frac{F \cdot P_s + \mu \cdot F \cdot P_s}{2\pi}
  \]
  \[
  = \frac{68.6 \times 10 \times 10^{-3}}{2\pi \times 0.9} + \frac{0.3 \times 22.9 \times 10 \times 10^{-3}}{2\pi}
  \]
  \[
  \approx 0.13 \text{ [N·m]}
  \]

   Here, the ball screw preload \( F_0 = \frac{1}{\eta} \cdot F \).

### Calculation of Load Inertia \( J_L \) [kg·m²]

- **Inertia of ball screw**
  \[
  J_s = \frac{\pi^2 \cdot \rho \cdot L_s \cdot D_s^4}{32}
  \]
  \[
  = \frac{9.807 	imes 10^5 	imes 1000 \times 10^{-3} \times (25 \times 10^{-3})^4}{32}
  \]
  \[
  \approx 3.03 \times 10^{-4} \text{ [kg·m²]}
  \]

- **Inertia of table and work**
  \[
  J_w = m \cdot \left( \frac{P_s}{2\pi} \right)^2
  \]
  \[
  = 100 \times \left( \frac{10 \times 10^{-3}}{2\pi} \right)^2
  \]
  \[
  \approx 3.03 \times 10^{-4} \text{ [kg·m²]}
  \]

- **Load inertia**
  \[
  J_c = J_s + J_w
  \]
  \[
  = 3.03 \times 10^{-4} + 2.53 \times 10^{-4} = 5.56 \times 10^{-4} \text{ [kg·m²]}
  \]

### Tentative Selection of Servo Motor

- **Safety factor** \( S_r = 1.5 \)

- **Load torque**
  \[
  T_r = T_c = 3.03 \times 10^{-4} + 0.13 = 0.195 \text{ [N·m]}
  \]

- **Load inertia**
  \[
  J_r = 5.56 \times 10^{-4} \text{ [kg·m²]}
  \]

   This gives us a speed of 1200 [r/min], and a rated torque of 0.195 [N·m] or higher is output. A servo motor with a permissible load inertia of \( 5.56 \times 10^{-4} \text{ [kg·m²] or higher is selected.} \)

### NX620AA-3

- **Rated speed** \( N = 3000 \text{ [r/min]} \)

- **Rated torque** \( T_u = 0.637 \text{ [N·m]} \)

- **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** \( T_{MAX} = 1.91 \text{ [N·m]} \)

   The above values are appropriate.

### Calculation of Acceleration Torque \( T_a \) [N·m] and Deceleration Torque \( T_d \) [N·m]

Acceleration/deceleration torque is calculated using the following formula.

\[
T_a = T_d = \frac{(J_c + J_w) N_u}{9.55 t_i}
\]

\[
= \frac{(5.56 \times 10^{-4} + 2.53 \times 10^{-4}) \times 1200}{9.55 \times 0.1}
\]

\[
= 0.72 \text{ [N·m]}
\]

### Calculation of Required Torque \( T \) [N·m]

\[
T = T_a + T_c
\]

\[
= 0.72 + 0.13 = 0.85 \text{ [N·m]}
\]

This required torque can be used with **NX620AA-3** in order to keep the maximum instantaneous torque of **NX620AA-3** at 1.91 [N·m] or less.
(9) Determination of Torque Pattern
The torque pattern is determined with the operating cycle, acceleration/deceleration torque, load torque and acceleration time.

$$T_r = \frac{(T_s + T_a) \cdot t_i + T_s^2 \cdot \dot{t}_i + (T_s - T_a) \cdot \dot{t}_i}{t_r}$$

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

$$= 0.24 \text{ [N-m]}$$

Here, from the operating cycle, $t_1 = t_2 + t_i = 2.1$ [s] and the acceleration/deceleration time $t_i = t_i = 0.1$. Based on this, $t_2 = 2.1 - 0.1 \times 2 = 1.9$ [s].

The ratio between this $T_r$ and the rated torque $T_u$ of the servo motor (the effective load safety factor) is determined with the following formula.

$$\frac{T_u}{T_r} = 0.637 \div 0.24 = 2.65$$

In general, a motor can operate at an effective load safety factor of 1.5 to 2.

(10) Calculation of Effective Load Torque $T_{r\text{es}}$ [N-m]

The effective load torque $T_{r\text{es}}$ is determined with the torque pattern and the following formula.

$$T_{r\text{es}} = \sqrt{\frac{(T_s + T_a) \cdot t_i + T_s^2 \cdot \dot{t}_i + (T_s - T_a) \cdot \dot{t}_i}{t_r}}$$

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

$$= 0.24 \text{ [N-m]}$$

Using Standard AC Motors

(1) Specifications and Operating Conditions of the Drive

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

- Total mass of the table and load: $m = 45$ [kg]
- Table speed: $V = 15 \pm 2$ [mm/s]
- External force: $F_E = 0$ [N]
- Ball screw type: $\alpha = 90$ [deg]
- Total length of ball screw: $L_b = 800$ [mm]
- Ball screw shaft diameter: $D_b = 20$ [mm]
- Ball screw lead: $P_b = 5$ [mm]
- Distance moved for one rotation of ball screw: $A = 5$ [mm]
- Ball screw efficiency: $\eta = 0.9$
- Ball screw material: Iron (density $\rho = 7.9 \times 10^3$ [kg/m$^3$])
- Internal friction coefficient of preload nut: $\mu_0 = 0.3$
- Friction coefficient of sliding surface: $\mu = 0.05$
- Motor power supply: Single-Phase 115 VAC 60 Hz
- Operating time: Intermittent operation, 5 hours/day
- Load with repeated starts and stops
- Required load holding

(2) Determine the Gear Ratio

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

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

$$\text{Gear ratio } i = \frac{1450 \sim 1550}{180 \pm 24} = 7.1 \sim 9.9$$

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

(3) Calculate the Required Torque $T_u$ [N-m]

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

$$= 0 + 45 \times 9.807 \times (\sin 90^\circ + 0.05 \cos 90^\circ)$$

$$= 441 \text{ [N]}$$

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

Load torque $T_\lambda = \frac{F_0 \cdot P_b}{2\pi \eta} + \frac{\mu_0 \cdot F_\text{r} \cdot P_b}{2\pi}$

$$= \frac{441 \times 5 \times 10^{-3}}{2\pi \times 0.9} + \frac{0.3 \times 147 \times 5 \times 10^{-3}}{2\pi}$$

$$= 0.426 \text{ [N-m]}$$

Allow for a safety factor of 2 times.

$$T_u = T_\lambda \times 2 = 0.426 \times 2 = 0.86 \text{ [N-m]}$$
Select an electromagnetic brake motor and gearhead satisfying the permissible torque of gearhead based on the calculation results (gear ratio \( i = 9 \), load torque \( T_l = 0.86 \) [N·m]) obtained so far.

Here, \( 4RK25GN-AW2MU \) and \( 4GN95A \) are tentatively selected as the motor and gearhead respectively, by referring to the "Gearmotor – Torque Table" on page C-125.

Next, convert this load torque to a value on the motor output shaft to obtain the required torque \( T_u \), as follows:

\[
T_u = \frac{T_l}{i} \cdot \eta_c = \frac{0.86}{9 \times 0.81} \cdot 0.118 \text{ [N·m]} = 118 \text{ [mN·m]}
\]

(Gearhead efficiency \( \eta_c = 0.81 \))

The starting torque of the \( 4RK25GN-AW2MU \) motor selected earlier is 140 mN·m. Since this is greater than the required torque of 118 mN·m, this motor can start the mechanism in question.

Next, check if the gravitational load acting upon the mechanism in standstill state can be held with the electromagnetic brake.

Here, the load equivalent to the load torque obtained earlier is assumed to act.

Torque \( T_u \) required for load holding on the motor output shaft:

\[
T_u = \frac{T_l}{i} = \frac{0.86}{9} \cdot 0.9056 \text{ [N·m]} = 95.6 \text{ [mN·m]}
\]

The static friction torque generated by the electromagnetic brake of the \( 4RK25GN-AW2MU \) motor selected earlier is 100 mN·m, which is greater than 95.6 mN·m required for the load holding.

(4) Check the Moment of Load Inertia \( j \) [kg·m²]

Inertia of ball screw \( J_b = \frac{\pi}{32} \cdot \rho \cdot L_s \cdot D_s^4 \)

\[
= \frac{\pi}{32} \times 7.9 \times 10^5 \times 800 \times 10^{-3} \times (20 \times 10^{-3})^4
= 0.993 \times 10^{-4} \text{ [kg·m²]}
\]

Inertia of table and load \( J_t = m \left( \frac{A'}{D'} \right)^2 \)

\[
= 45 \left( \frac{5 \times 10^{-3}}{2 \pi} \right)^2
= 0.286 \times 10^{-4} \text{ [kg·m²]}
\]

Load inertia at the gearhead shaft \( J \) is calculated as follows:

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

Here, permissible load inertia of gearhead \( 4GN95A \) (gear ratio \( i = 9 \)) \( J_c \) is (Refer to page C-18):

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

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

\[
V = \frac{N_{Motor} \cdot \rho_s}{60 \cdot i} = \frac{1750 \times 5}{60 \times 9} = 16.2 \text{ [mm/s]}
\]

This confirms that the motor meets the specifications.

Based on the above, \( 4RK25GN-AW2MU \) and \( 4GN95A \) are selected as the motor and gearhead, respectively.

● Belt and Pulley Mechanism

Using Standard AC Motors

(1) Specifications and Operating Conditions of the Drive Mechanism

Here is an example of how to select an induction motor to drive a belt conveyor.

In this case, a motor must be selected that meets the following required specifications.

Total mass of belt and load .................................................. \( m = 25 \) [kg]
External force ............................................................................ \( F_s = 0 \) [N]
Friction coefficient of sliding surface ........................................ \( \mu = 0.3 \)
Roller diameter ........................................................................ \( D = 90 \) [mm]
Roller mass ................................................................................ \( m_s = 1 \) [kg]
Belt and roller efficiency ................................................................ \( \eta_s = 0.9 \)
Belt speed .................................................................................. \( V = 150 \) [mm/s] ± 10%
Motor power supply ..................................................Single-Phase 115 VAC 60 Hz
Operating time ......................................................................... 8 hours/day

(2) Determine the Gear Ratio

Speed at the gearhead output shaft \( N_{G} = \frac{V \cdot 60 \pi \cdot D}{\pi \cdot 90} = \frac{(150 \pm 15) \times 60}{\pi \cdot 90} = 31.8 \pm 3.2 \text{ [r/min]}

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

\[
\text{Gear ratio } i = \frac{1450 \sim 1550}{31.8 \pm 3.2} = 46.4 \sim 54.2
\]

This gives us a gear ratio of \( i = 50 \).

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

Friction coefficient of sliding surface \( F \) is calculated as follows:

\[
F = F_s + m \cdot g \cdot (\sin \theta + \mu \cdot \cos \theta)
= 0 + 25 \times 9.807 \times (0.3 \cos 0^\circ + 0.3 \times \cos 0^\circ)
= 73.6 \text{ [N]}
\]

Load torque \( T_l = \frac{F \cdot D}{2 \cdot \eta} \)

\[
= \frac{73.6 \times 90 \times 10^{-3}}{2 \times 0.9} = 3.68 \text{ [N·m]}
\]

Allow for a safety factor of 2 times.

\[
T_l = T_l \cdot 2 = 3.68 \times 2 = 7.36 \text{ [N·m]}
\]

Select an induction motor and gearhead satisfying the permissible torque of gearhead based on the calculation results (gear ratio \( i = 50 \), load torque \( T_l = 7.36 \) [N·m]) obtained so far.

Here, \( 5IK60GE-AW2U \) and \( 5GE60SA \) are tentatively selected as the motor and gearhead respectively, by referring to the "Gearmotor – Torque Table" on page C-18.

Next, convert this load torque to a value on the motor output shaft to obtain the required torque \( T_u \), as follows:

\[
T_u = \frac{T_l}{i \cdot \eta_c} = \frac{7.36}{50 \times 0.66} = 0.22 \text{ [N·m]} = 220 \text{ [mN·m]}
\]

(Gearhead efficiency \( \eta_c = 0.66 \))

Since the starting torque of the \( 5IK60GE-AW2U \) motor is 320 mN·m, this is greater than the required torque of 220 mN·m.
(4) Check the Moment of Load Inertia $J$ [kg·m²]

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

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

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

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

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

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

Load inertia at the gearhead shaft $J$ is calculated as follows:

$$J = J_{m} + J_{oc} \cdot 2$$

$$= 507 \times 10^{-4} + 10.2 \times 10^{-4} \times 2$$

$$= 528 \times 10^{-4} \text{ [kg·m²]}$$

Here, permissible load inertia of gearhead 5GE50SA (gear ratio $i = 50$) $J_0$ is (Refer to page C-18):

$$J_0 = 1.1 \times 10^{-4} \times 50^2$$

$$= 2750 \times 10^{-4} \text{ [kg·m²]}$$

Therefore, $J < J_0$, the load inertia is less than the permissible inertia, so there is no problem. Since the motor selected has a rated torque of 405 mN·m, which is greater than the actual load torque, the motor will operate at a higher speed than the rated speed.

Therefore, the belt speed is calculated from the speed under no load (approximately 1470 r/min), and thus determine whether the selected product meets the required specifications.

$$V = \frac{N \cdot \pi \cdot D}{60 \cdot i} = \frac{1750 \times \pi \times 90}{60 \times 50} = 165 \text{ [mm/s]}$$

This confirms that the motor meets the specifications.

Based on the above, 5IK60GE-AW2U and 5GE50SA are selected as the motor and gearhead respectively.

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

(1) Specifications and Operating Conditions of the Drive Mechanism

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

![Fig. 1 Example of Belt Drive](image)

Total mass of belt and load ................. $m_1 = 1.5 \text{ [kg]}$

Roller diameter ................................ $D = 30 \text{ [mm]}$

Mass of roller ..................................... $m_2 = 0.1 \text{ [kg]}$

Frictional coefficient of sliding surfaces ... $\mu = 0.04$

Belt and pulley efficiency ....................... $\eta = 0.9$

Frequency of power supply ..................... 60 Hz (Motor speed: 72 r/min)

![Fig. 2 Operating Pattern](image)

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

(2) Belt speed $V$ [mm/s]

Check the belt (load) speed

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

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

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

$$= 0 + 1.5 \times 9.807 \cdot (\sin 0° + 0.04 \cos 0°)$$

$$= 0.589 \text{ [N]}$$

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

(4) Calculate the Moment of Load Inertia $J_l$ [kg·m²]

Load inertia of belt and load $J_{oc} = m_1 \times \left( \frac{\pi \cdot D}{2 \pi} \right)^2$

$$= 1.5 \times \left( \frac{90 \times 10^{-3}}{2 \pi} \right)^2$$

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

Load Inertia of Roller $J_{oc} = \frac{1}{8} \times m_2 \times D^2$

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

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

The load inertia $J_l$ is calculated as follows:

$$J_l = J_{oc} + J_{oc} \times 2 = 3.38 \times 10^{-4} + 0.113 \times 10^{-4} \times 2 = 3.5 \times 10^{-4} \text{ [kg·m²]}$$
(5) Calculate the Acceleration Torque \( T_a \) [N·m]

\[
T_a = (J_h + J_s) \times \frac{\pi \cdot 2 \theta}{180 \cdot n} \times f^2 = (J_h + 3.5 \times 10^{-4}) \times \frac{\pi \times 7.2}{180 \times 0.5} \times 60^2
\]

\[= 905 \cdot J_h + 0.32 \text{ [N·m]}\]

Here, \( \theta \text{s} = 7.2^\circ \), \( f = 60 \text{ Hz} \), \( n = 3.6^\circ/\text{s} = 0.5 \) 
\( J_h \): Rotor Inertia

(6) Calculate the Required Torque \( T_m \) [N·m] (Look for a margin of safety of 2 times)

Required Torque \( T_m = (T_a + T_L) \times 2 \)
\[= (9.82 \times 10^{-3} + 905 \cdot J_h + 0.32) \times 2 \]
\[= 1810 \cdot J_h + 0.66 \text{ [N·m]}\]

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

<table>
<thead>
<tr>
<th>Motor</th>
<th>Rotor Inertia [kg·m(^2)]</th>
<th>Permissible Load Inertia [kg·m(^2)]</th>
<th>Output Torque [N·m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>SMK5100A-AA</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, \( T_m \) is obtained as 0.914 N·m, which is below the output torque. Next, check the permissible load inertia. Since the load inertia calculated in (4) is also below the permissible load inertia, SMK5100A-AA can be used in this application.

Using Brushless Motors

(1) Specifications and Operating Conditions of the Drive Mechanism

Here is an example of how to select a brushless motor to drive a belt conveyor.

![Belt conveyor diagram](image)

Belt speed ....................................................... \( V_c = 0.05\sim1 \text{ [m/s]} \)
Motor power supply ...................................... Single-Phase 115 VAC
Belt conveyor drive
- Roller diameter ........................................ \( D = 0.1 \text{ [m]} \)
- Roller mass ................................................ \( m_r = 7 \text{ [kg]} \)
- Total mass of belt and load .............................. \( m_l = 7 \text{ [kg]} \)
- External force ............................................ \( F_s = 0 \text{ [N]} \)
- Friction coefficient of sliding surface ............... \( \mu = 0.3 \)
- Belt and roller efficiency .............................. \( \eta = 0.9 \)

(2) Find the Required Speed Range

For the gear ratio, select 15:1 (speed range: 5.3\sim200) from the “Gearmotor – Torque Table of Combination Type” on page D-67 so that the minimum/maximum speed falls within the speed range.

\[ N_c = \frac{60 \cdot V_c}{\pi \cdot D} \\] \( N_c \): Speed at the gearhead shaft

Belt speed 0.015 [m/s] ........... \( \frac{60 \cdot 0.05}{\pi \cdot 0.1} = 9.55 \text{ [r/min]} \) (Minimum speed)
Belt speed 1 [m/s] ............... \( \frac{60 \cdot 1}{\pi \cdot 0.1} = 191 \text{ [r/min]} \) (Maximum speed)

(3) Calculate the Moment of Load Inertia \( J_L \) [kg·m\(^2\)]

\[
J_L = m_l \cdot \left( \frac{\pi \cdot D}{2\pi} \right)^2 = 7 \times \left( \frac{\pi \times 0.1}{2\pi} \right)^2
\]
\[= 175 \times 10^{-4} \text{ [kg·m}^2\text{]}\]

Inertia of roller \( J_r = \frac{1}{8} \cdot m_r \cdot D^2 \)
\[= \frac{1}{8} \times 1 \times 0.1^2 = 12.5 \times 10^{-4} \text{ [kg·m}^2\text{]}\]

The load inertia \( J_L \) is calculated as follows:

\[ J_L = J_m + J_r = 175 \times 10^{-4} + 12.5 \times 10^{-4} \times 2 \]
\[= 200 \times 10^{-4} \text{ [kg·m}^2\text{]}\]

From the specifications on page D-69, the permissible load inertia of BLF5120A-15 is \( 225 \times 10^{-4} \text{ [kg·m}^2\text{]} \).

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

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

Select BLF5120A-15 from the “Gearmotor – Torque Table of Combination Type” on page D-67.

Since the permissible torque is 5.4 N·m, the safety factor is
\[ T_a \text{ / } T_L = 5.4 \text{ / } 1.15 \approx 4.6 \]

Usually, a motor can operate at the safety factor of 1.5\sim2 or more.
### Selection Calculations

#### Motors

#### Index Mechanism

(1) Specifications and Operating Conditions of the Drive Mechanism

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

- **Index table diameter**: $D_{\text{v}} = 300 \text{ [mm]}$
- **Index table thickness**: $L_{\text{v}} = 5 \text{ [mm]}$
- **Load diameter**: $D_{\text{w}} = 40 \text{ [mm]}$
- **Load thickness**: $L_{\text{w}} = 30 \text{ [mm]}$
- **Material of table**: Aluminum (density $\rho = 2.8 \times 10^3 \text{ [kg/m}^3\text{]}$)
- **Number of loads**: 10 (one every 36°)
- **Positioning angle**: $\theta = 36^\circ$
- **Positioning time**: $t_{\text{p}} = 0.25 \text{ [sec]}$

The **RK Series** **PN** geared type (gear ratio 10, resolution per pulse $= 0.072^\circ$) can be used at the maximum starting/stopping torque in the inertial drive mode.

The **PN** geared type can be used at the maximum starting/stopping torque.

#### Gear ratio

- **Gear ratio**: $i = 10$
- **Resolution**: $\theta_{\text{p}} = 0.072^\circ$

#### (2) Determine the Operating Pattern (Refer to page G-4 for formula)

1. **Calculate the number of operating pulses** $A$ [Pulse]

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

2. **Determine the acceleration (deceleration) time** $t_{\text{n}}$ [s]

   An acceleration (deceleration) time of 25% of the positioning time is appropriate.

   Here we shall let

   $$t_{\text{n}} = 0.1 \text{ [s]}.$$  

3. **Calculate the operating pulse speed** $f_{\text{p}}$ [Hz]

   $$f_{\text{p}} = \frac{A}{t_{\text{n}} - t} = \frac{500}{0.25 - 0.1} = 3334 \text{ [Hz]}$$

#### (3) Calculate the Required Torque $T_{\text{u}}$ [N·m] (Refer to page G-4)

1. **Calculate the load torque** $T_{\text{l}}$ [N·m]

   Friction load is negligible and therefore omitted. The load torque is assumed as 0.

   $$T_{\text{l}} = 0 \text{ [N·m]}$$

2. **Calculate the acceleration torque** $T_{\text{a}}$ [N·m]

   - **Calculate the moment of load inertia** $J_{\text{L}}$ [kg·m²]
     
     Refer to page G-3 for formula
     
     Inertia of table $J_{\text{r}} = \frac{\pi}{32} \times \rho \times L_{\text{r}} \times D_{\text{r}}^4$
     
     $$J_{\text{r}} = \frac{\pi}{32} \times 2.8 \times 10^3 \times (5 \times 10^-3) \times (300 \times 10^-3)^4 = 1.11 \times 10^{-6} \text{ [kg·m}^2\text{]}$$

     Inertia of load $J_{\text{L}} = \frac{\pi}{32} \times \rho \times L_{\text{w}} \times D_{\text{w}}^4$
     
     $$J_{\text{L}} = \frac{\pi}{32} \times 2.8 \times 10^3 \times (30 \times 10^-3) \times (40 \times 10^-3)^4 = 0.211 \times 10^{-5} \text{ [kg·m}^2\text{]}$$

     Mass of load $m_{\text{L}} = \frac{\pi}{4} \times \rho \times L_{\text{w}} \times D_{\text{w}}^2$
     
     $$m_{\text{L}} = \frac{\pi}{4} \times 2.8 \times 10^3 \times (30 \times 10^-3) \times (40 \times 10^-3)^2 = 0.106 \text{ [kg]}$$

     Inertia of load $J_{\text{L}}$ [kg·m²] relative to the center of rotation can be obtained from distance $L$ [mm] between the center of load and center of rotation, mass of load $m_{\text{L}}$ [kg], and inertia of load (center shaft of load) $J_{\text{L1}}$ [kg·m²].

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

     Inertia of load $J_{\text{L}} = m_{\text{L}} \times (J_{\text{L1}} + m_{\text{L}} \times L^2)$ (Center shaft of load)
     
     $$J_{\text{L}} = 10 \times ((0.211 \times 10^{-5}) + 0.106 \times (120 \times 10^{-3})^2) = 1.55 \times 10^{-3} \text{ [kg·m}^2\text{]}$$

     Load inertia $J_{\text{L}} = J_{\text{r}} + J_{\text{L}}$
     
     $$(1.11 + 1.55) \times 10^{-3} = 2.66 \times 10^{-2} \text{ [kg·m}^2\text{]}$$

The permissible speed range for the **PN** geared motor with a gear ratio of 10 is from 0 to 300 r/min.
②-2 Calculate the acceleration torque \( T_a \) [N·m]
\[
T_a = \left( J_0 \times \frac{\theta_2}{180} \times \frac{f_2 - f_1}{n} \right) 
\]
\[
= (4.19 \times 10^2 \times 2.66 \times 10^{-2}) \times \frac{180}{\pi} \times 3334 - 0.1
\]
\[
= 4.19 \times 10^3 \text{ [N·m]}
\]
③ Calculate the required torque \( T_M \) [N·m]
Safety factor \( S_f = 2.0 \)
\[
T_M = (T_i + T_a) \times S_f
\]
\[
= (0 + (4.19 \times 10^2 \times J_0 + 1.11)) \times 2.0
\]
\[
= 8.38 \times 10^3 \text{ [N·m]}
\]
(4) Select a Motor
① Tentative motor selection

<table>
<thead>
<tr>
<th>Model</th>
<th>Rotor Inertia [kg·m²]</th>
<th>Required Torque [N·m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>RK566AAE-N10</td>
<td>280 \times 10^{-7}</td>
<td>2.45</td>
</tr>
</tbody>
</table>

② Determine the motor from the speed – torque characteristics

RK566AAE-N10

PN geared type can operate inertia load up at starting/stopping to acceleration torque less than maximum torque. Select a motor for which the operating area indicated by operating speed and required torque falls within the speed – torque characteristics. Check the inertia ratio and acceleration/deceleration rate to ensure that your selection is the most appropriate.

(5) Check the Inertia Ratio (Refer to page G-6)
The RK566AAE-N10 has a gear ratio 10, therefore, the inertia ratio is calculated as follows.
\[
\frac{J_i}{J_0 \times i^2} = \frac{2.66 \times 10^{-2}}{280 \times 10^{-7} \times 10^2}
\]
\[
= 9.5
\]
RK566AAE-N10 motor is the equivalent of the RK566AAE 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 G-6)
Note when calculating that the units for acceleration/deceleration rate \( T_a \) are [ms/kHz].
\[
T_a = \frac{n}{f_2 - f_1} = \frac{0.1 \text{ [s]}}{3334 \text{ [Hz]} - 0 \text{ [Hz]}}
\]
\[
= \frac{100 \text{ [ms]}}{3.334 \text{ [kHz]} - 0 \text{ [kHz]}}
\]
\[
= 30 \text{ [ms/kHz]}
\]
The RK566AAE-N10 motor is the equivalent of the RK566AAE 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 whether motor operation is possible.
Selection Calculations
Motors

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

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

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

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

Torque motors have ideal characteristics to meet these conditions.

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

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

Calculate the speed $N_2$ required at the end of winding.

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

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

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

Calculate the torque $T_2$ required at the end of winding.

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

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

③ Select a Motor
Check the Speed – Torque Characteristics
Select a motor that meets the required conditions specified above. If the required conditions are plotted on the Speed – Torque Characteristics for 4TK10A-AW2U, it is clear that the conditions roughly correspond to the characteristics at a torque setting voltage of 1.9 VDC.

Speed – Torque Characteristics

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

Note
- If a torque motor is operated continuously in a winding application, select conditions where the service rating of the torque motor remains continuous.
(3) Select a Tensioning Motor

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

① Calculate the Required Speed $N_3$

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

② Calculate the Required Torque $T_3$

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

③ Select a Motor

Select a motor that meets the required conditions specified above. If the required conditions are plotted on the speed – brake torque characteristics* for the 4TK10A-AW2U reverse-phase brake, it is clear that the conditions roughly correspond to the characteristics at a torque setting voltage of 1.0 VDC.

Speed – Brake Torque Characteristics with Reverse-Phase Brake

![Graph showing speed and brake torque characteristics]

Note

- If a torque motor is operated continuously in a brake application, how much the motor temperature rises varies depending on the applicable speed and torque setting voltage. Be sure to keep the temperature of the motor case at 90˚C max.

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

*Please contact the nearest Oriental Motor sales office or customer support centre for information on the speed – brake torque characteristics of each product.
Selection Calculations
For Linear and Rotary Actuators

Motorized Linear Slides and Cylinders
EZSII Series, EZCII Series

First determine your series, then select your product.
Select the actuator that you will use based on the following flow charts:

1. Determine the Actuator Type
   Select the actuator type that you will use.
   (Linear slide type or cylinder type)

2. Check the Actuator Size and Transport Mass
   Select the cylinder or linear slide size that satisfies your desired conditions.
   (Check the frame size, table height, transport mass and thrust force.)

3. Check the Positioning Time
   Check whether your desired positioning time is sufficient using the "Positioning Distance – Positioning Time" graph.
   As a reference, the positioning time by the linear slide corresponds to the positioning time calculated from the graph, multiplied by the "positioning time coefficient" corresponding to the applicable stroke.

4. Check the Operating Conditions
   Check that the operating speed and acceleration satisfy the conditions in [3] using the "Positioning Distance – Operating Speed" and "Positioning Distance – Acceleration" graphs.

5. Check the Moment (Linear slide only)
   Include the calculated acceleration conditions and check that it is within the specified values of the dynamic permissible moment applied to the motorized linear slides.
   Refer to the following page for the moment calculation methods.

Selection complete
Calculating Load Moment

When a load is transported with the motorized linear slides, the load moment acts on the linear guide if the load position is offset from the center of the table. The direction of action applies to three directions, pitching ($M_P$), yawing ($M_Y$), and rolling ($M_R$) depending on the position of the offset.

Even though the selected actuator satisfies the transport mass and positioning time, when the fixed load is overhung from the table, the run life may decrease as a result of the load moment. Load moment calculations must be completed and the conditions entered in as specified values must be checked. The moment applied under static conditions is the static permissible moment. The moment applied under movement is the dynamic permissible moment.

Calculate the load moment of the linear slide based on loads. Check that the static permissible moment and dynamic permissible moment are within limits and check that strength is sufficient.

**Load Moment Formula:**

$$\left| \frac{\Delta M_P}{M_P} \right| + \left| \frac{\Delta M_Y}{M_Y} \right| + \left| \frac{\Delta M_R}{M_R} \right| \leq 1$$

When there are several overhung loads, etc., this equation determines the moment from all loads.

**When there are multiple loads (n loads)**

$$\left| \frac{\Delta M_{P1} + \Delta M_{P2} + \cdots + \Delta M_{Pn}}{M_P} \right| + \left| \frac{\Delta M_{Y1} + \Delta M_{Y2} + \cdots + \Delta M_{Yn}}{M_Y} \right| + \left| \frac{\Delta M_{R1} + \Delta M_{R2} + \cdots + \Delta M_{Rn}}{M_R} \right| \leq 1$$

- $m$: Load mass (kg)
- $g$: Gravitational acceleration 9.807 (m/s$^2$)
- $a$: Acceleration (m/s$^2$)
- $h$: Linear slide table height (m)
- $L_x$: Overhung distance in the direction of the x-axis (m)
- $L_y$: Overhung distance in the direction of the y-axis (m)
- $L_z$: Overhung distance in the direction of the z-axis (m)
- $\Delta M_P$: Load moment in the pitching direction (N·m)
- $\Delta M_Y$: Load moment in the yawing direction (N·m)
- $\Delta M_R$: Load moment in the rolling direction (N·m)
Selection Calculations
Linear and Rotary Actuators

● Concept of Static Permissible Moment Application
Check the static permissible moment when the load moment is applied to the stopped linear slide.

<table>
<thead>
<tr>
<th>Horizontal</th>
<th>Vertical</th>
<th>Wall Mounting</th>
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</thead>
<tbody>
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</table>

\[ \Delta M_s = m \cdot g \cdot (L_z + h) \]
\[ \frac{\Delta M_s}{M_s} \leq 1 \]

\[ \Delta M_r = m \cdot g \cdot (L_x + L_y + h) \]
\[ \frac{\Delta M_r}{M_r} \leq 1 \]

\[ \Delta M_w = m \cdot g \cdot (L_z + h) \]
\[ \frac{\Delta M_w}{M_w} \leq 1 \]

● Concept of Dynamic Moment Application
Take into account the acceleration and check that the dynamic permissible moment is not exceeded when the load moment is applied during linear slide operation.

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<thead>
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\[ \Delta M_s = m \cdot g \cdot (L_z + h) \]
\[ \frac{\Delta M_s}{M_s} + \frac{\Delta M_r}{M_r} + \frac{\Delta M_w}{M_w} \leq 1 \]

\[ \Delta M_s = m \cdot g \cdot (L_z + h) \]
\[ \frac{\Delta M_s}{M_s} + \frac{\Delta M_r}{M_r} + \frac{\Delta M_w}{M_w} \leq 1 \]

\[ \Delta M_s = m \cdot g \cdot (L_z + h) \]
\[ \frac{\Delta M_s}{M_s} + \frac{\Delta M_r}{M_r} + \frac{\Delta M_w}{M_w} \leq 1 \]

The linear guide of the linear slide is designed with an expected life of 5000 km. However, when the load factor of the load moment for the calculated dynamic permissible moment is one or more, the expected life distance is halved. How much of the expected life distance can be checked in the formula below.

Expected life* (km) = Reference value of the service life of each series* \( \times \left( \frac{1}{\frac{\Delta M_s}{M_s} + \frac{\Delta M_r}{M_r} + \frac{\Delta M_w}{M_w}} \right)^{1.5} \)

*Refer to "● Concept of Service Life" on page G-38 for the reference value of the service life of each series.
**EZS Series**

Positioning Distance – Operating Speed, Positioning Distance – Acceleration

- **EZS3D□-K** (Lead 12 mm, 24 VDC)
  - Horizontal Installation
    - Positioning Distance – Operating Speed
      - Maximum Speed by Stroke
        | Stroke [mm] | Max. Speed [mm/s] |
        |------------|-------------------|
        | 50–550     | 600               |
        | 600        | 550               |
        | 650        | 460               |
        | 700        | 400               |
  - Vertical Installation
    - Positioning Distance – Operating Speed
      - Maximum Speed by Stroke
        | Stroke [mm] | Max. Speed [mm/s] |
        |------------|-------------------|
        | 50–550     | 300               |
        | 600        | 270               |
        | 650        | 220               |
        | 700        | 200               |

- **EZS3D□-C** (Lead 12 mm, Single-Phase 100-115 VAC/Single-Phase 200-230 VAC)
  - Horizontal Installation
    - Positioning Distance – Operating Speed
      - Maximum Speed by Stroke
        | Stroke [mm] | Max. Speed [mm/s] |
        |------------|-------------------|
        | 50–550     | 800               |
        | 550        | 650               |
        | 600        | 550               |
        | 650        | 460               |
        | 700        | 400               |
  - Vertical Installation
    - Positioning Distance – Operating Speed
      - Maximum Speed by Stroke
        | Stroke [mm] | Max. Speed [mm/s] |
        |------------|-------------------|
        | 50–550     | 300               |
        | 600        | 270               |
        | 650        | 220               |
        | 700        | 200               |

**Positioning Distance – Acceleration**

- Load Mass
  - 0 kg
  - 5 kg
  - 10 kg
  - 15 kg

**EZS3D-□/EZS3D□-C** (Lead 12 mm, Single-Phase 100-115 VAC/Single-Phase 200-230 VAC)
Selection Calculations
Linear and Rotary Actuators

**EZS3E-A/EZS3E-C** (Lead 6 mm, Single-Phase 100-115 VAC/Single-Phase 200-230 VAC)

**Horizontal Installation**

- **Positioning Distance – Operating Speed**

<table>
<thead>
<tr>
<th>Operating Speed [mm/s]</th>
<th>Positioning Distance [mm]</th>
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<tbody>
<tr>
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- **Maximum Speed by Stroke**

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<thead>
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<th>Max. Speed [mm/s]</th>
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- **Positioning Distance – Acceleration**

<table>
<thead>
<tr>
<th>Acceleration [m/s²]</th>
<th>Positioning Distance [mm]</th>
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</table>

**Vertical Installation**

- **Positioning Distance – Operating Speed**

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<thead>
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<th>Operating Speed [mm/s]</th>
<th>Positioning Distance [mm]</th>
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- **Maximum Speed by Stroke**

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<th>Max. Speed [mm/s]</th>
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- **Positioning Distance – Acceleration**

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<th>Acceleration [m/s²]</th>
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**EZS4D-K** (Lead 12 mm, 24 VDC)

**Horizontal Installation**

- **Positioning Distance – Operating Speed**

<table>
<thead>
<tr>
<th>Operating Speed [mm/s]</th>
<th>Positioning Distance [mm]</th>
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- **Maximum Speed by Stroke**

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- **Positioning Distance – Acceleration**

<table>
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<th>Acceleration [m/s²]</th>
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**Vertical Installation**

- **Positioning Distance – Operating Speed**

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<th>Operating Speed [mm/s]</th>
<th>Positioning Distance [mm]</th>
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</table>

- **Positioning Distance – Acceleration**

<table>
<thead>
<tr>
<th>Acceleration [m/s²]</th>
<th>Positioning Distance [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>100</td>
</tr>
<tr>
<td>10</td>
<td>50</td>
</tr>
<tr>
<td>8</td>
<td>30</td>
</tr>
<tr>
<td>6</td>
<td>20</td>
</tr>
<tr>
<td>4</td>
<td>10</td>
</tr>
<tr>
<td>2</td>
<td>5</td>
</tr>
</tbody>
</table>

*ORIENTAL MOTOR GENERAL CATALOG 2012/2013*
**EZS4E-K (Lead 6 mm, 24 VDC)**

- **Horizontal Installation**
  - Positioning Distance – Operating Speed
  - Maximum Speed by Stroke
    | Stroke [mm] | Max. Speed [mm/s] |
    |------------|------------------|
    | 50–550     | 300              |
    | 600        | 270              |
    | 650        | 220              |
    | 700        | 200              |

- **Vertical Installation**
  - Positioning Distance – Operating Speed
  - Maximum Speed by Stroke
    | Stroke [mm] | Max. Speed [mm/s] |
    |------------|------------------|
    | 50–550     | 300              |
    | 600        | 270              |
    | 650        | 220              |
    | 700        | 200              |

**EZS4D-A/EZS4E-C (Lead 12 mm, Single-Phase 100-115 VAC/Single-Phase 200-230 VAC)**

- **Horizontal Installation**
  - Positioning Distance – Operating Speed
  - Maximum Speed by Stroke
    | Stroke [mm] | Max. Speed [mm/s] |
    |------------|------------------|
    | 50–550     | 800              |
    | 600        | 650              |
    | 650        | 550              |
    | 700        | 460              |

- **Vertical Installation**
  - Positioning Distance – Operating Speed
  - Maximum Speed by Stroke
    | Stroke [mm] | Max. Speed [mm/s] |
    |------------|------------------|
    | 50–550     | 800              |
    | 600        | 650              |
    | 650        | 550              |
    | 700        | 460              |

**EZS4E-A/EZS4E-C (Lead 6 mm, Single-Phase 100-115 VAC/Single-Phase 200-230 VAC)**

- **Horizontal Installation**
  - Positioning Distance – Operating Speed
  - Maximum Speed by Stroke
    | Stroke [mm] | Max. Speed [mm/s] |
    |------------|------------------|
    | 50–550     | 400              |
    | 550        | 320              |
    | 600        | 270              |
    | 650        | 220              |
    | 700        | 200              |
### Selection Calculations
#### Linear and Rotary Actuators

**ORIENTAL MOTOR GENERAL CATALOG**

**EZS6E**
- **K** (Lead 6 mm, 24 VDC)

**Horizontal Installation**
- Positioning Distance – Operating Speed

<table>
<thead>
<tr>
<th>Positioning Distance [mm]</th>
<th>Operating Speed [mm/s]</th>
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</thead>
<tbody>
<tr>
<td>50–650</td>
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<td>700</td>
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<tr>
<td>800</td>
<td>200</td>
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<tr>
<td>850</td>
<td>180</td>
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**Vertical Installation**
- Positioning Distance – Operating Speed

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<tbody>
<tr>
<td>100</td>
<td>10.0</td>
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<tr>
<td>200</td>
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**EZS6D**
- **K** (Lead 12 mm, 24 VDC)

**Horizontal Installation**
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- Positioning Distance – Operating Speed

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<tr>
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<td>4.0</td>
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</tbody>
</table>
**EZS6D-A/EZS6D-C** (Lead 12 mm, Single-Phase 100-115 VAC/Single-Phase 200-230 VAC)

**Horizontal Installation**

- Positioning Distance – Operating Speed

- Positioning Distance – Acceleration

**Vertical Installation**

- Positioning Distance – Operating Speed

- Positioning Distance – Acceleration

**EZS6E-A/EZS6E-C** (Lead 6 mm, Single-Phase 100-115 VAC/Single-Phase 200-230 VAC)

**Horizontal Installation**

- Positioning Distance – Operating Speed

- Positioning Distance – Acceleration

**Vertical Installation**

- Positioning Distance – Operating Speed

- Positioning Distance – Acceleration

**EZCII Series**

Positioning Distance-Operating Speed, Positioning Distance-Acceleration

Refer to pages E-62 to E-69 for the EZCII series.
For Motorized Linear Slides Using Dual Axes Mounting Brackets

The following explains the calculation when using a dual axes mounting bracket dedicated to the EZSII Series. A required dual axes mounting bracket is determined by selecting any biaxial combination of the EZSII Series based on your conditions. Select an optimum combination by using the following the procedure.

Selection Procedure

1. Check your conditions
2. Select the combination of motorized linear slides using the table of transportable mass per acceleration. Once the combination is determined, you can figure out required dual axes mounting bracket.
3. Check the acceleration
4. Check the operating speed
5. Find an acceleration from the table of transportable mass per acceleration, and check a speed of each axis in the speed – transportable mass characteristics graph.
6. Check the positioning time
7. Calculate a positioning time. Check if your preferred positioning time can be met.

Example of Selection

Follow the procedure for selection based on the following conditions.

[Conditions]
Load 3 kg mass in X-Y mounting with 100 mm in 0.5 s.
Moveable range is 500 mm in X-axis and 250 mm in Y-axis.
The center of gravity for load in Y-axis: \((G_1, G_2, G_3) = (45, 20, 25)\)
Power supply voltage: 24 VDC input

(1) Select the Combination of Motorized Linear Slides and Dual Axes Mounting Bracket

Check the combination of motorized linear slides using the "transportable mass per acceleration" table (Refer to page G-27).
Find the maximum absolute value within \(G_1, G_2, G_3\). As the conditions state \(|G_1| = 45\) is the maximum value, check the table for center of gravity conditions of \(30 < |G_n| \leq 50\).
The following combination of linear slides can bear a mass of 3 kg with a 250 mm stroke.

[Combination 1] X-axis: EZS6D  Y-axis: EZS3D
[Combination 2] X-axis: EZS6D  Y-axis: EZS4D

Select [Combination 1] as the smaller product size.

The following products are tentatively selected.
X-axis: EZS6D050-K
Y-axis: EZS3D025-K
EZS6D is tentatively selected for the first axis, and EZS3D for the second. As the second axis stroke is 250 mm, and the combination pattern (Refer to page E-105) is R-type, the required dual axes mounting bracket can be determined as PAB-S6S3R025.
(2) Check the Acceleration of Linear Slides

Check an acceleration value from the "transportable mass per acceleration" table. The maximum acceleration is 2.5 m/s² when a transportable mass is 3 kg.

(3) Check the Speed of Linear Slides

Check the "speed – transportable mass characteristics" graph (Refer to page G-29). Draw a horizontal line for 3 kg mass in Y-axis. The speed at which the acceleration 2.5 m/s² line intersects with the above-mentioned line is the maximum speed (upper limit) for dual axes combined configuration.

X-axis speed: 460 mm/s or less
Y-axis speed: 560 mm/s or less

Speed and acceleration can be increased for the same mass, by replacing the power supply with single-phase 100-115 VAC/single-phase 200-230 VAC and/or by using linear slides with greater size.

(4) Check the Positioning Time

Make a simple calculation of the positioning time to verify if your preferred positioning time can be met. The simple formulas are as follows:

1. Check the operating pattern

$$V_{max} = \sqrt{L \cdot a \times 10^3}$$

$$V_{max} \leq V_s \rightarrow \text{Triangular drive}$$

$$V_{max} > V_s \rightarrow \text{Trapezoidal drive}$$

2. Calculate the positioning time

Triangular drive

$$T = 2 \cdot \frac{V_{max}}{a \times 10^3} \quad \text{or} \quad T = \frac{L}{a \times 10^3} \times 2$$

Trapezoidal drive

$$T = \frac{L}{V_s} + \frac{V_s}{a \times 10^3}$$
## Example of Calculation

Check if the combination on page G-26 can move 100 mm in 0.5 seconds.

### X-Axis: EZS6D050-K

- Conditions
  - Speed: \( V_s : 460 \text{ mm/s} \)
  - Acceleration: \( a : 2.5 \text{ mm/s}^2 \)
  - Positioning distance: \( L : 100 \text{ mm} \)

- Check the operating pattern
  \[ V_{\text{max}} = \sqrt{100 \times 2.5 \times 10^3} \]
  \[ = 500 > V_s \quad \text{Trapezoidal drive} \]

- Calculate the positioning time
  \[ T = \frac{100}{460} + \frac{460}{2.5 \times 10^3} \]
  \[ = 0.401 \text{ s} \]

Calculation revealed that the preferred positioning time can be met.

### Y-Axis: EZS3D025-K

- Conditions
  - Speed: \( V_s : 560 \text{ mm/s} \)
  - Acceleration: \( a : 2.5 \text{ mm/s}^2 \)
  - Positioning distance: \( L : 100 \text{ mm} \)

- Check the operating pattern
  \[ V_{\text{max}} = \sqrt{100 \times 2.5 \times 10^3} \]
  \[ = 500 \leq V_s \quad \text{Triangular drive} \]

- Calculate the positioning time
  \[ T = \frac{2 \times 500}{2.5 \times 10^3} \]
  \[ = 0.400 \text{ s} \]

### Translatable Mass Per Acceleration

#### X-Y Mounting

<table>
<thead>
<tr>
<th>Acceleration [mm/s²]</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>X-Axis: EZS4D</td>
<td>X-Axis: EZS5D</td>
<td>Y-Axis: EZS3D</td>
</tr>
<tr>
<td>1.0 m/s²</td>
<td>2.3</td>
<td>1.9</td>
</tr>
<tr>
<td>2.5 m/s²</td>
<td>1.3</td>
<td>0.9</td>
</tr>
<tr>
<td>5.0 m/s²</td>
<td>0.3</td>
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</tr>
</tbody>
</table>

<table>
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<tr>
<th>Acceleration [mm/s²]</th>
<th></th>
<th></th>
</tr>
</thead>
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<td>7.1</td>
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</table>

#### X-Z Mounting

<table>
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<tr>
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<tbody>
<tr>
<td>X-Axis: EZS4D</td>
<td>X-Axis: EZS5D</td>
<td>Y-Axis: EZS3D</td>
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<tr>
<td>1.0 m/s²</td>
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<td>3.3</td>
</tr>
<tr>
<td>2.5 m/s²</td>
<td>2.1</td>
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<table>
<thead>
<tr>
<th>Acceleration [mm/s²]</th>
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<tr>
<td>1.0 m/s²</td>
<td>3.5</td>
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</tr>
<tr>
<td>2.5 m/s²</td>
<td>3.1</td>
<td>3.1</td>
</tr>
<tr>
<td>5.0 m/s²</td>
<td>2.2</td>
<td>2.2</td>
</tr>
</tbody>
</table>

\( G_n \) represents the distance from table to center of gravity of the load (unit: mm).
Speed – Transportable Mass Characteristics

X-Axis Speed (Common to electromagnetic brake type)*
- 24 VDC

Y-Axis Speed (Common to electromagnetic brake type)
- 24 VDC

Single-Phase 100-115 VAC/Single-Phase 200-230 VAC

For X-axis, the maximum speed read from the graph is limited by the stroke. Check the maximum speed for each stroke in EZSII Series products.

Enter the stroke in the box (□) within the model name.
Z-Axis Speed (Common to electromagnetic brake type)

- 24 VDC
  - EZS3D□(M)-K
  - EZS3D□(M)-C

- Single-Phase 100-115 VAC/Single-Phase 200-230 VAC
  - EZS3D□(M)-A
  - EZS3D□(M)-C

Enter the stroke in the box (□) within the model name.
Motorized Linear Slides and Motorized Cylinders (Obtained by calculations)

The parameters listed below are required when selecting motorized linear slides and motorized cylinders for transferring a load from A to B, as shown below.

The required parameters are as follows:
- Mass of load \( (m) \) or thrust force \( (F) \)
- Positioning distance \( (L) \)
- Positioning time \( (T) \)
- Repetitive positioning accuracy
- Maximum stroke

Among the above parameters, the thrust force and positioning time can be calculated using the formula shown below.

**Calculate the Thrust Force**

The specified maximum thrust force indicates the value when no load is added to the rod, which is operating at a constant speed. In an application where an external force is pushed or pulled, the load is generally mounted to the rod and receives external force. The method to check the thrust force in this application is explained below:

1. Calculate the required thrust force when accelerating the load mounted to the rod.
   \[
   F_a = m \times \{ a + g \times \{ \mu \times \cos \alpha + \sin \alpha \} \}
   \]

2. Calculate the thrust force that allows for pushing or pulling
   \[
   F = F_{\text{max}} - F_a
   \]

If the external force applied to the load is smaller than \( F \), then push-pull motion is enabled.

- \( F_{\text{max}} \): Maximum thrust force of the motorized cylinder [N]
- \( F_a \): Required thrust force during acceleration/deceleration operation [N]
- \( F \): Thrust force that allows for pushing or pulling of external force [N]
- \( m \): Mass of load mounted to the rod [kg]
- \( a \): Acceleration [m/s²]
- \( g \): Gravitational acceleration 9.807 [m/s²]
- \( \mu \): Friction coefficient of the guide supporting the load 0.01
- \( \theta \): Angle formed by the traveling direction and the horizontal plane [deg]

**Calculate the Positioning Time**

1. Check the operating conditions

Check the following conditions:
- Mounting direction, load mass, positioning distance, starting speed, acceleration, operating speed

2. From the above operating conditions, check to see if the drive pattern constitutes a triangular drive or trapezoidal drive. Calculate the maximum speed of triangular drive from the positioning distance, starting speed, acceleration and operating speed. If the calculated maximum speed is equal to or below the operating speed, the operation is considered a triangular drive. If the maximum speed exceeds the operating speed, the operation is considered a trapezoidal drive.

   \[
   V_{\text{trapezoidal}} = \sqrt{\frac{2 \times a \times a \times L}{a_1 + a_2}} \times 10^3 + V_S^2
   \]

   \[
   V_{\text{triangular}} = V_S \rightarrow \text{Triangular drive}
   \]

   \[
   V_{\text{trapezoidal}} > V_S \rightarrow \text{Trapezoidal drive}
   \]

3. Calculate the positioning time

   **Trapezoidal drive**
   \[
   T = T_1 + T_2 + T_3
   \]
   \[
   = \frac{V_S - V_L}{a_1 \times 10^3} + \frac{V_S - V_L}{a_2 \times 10^3} + \frac{L}{V_S} \left( \frac{a_1 + a_2}{2} \times \frac{(V_L^2 - V_S^2)}{V_S} \right)
   \]

   **Triangular drive**
   \[
   T = T_1 + T_2
   \]
   \[
   = \frac{V_{\text{max}} - V_L}{a_1 \times 10^3} + \frac{V_{\text{max}} - V_L}{a_2 \times 10^3}
   \]

**Other conversion formula is explained below.**

The pulse speed and operating speed can be converted to each other using the formula shown below. Keep the operating speed below the specified maximum speed:

\[
\text{Pulse speed [Hz]} = \frac{\text{Operating speed [mm/s]}}{\text{Resolution [mm]}}
\]

The number of operating pulses and movement can be converted to each other using the formula shown below:

\[
\text{Number of operating pulses [pulses]} = \frac{\text{Movement [mm]}}{\text{Resolution [mm]}}
\]

The acceleration/deceleration rate and acceleration can be converted to each other using the formula shown below:

\[
\text{Acceleration/deceleration rate [ms/kHz]} = \frac{\text{Resolution [mm] \times 10^3}}{\text{Acceleration [m/s²]}}
\]
Compact Linear Actuators (DRL Series)

The parameters listed below are required when selecting compact linear actuators for transferring a load from A to B, as shown below.

The required parameters are as follows:
• Mass of load \( (m) \) or thrust force \( (F) \)
• Positioning distance \( (L) \)
• Positioning time \( (T) \)

Among the above parameters, the thrust force and positioning time can be calculated using the formula shown below.

Calculate the Thrust Force

The specified maximum thrust force indicates the value when no load is added to the screw shaft, which is operating at a constant speed.

In an application where an external force is pushed or pulled, the load is generally mounted to the rod receives and external force. The method to check the thrust force in this application is explained below:

1. Calculate the required thrust force when accelerating the load
   \[ F_a = m \times \left[a + g \times \left(\mu \cos \alpha + \sin \alpha \right)\right] \]

2. Calculate the thrust force that allows for pushing or pulling
   \[ F = F_{\text{max}} - F_a \]

If the external force applied to the load is smaller than \( F \), then push-pull motion is enabled.

\( F_{\text{max}} \): Maximum thrust force of the actuator [N]
\( F_a \): Required thrust force during acceleration/deceleration operation [N]
\( F \): Thrust force that allows for pushing or pulling of external force [N]
\( m \): Mass of load [kg]
\( a \): Acceleration [m/s²]
\( g \): Gravitational acceleration 9.807 [m/s²]
\( \mu \): Friction coefficient of the guide supporting the load 0.01
\( \alpha \): Angle formed by the traveling direction and the horizontal plane [deg]

Calculate thePositioning Time

Check to see if the actuators can perform the specified positioning within the specified time. This can be checked by determining a rough positioning time from a graph or by obtaining a fairly accurate positioning time by calculation. The respective check procedures are explained below.

The obtained positioning time should be used only as a reference, since there is always a small margin of error with respect to the actual operation time.

Obtaining from a Graph

(Example) Position a 5 kg load over a distance of 20 mm within 1.0 second via vertical drive, using DRL42PB2-04G (tentative selection).

Check line ① on the DRL42 graph.

The above graph shows that the load can be positioned over 20 mm within 1.0 second.

Obtaining by Calculations

1. Check the operating conditions
   Check the following conditions:
   Mounting direction, load mass, positioning distance, starting speed, acceleration, operating speed

2. From the above operating conditions, check to see if the drive pattern constitutes a triangular drive or trapezoidal drive.
   Calculate the maximum speed of triangular drive from the positioning distance, starting speed, acceleration and operating speed. If the calculated maximum speed is equal to or below the operating speed, the operation is considered a triangular drive. If the maximum speed exceeds the operating speed, the operation is considered a trapezoidal drive.

\[ V_{\text{max}} = \sqrt{\frac{2 \times a \times a \times L}{a + a} \times 10^3 + V_s^2} \]

\( V_{\text{max}} \leq V_s \) → Triangular drive

\( V_{\text{max}} > V_s \) → Trapezoidal drive

3. Calculate the positioning time
   Trapezoidal drive
   \[ T = T_1 + T_2 + T_3 \]
   \[ = \frac{V_s - V_1}{a_1 \times 10^3} + \frac{V_s - V_2}{a_2 \times 10^3} + \frac{L}{V_s} - \frac{(a_1 + a_2) \times (V_s^2 - V_1^2)}{2 \times a_1 \times a_2 \times V_s \times 10^3} \]

   Triangular drive
   \[ T = T_1 + T_2 \]
   \[ = \frac{V_{\text{max}} - V_1}{a_1 \times 10^3} + \frac{V_{\text{max}} - V_2}{a_2 \times 10^3} \]
The following sections describe the selection calculations for the DG Series actuators.

1. Calculate the Inertia Load Inertia

Use less than 30 times the actuator inertia as a reference for the inertia of the load.

2. Determine the Positioning Angle

3. If there is no friction torque, check the positioning time from the load inertia – positioning time graph. Refer to page E-136 for the load inertia – positioning time graph.

4. Determine the positioning time and acceleration/deceleration time.

However, make sure that:
- Positioning time $\geq$ shortest positioning time identified from the load inertia – positioning time graph
- Acceleration/deceleration time $n \times s \leq s$ positioning time

5. Determine the starting speed $N_s$, and calculate the operating speed $N_o$ using the following formula. Set $N_0$ to a low speed [0 to several r/min] but be careful not to increase it more than necessary.

$$N_o = \frac{\theta \times 6N_s}{6 \left( t - n \right)}$$

- $N_o$: Operating speed [r/min]
- $\theta$: Positioning angle [deg]
- $N_s$: Starting speed [r/min]
- $t$: Positioning time [s]
- $n$: Acceleration (deceleration) time [s]

If you cannot achieve $N_s \leq N_0 \leq 200$ [r/min] with the above formula, return to 4 and review the conditions.

6. Calculate the acceleration torque using the following formula.

$$T_a [N \cdot m] = (J_t + J_o) \times \frac{\pi}{30} \times \left( \frac{N_o \times N_s}{n} \right)$$

- $J_t$: Inertia of actuator [kg·m²]
- $J_o$: Total inertia [kg·m²]
- $N_o$: Operating speed [r/min]
- $N_s$: Starting speed [r/min]
- $n$: Acceleration (deceleration) time [s]

Use the following formula to convert the speed into a pulse speed.

$$f [Hz] = \frac{6N}{\theta}$$

- $f$: Pulse speed [Hz]
- $N$: Speed [r/min]
- $\theta$: Output table step angle [deg/step]

7. Calculate the required torque. The required torque is equal to the load torque due to friction resistance plus the acceleration torque due to inertia, multiplied by the safety factor.

$$T = (T_L + T_a) \times \text{safety factor}$$

Set the safety factor $s$ to at least 1.5.

8. Check whether the required torque $T$ falls within the speed – torque characteristics. If the required torque does not fall within the range, return to 4 to change the conditions, and recalculate the value.
### Selection Calculations

For Cooling Fans

#### Selection Procedure

This section describes basic methods of selecting typical ventilation and cooling products based on their use.

- **Specifications and Conditions of the Machinery**
  Determine the required internal temperature of the machinery.

- **Heat Generation Within the Device**
  Determine the amount of heat generated internally by the machinery.

- **Calculate Required Air Flow**
  Calculate the air flow required once you have determined the heat generation, the number of degrees the temperature must be lowered and what the ambient temperature should be.

- **Selecting a Fan**
  Select a fan using the required air flow. The air flow of a mounted fan can be found from the air flow – static pressure characteristics and the pressure loss of the machinery. It is difficult to calculate the pressure loss of the machinery, so a fan with a maximum air flow of 1.3 to 2 times as the required air flow may be used.

#### Selection Procedure

Determine the requirements of the machinery
Determine how many degrees to lower the internal temperature based on the guaranteed operating temperatures of the internal components and elements of the machinery.

Calculate the amount of heat produced
Calculate the amount of heat generated internally from the input/output of the machinery, efficiency, etc.

Calculate the required air flow
Calculate the air flow required for desired temperature.

Select a fan
Select a fan with a maximum air flow of 1.3 to 2 times as the required air flow.

#### Fan Selection Procedure

#### Example of Selection – Ventilation and Cooling of Control Box

**Specification of Control Box**

<table>
<thead>
<tr>
<th>Item</th>
<th>Letter</th>
<th>Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size</td>
<td>W</td>
<td>Width 700 mm</td>
</tr>
<tr>
<td></td>
<td>H</td>
<td>Height 1000 mm</td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>Depth 400 mm</td>
</tr>
<tr>
<td>Surface Area</td>
<td>S</td>
<td>2.37 m²</td>
</tr>
<tr>
<td>Material</td>
<td></td>
<td>SPCC</td>
</tr>
<tr>
<td>Permissible Temperature Rise</td>
<td>ΔT</td>
<td>20˚C</td>
</tr>
<tr>
<td>Ambient temperature T₁: 25˚C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Internal permissible temperature T₂: 45˚C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Heat Generation</td>
<td>Q</td>
<td>450 W</td>
</tr>
<tr>
<td>Power Supply</td>
<td></td>
<td>60 Hz 115 VAC</td>
</tr>
</tbody>
</table>

**Example of Selection**

Calculating by formula:

\[
 V = \frac{1}{20} \times (Q + \Delta T U S S') = \frac{1}{20} \times (450 + 20 \times 5 \times 2.37) \times 2 = 1.07 \text{ m}^3/\text{min}
\]

Internal pressure loss must be considered when calculating the required air flow.

In general, pressure loss inside the control box is not known. Therefore, the air flow at the operation point is assumed as 50% of the maximum air flow and a safety factor \( S' = 2 \) is applied.

Calculating by a graph:

- Draw a line parallel with the horizontal axis from point A.
- Draw a line perpendicular to the horizontal axis from point B.
- Required air flow is approximately 0.5 m³/min.

**Obtaining by Calculations**

**Obtaining by a Graph**

1. Search for the cross point A between heat generation \( Q \) (450 W) and permissible temperature rise \( \Delta T \) (20˚C).
2. Draw a line parallel with the horizontal axis from point A.
3. Search for the cross point B between the parallel line and surface area \( S \) (2.37 m²) line.
4. Draw a line perpendicular to the horizontal axis from point B.
5. Required air flow is approximately 0.5 m³/min.
6. Allow for a safety factor \( S' \) of 2 times. Required air flow will be 1.00 m³/min.
Applicable Fans
Based on the above, MU Series MU925M-21 is selected.

**MU925M-21 Specifications**

<table>
<thead>
<tr>
<th>Input Voltage</th>
<th>Frequency</th>
<th>Input</th>
<th>Current</th>
<th>Speed</th>
<th>Max. Air Flow</th>
<th>Max. Static Pressure</th>
<th>Noise Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single-Phase 115 VAC</td>
<td>60 Hz</td>
<td>8 A</td>
<td>0.1</td>
<td>2700 r/min</td>
<td>1 m³/min</td>
<td>44 Pa</td>
<td>38 dB (A)</td>
</tr>
</tbody>
</table>