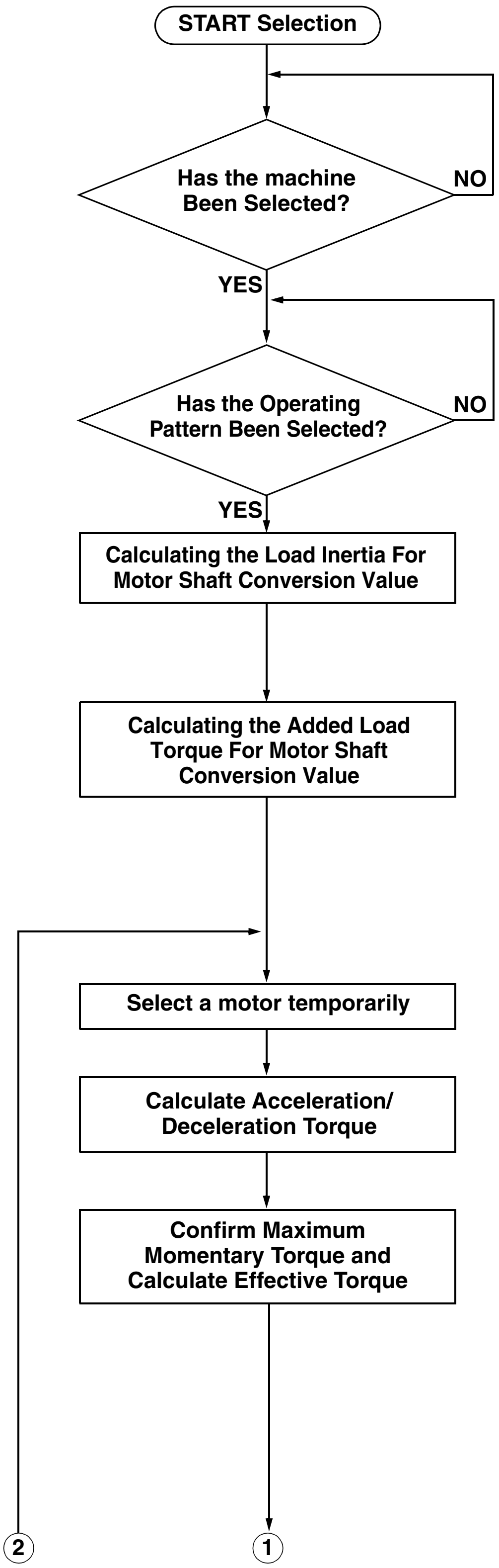
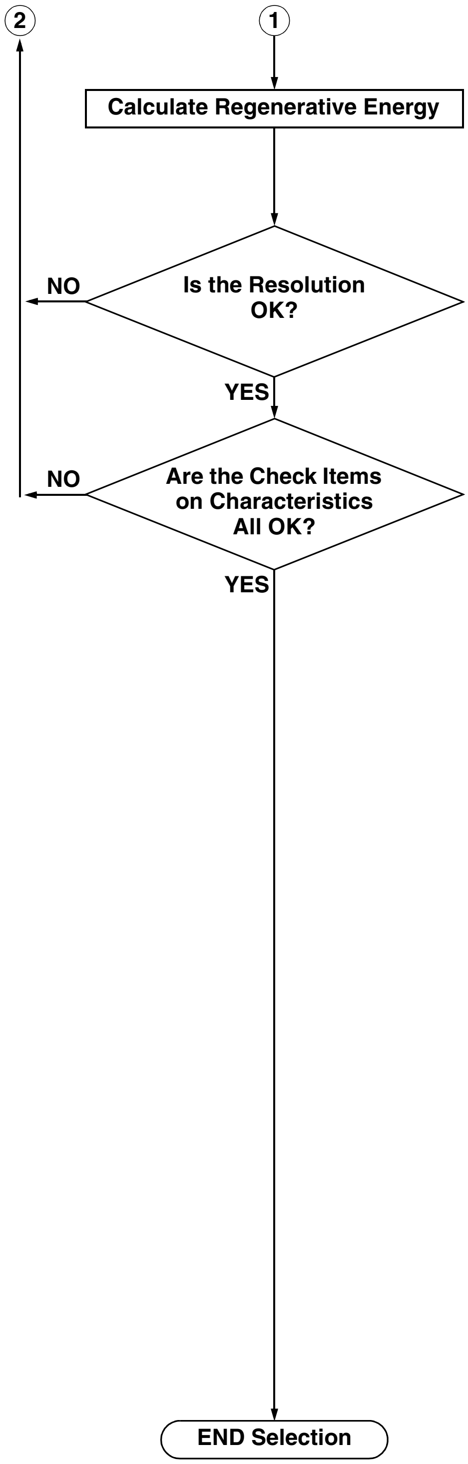
Servo Motor Selection Flow Chart



Explanation	References
• Determine the size, mass, coefficient of friction, and external forces of all the moving part of the Servo Motor the rotation of which affects.	---
• Determine the operating pattern (relationship between time and speed) of each part that must be controlled. • Convert the operating pattern of each controlled element into the motor shaft operating pattern.	• Operation Pattern Formula
• The elements of the machine can be separated so that inertia can be calculated for each part that moves as the Servo Motor rotates. • Calculate the inertia applied to each element to calculate the total load inertia of the motor shaft conversion value.	• Inertia Formulas
• Calculation of Friction Torque Calculates the frictional force for each element, where necessary, and converts it to friction torque for a motor shaft. • Calculation of External Torque Calculates the external force for each element, where necessary, and converts it to external torque of a motor shaft. • Calculates the total load torque for the motor shaft conversion value.	• Load Torque Formulas
• Select a motor temporarily based upon the motor shaft converted load inertia, friction torque, external torque and r.p.m of a motor.	---
• Calculate the Acceleration/Deceleration Torque from the Load Inertia or Operating Pattern.	• Acceleration/Deceleration Torque Formulas
• Calculate the necessary torque for each part of the Operating Pattern from the Friction Torque, External Torque and Acceleration/ Deceleration Torque. • Confirm that the maximum value for the Torque for each operating part (Maximum Momentary Torque) is less than the Maximum Momentary Torque of the motor. • Calculate the Effective Torque from the Torque for each Operating part, and confirm that it is less than the Rated Torque for the motor.	• Calculation of Maximum Momentary Torque, Effective Torque



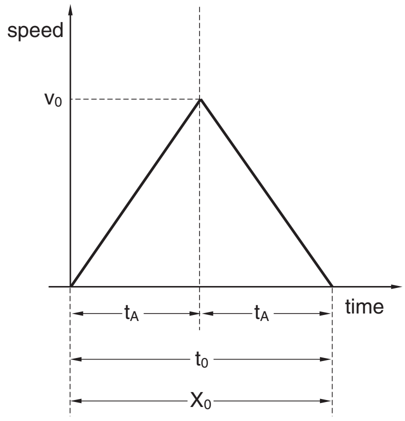
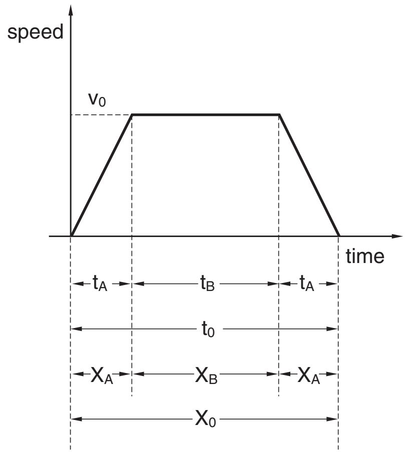
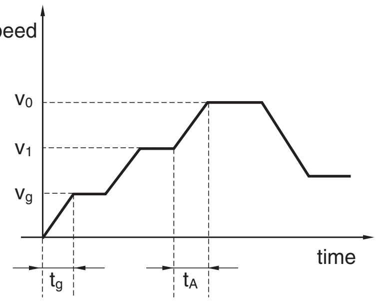
Explanation	References
• Calculate Regenerative Energy from the Torque of all the moving parts.	• Please see the user manual of each product for the details on calculation of the regenerative energy.
• Check if the the number of encoder pulses meets the system specified resolution.	• Accuracy of Positioning
• Check if the calculation meets the specifications of the temporarily selected motor. If not, change the temporarily selected motor and re-calculate it.	• The following table

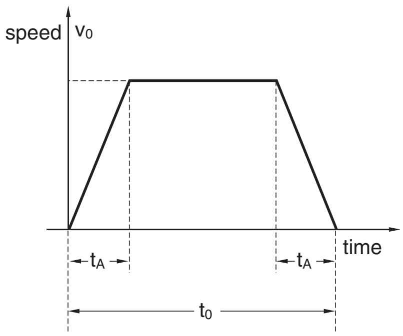
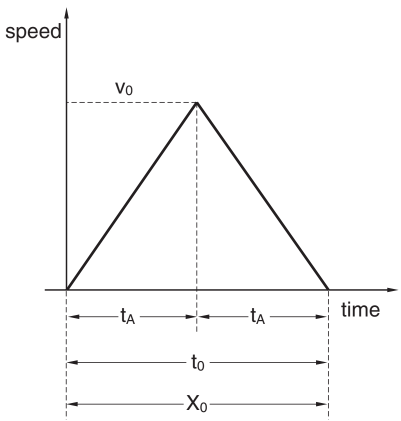
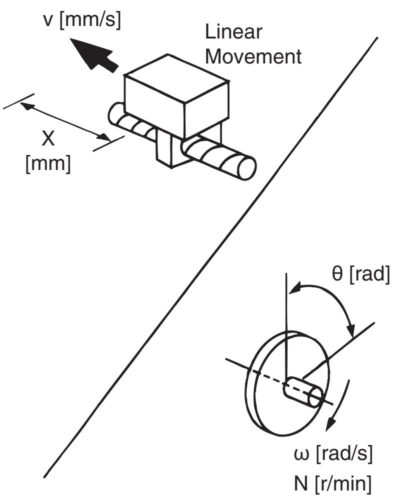
Specialized Check Items	Check Items
Load Inertia	Load Inertia ≤ Motor Rotor Inertia x Applicable Inertia Ratio
Effective Torque	Effective Torque < Motor Rated Torque • Please allow a margin of about 20%. ✻
Maximum Momentary Torque	Maximum Momentary Torque < Motor Maximum Momentary Torque • Please allow a margin of about 20%. ✻ • For the motor Maximum Momentary Torque, use the value that is combined with a driver and the one of the motor itself.
Maximum Rotation Speed	Maximum Rotation Speed ≤ Rated Rotation Speed of a motor • Try to get as close to the motor's rated rotations as possible. It will increase the operating efficiency of a motor. • For the formula, please see "**Straight-line Speed and Motor Rotation Speed**" **on Page 11**.
Regenerative Energy	Regenerative Energy ≤ Regenerative Energy Absorption of a motor • When the Regenerative Energy is large, connect a Regenerative Energy Absorption Resistance to increase the Absorption capacity of the driver.
Encoder Resolution	Ensure that the Encoder Resolution meets the system specifications.
Characteristics of a Positioner	Check if the Pulse Frequency does not exceed the Maximum Response Frequency or Maximum Command Frequency of a Positioner.
Operating Conditions	Ensure that values of the ambient operating temperature/ humidity, operating atmosphere, shock and vibrations meet the product specifications.

✻ When handling vertical loads and a load affected by the external torque, allow for about 30% of capacity.

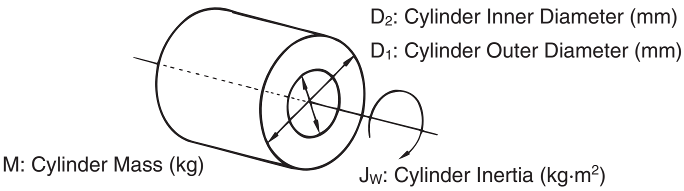
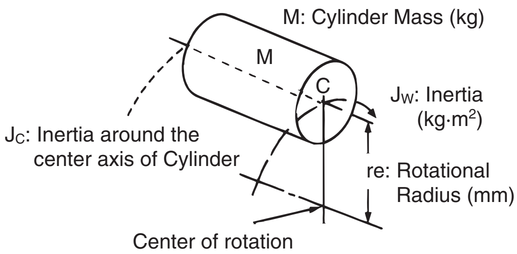
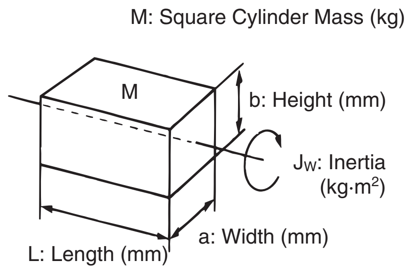
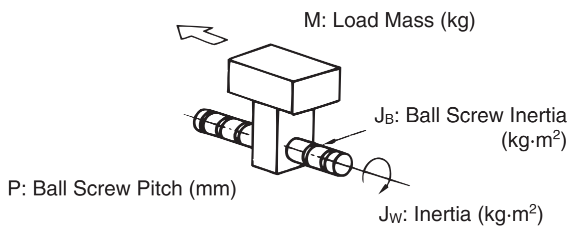
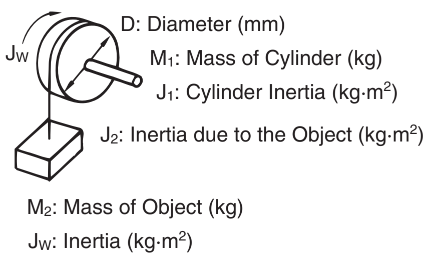
Formulas

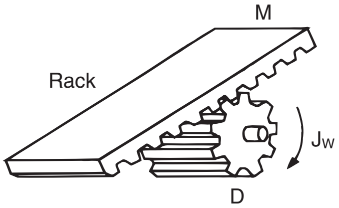
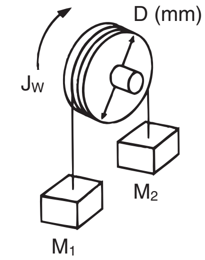
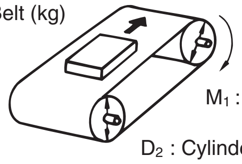
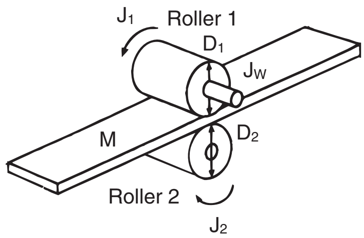
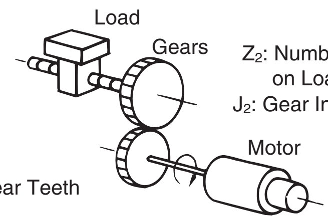
■Formulas for Operating Patterns

Triangular		**Maximum Speed** $v_0 = \frac{X_0}{t_A}$ **Acceleration/Deceleration Time** $t_A = \frac{X_0}{v_0}$ **Travel Distance** $X_0 = v_0 \cdot t_A$ X_0: Distance Moved in t_0 Time (mm) v_0: Maximum Speed (mm/s) t_0: Positioning Time (s) t_A: Acceleration/ Deceleration Time (s)
Trapezoid		**Maximum Speed** $v_0 = \frac{X_0}{t_0 - t_A}$ **Acceleration/Deceleration Time** $t_A = t_0 - \frac{X_0}{v_0}$ **Total Travel Time** $t_0 = t_A + \frac{X_0}{v_0}$ **Constant-velocity travel time** $t_B = t_0 - 2 \cdot t_A = 2\ \frac{2 \cdot X_0}{v_0} - t_0 = \frac{X_0}{v_0} - t$ **Total Travel Distance** $X_0 = v_0\ (t_0 - t_A)$ **Acceleration/Deceleration Travel Distance** $X_A = \frac{v_0 \cdot t_A}{2} = \frac{v_0 \cdot t_0 - X_0}{2}$ **Constant-velocity travel distance** $X_B = v_0 \cdot t_B = 2 \cdot X_0 - v_0 \cdot t_0$
Speed and Slope When Ascending	Speed Gradient $\alpha = \frac{v_g}{t_g}$	**Ascending Time** $t_A = \frac{v_0 - v_1}{\alpha}$ **Ascending Time (t_A) including distance moved** $X_A = \frac{1}{2}\ \alpha \cdot {t_A}^2 + v_1 \cdot t_A$ $= \frac{1}{2}\ \frac{(v_0 - v_1)^2}{\alpha} + v_1 \cdot t_A$ **Speed after Ascending** $v_0 = v_1 + \alpha \cdot t_A$

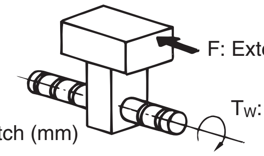
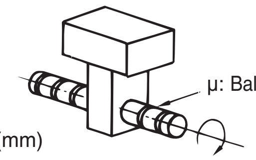
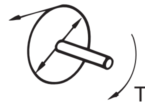
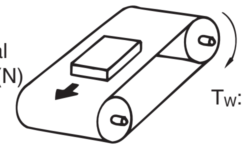
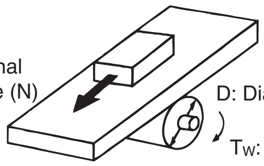
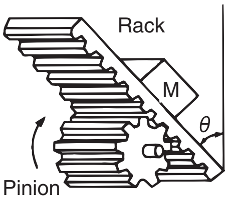
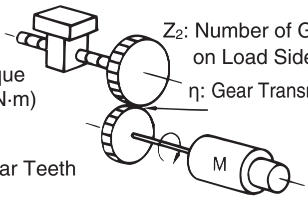
<table>
<tr>
<td>Speed and Slope Trapezoid pattern</td>
<td>
</td>
<td>Conditions for Trapezoidal Operating Pattern
$X_0 < \frac{t_0^2 \cdot \alpha}{4}$
Maximum Speed
$v_0 = \frac{t_0 \cdot \alpha}{2} \left(1 - \sqrt{1 - \frac{4X_0}{t_0 \cdot \alpha}}\right)$
Ascending Time
$t_A = \frac{v_0}{\alpha} = \frac{t_0}{2} \left(1 - \sqrt{1 - \frac{4X_0}{t_0 \cdot \alpha}}\right)$
X_0: Positioning Distance (mm)
t_0: Positioning Time (s)
t_A: Acceleration/Deceleration Time (s)
v_0: Maximum Speed (mm/s)
α: Speed Gradient</td>
</tr>
<tr>
<td>Speed and Slope Triangular Pattern</td>
<td>
</td>
<td>Conditions for Triangular Operating Pattern
$X_0 \geq \frac{t_0^2 \cdot \alpha}{4}$
Maximum Speed
$v_0 = \sqrt{\alpha \cdot X_0}$
Ascending Time
$t_A = \sqrt{\frac{X_0}{\alpha}}$</td>
</tr>
<tr>
<td>Rotating Part</td>
<td>
</td>
<td>Perform the following unitary conversions
<table>
<tr><th>Linear Movement</th><th>Rotating Movement</th></tr>
<tr><td>X: Distance (mm)</td><td>θ: Angle (rad)</td></tr>
<tr><td>v: Speed (mm/s)</td><td>ω: Angular Velocity (rad/s)</td></tr>
</table>
$\left(\omega = \frac{2\pi \cdot N}{60}\right.$
N: Rotating Speed (r/min))</td>
</tr>
</table>

■Inertia Formulas

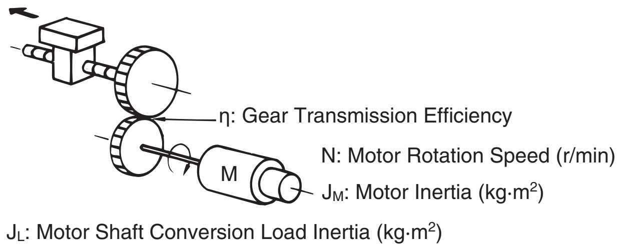
<table>
<tr><td>Cylindrical Inertia</td><td>
</td><td>$J_W = \frac{M(D_1^2 + D_2^2)}{8} \times 10^{-6}\ (kg \cdot m^2)$</td></tr>
<tr><td>Eccentric Disc Inertia (Cylinder which rotates off the center axis)</td><td>
</td><td>$J_W = J_C + M \cdot re^2 \times 10^{-6}\ (kg \cdot m^2)$</td></tr>
<tr><td>Inertia of Rotating Square Cylinder</td><td>
</td><td>$J_W = \frac{M(a^2 + b^2)}{12} \times 10^{-6}\ (kg \cdot m^2)$</td></tr>
<tr><td>Inertia of Linear Movement</td><td>
</td><td>$J_W = M\left(\frac{P}{2\pi}\right)^2 \times 10^{-6} + J_B\ (kg \cdot m^2)$</td></tr>
<tr><td>Inertia of Lifting Object by Pulley</td><td>
</td><td>$J_W = J_1 + J_2$
$= \left(\frac{M_1 \cdot D^2}{8} + \frac{M_2 \cdot D^2}{4}\right) \times 10^{-6}\ (kg \cdot m^2)$</td></tr>
</table>

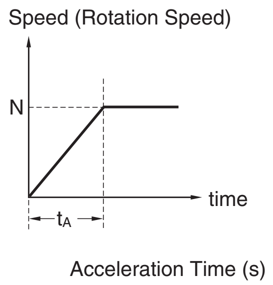
Inertia of Rack and Pinion Movement	 J_W: Inertia (kg·m^2) M: Mass (kg) D: Pinion Diameter (mm)	$J_W = \frac{M \cdot D^2}{4} \times 10^{-6}$ (kg·m^2)
Inertia of Suspended Counterbalance	 J_W: Inertia (kg·m^2) M_1: Mass (kg) M_2: Mass (kg)	$J_W = \frac{D^2 (M_1 + M_2)}{4} \times 10^{-6}$ (kg·m^2)
Inertia when Carrying Object via Conveyor Belt	M_3 : Mass of Object (kg) M_4 : Mass of Belt (kg) D_1 : Cylinder 1 Diameter (mm) J_W: Inertia (kg·m^2) M_1 : Mass of Cylinder 1 (kg)  D_2 : Cylinder 2 Diameter (mm) M_2 : Mass of Cylinder 2 (kg) J_W : Inertia (kg·m^2) J_1 : Cylinder 1 Inertia (kg·m^2) J_2 : Inertia due to Cylinder 2 (kg·m^2) J_3 : Inertia due to the Object (kg·m^2) J_4 : Inertia due to the Belt (kg·m^2)	$J_W = J_1 + J_2 + J_3 + J_4$ $= \left(\frac{M_1 \cdot D_1^2}{8} + \frac{M_2 \cdot D_2^2}{8} \cdot \frac{D_1^2}{D_2^2} + \frac{M_3 \cdot D_1^2}{4} + \frac{M_4 \cdot D_1^2}{4}\right) \times 10^{-6}$ (kg·m^2)
Inertia where Work is Placed between Rollers	J_W : System Inertia (kg·m^2) J_1 : Roller 1 Inertia (kg·m^2) J_2 : Roller 2 Inertia (kg·m^2) D_1 : Roller 1 Diameter (mm) D_2 : Roller 2 Diameter (mm) M : Equivalent Mass of Work (kg)  	$J_W = J_1 + \left(\frac{D_1}{D_2}\right)^2 J_2 + \frac{M \cdot D_1^2}{4} \times 10^{-6}$ (kg·m^2)
Inertia of a Load Value Converted to Motor Shaft	 Z_2: Number of Gear Teeth on Load Side J_2: Gear Inertia on Load Side (kg·m^2) J_W: Load Inertia (kg·m^2) Z_1: Number of Gear Teeth on Motor Side J_1: Gear Inertia on Motor Side (kg·m^2) J_L: Motor Shaft Conversion Load Inertia (kg·m^2) Gear Ratio $G = Z_1/Z_2$	$J_L = J_1 + G^2 (J_2 + J_W)$ (kg·m^2)

■Load Torque Formulas

Torque against external force		$T_W = \frac{F \cdot P}{2\pi} \times 10^{-3}$ (N·m)
Torque against frictional force		$T_W = \mu Mg \cdot \frac{P}{2\pi} \times 10^{-3}$ (N·m)
Torque when external force is applied to a rotating object		$T_W = F \cdot \frac{D}{2} \times 10^{-3}$ (N·m)
Torque of an object on the conveyer belt to which the external force is applied		$T_W = F \cdot \frac{D}{2} \times 10^{-3}$ (N·m)
Torque of an object to which the external force is applied by Rack and Pinion		$T_W = F \cdot \frac{D}{2} \times 10^{-3}$ (N·m)
Torque when work is lifted at an angle.		$T_W = Mg \cdot \cos\theta \cdot \frac{D}{2} \times 10^{-3}$ (N·m)
Torque of a Load Value Converted to Motor Shaft		$T_L = T_W \cdot \frac{G}{\eta}$ (N·m)

■Acceleration/Deceleration Torque Formula





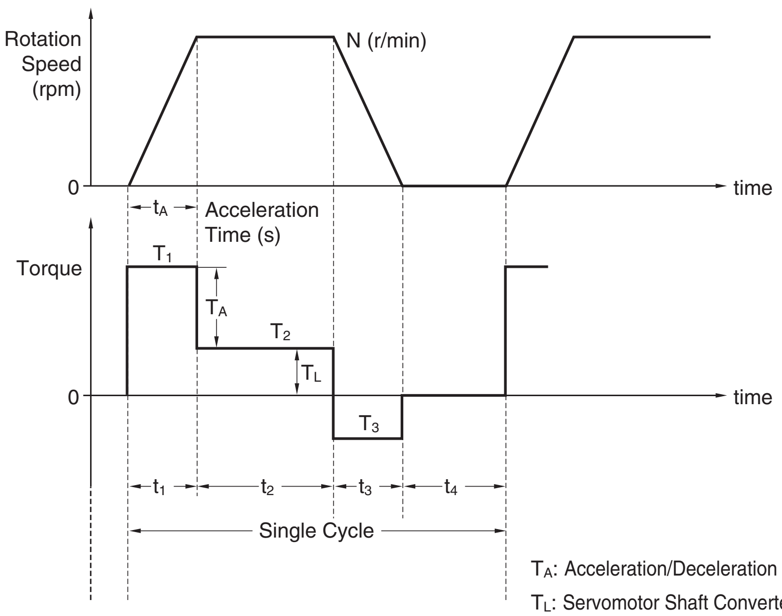
N: Rotation Speed (r/min)

T_A: Acceleration/Deceleration Torque (N·m)

Acceleration/Deceleration Torque (T_A)

$$T_A = \frac{2\pi N}{60 t_A}\left(J_M + \frac{J_L}{\eta}\right) \text{ (N·m)}$$

■Calculation of Maximum Momentary Torque, Effective Torque



T_A: Acceleration/Deceleration Torque (N·m)

T_L: Servomotor Shaft Converted Load Torque (N·m)

T_1: Maximum Momentary Torque (N·m)

Trms: Effective Torque (N·m)

Maximum Momentary Torque (T_1)

$T_1 = T_A + T_L$ (N·m)

Effective Torque (Trms)

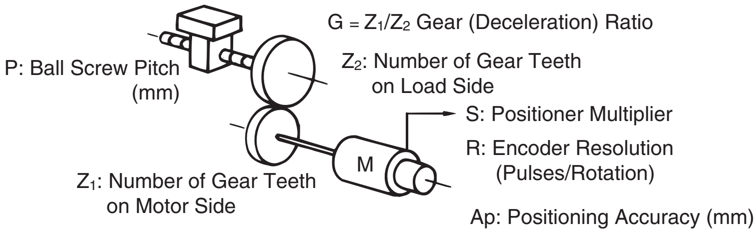
$$\text{Trms} = \sqrt{\frac{T_1^2 \cdot t_1 + T_2^2 \cdot t_2 + T_3^2 \cdot t_3}{t_1 + t_2 + t_3 + t_4}} \text{ (N·m)}$$

$T_2 = T_L$ (N·m)

$T_3 = T_L - T_A$ (N·m)

$t_1 = t_A$ (N·m)

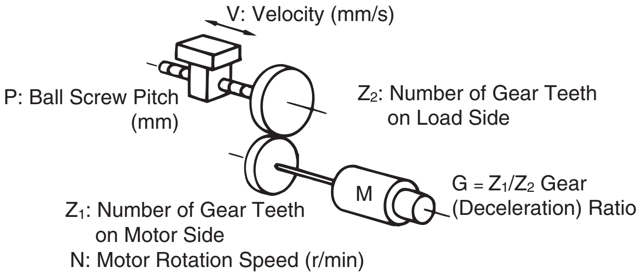
■Positioning Accuracy



Positioning Accuracy (A_P)

$$Ap = \frac{P \cdot G}{R \cdot S} \text{ (mm)}$$

■Straight Line Speed and Motor Rotation Speed



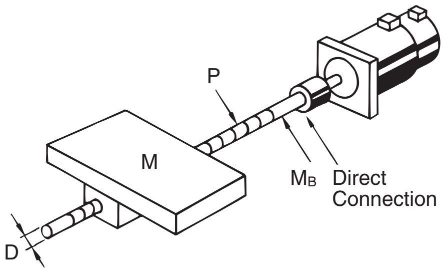
Motor Rotations

$$N = \frac{60V}{P \cdot G} \text{ (r/min)}$$

Sample Calculations

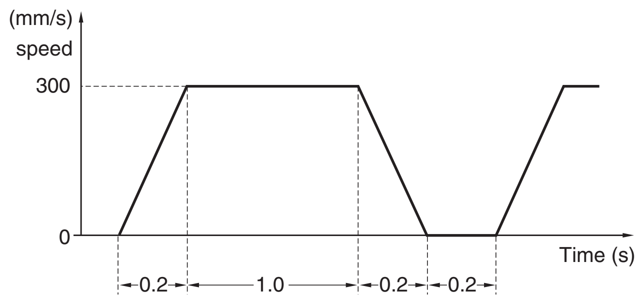
①Machinery Selection

- Load Mass M = 5 (kg)
- Ball Screw Pitch P = 10 (mm)
- Ball Screw Diameter D = 20 (mm)
- Ball Screw Mass M_B = 3 (kg)
- Ball Screw Friction Coefficient $\mu = 0.1$
- Since there is no decelerator, G = 1, $\eta = 1$



②Determining Operating Pattern

- One Speed Change
- Velocity for a Load Travel V = 300 (mm/s)
- Strokes L = 360 (mm)
- Stroke Travel Time tS = 1.4 (s)
- Acceleration/Deceleration Time tA = 0.2 (s)
- Positioning Accuracy AP = 0.01 (mm)



③Calculation of Motor Shaft Conversion Load Inertia

Ball screw Inertia J_B	$J_B = \frac{M_B D^2}{8} \times 10^{-6}$	$J_B = \frac{3 \times 20^2}{8} \times 10^{-6} = 1.5 \times 10^{-4}$ (kg·m²)
Load Inertia J_W	$J_W = M\left(\frac{P}{2\pi}\right)^2 \times 10^{-6} + J_B$	$J_W = 5 \times \left(\frac{10}{2 \times 3.14}\right)^2 \times 10^{-6} + 1.5 \times 10^{-4} = 1.63 \times 10^{-4}$ (kg·m²)
Motor Shaft Conversion Load Inertia J_L	$J_L = G^2 \times (J_W + J_2) + J_1$	$J_L = J_W = 1.63 \times 10^{-4}$ (kg·m²)

④Load Torque Calculation

Torque against Friction Torque T_W	$T_W = \mu Mg \frac{P}{2\pi} \times 10^{-3}$	$T_W = 0.1 \times 5 \times 9.8 \times \frac{10}{2 \times 3.14} \times 10^{-3} = 7.8 \times 10^{-3}$ (N·m)
Motor Shaft Conversion Load Torque T_L	$T_L = \frac{G}{\eta} \cdot T_W$	$T_L = T_W = 7.8 \times 10^{-3}$ (N·m)

⑤Calculation of Rotation Speed

Rotations N	$N = \frac{60V}{P \cdot G}$	$N = \frac{60 \times 300}{10 \times 1} = 1800$ (r/min)

⑥Motor Temporary Selection [In case OMNUC U Series Servo Motor is temporarily selected]

The Rotor/Inertia of the selected servo motor is more than 1/30✻ of a load	$JM \geq \frac{J_L}{30}$	$\frac{J_L}{30} = \frac{1.63 \times 10^{-4}}{30} = 5.43 \times 10^{-6}$ (kg·m²) Temporarily selected Model R88M-U20030 ($J_M = 1.23 \times 10^{-5}$).
80% of the Rated Torque of the selected servo motor is more than the load torque of the servomotor shaft conversion value	$T_M \times 0.8 > T_L$	Rated Torque for R88M – U20030 Model from TM = 0.637 (N·m) $T_M = 0.637$ (N·m) $\times 0.8 > T_L = 7.8 \times 10^{-3}$ (N·m)

✻ Note that this value changes according to the Series.

⑦Calculation of Acceleration/Deceleration Torque

Acceleration/ Deceleration Torque T_A	$T_A = \frac{2\pi \cdot N}{60 t_A}\left(J_M + \frac{J_L}{\eta}\right)$	$T_A = \frac{2\pi \times 1800}{60 \times 0.2} \times \left(1.23 \times 10^{-5} + \frac{1.63 \times 10^{-4}}{1.0}\right) = 0.165$ (N·m)

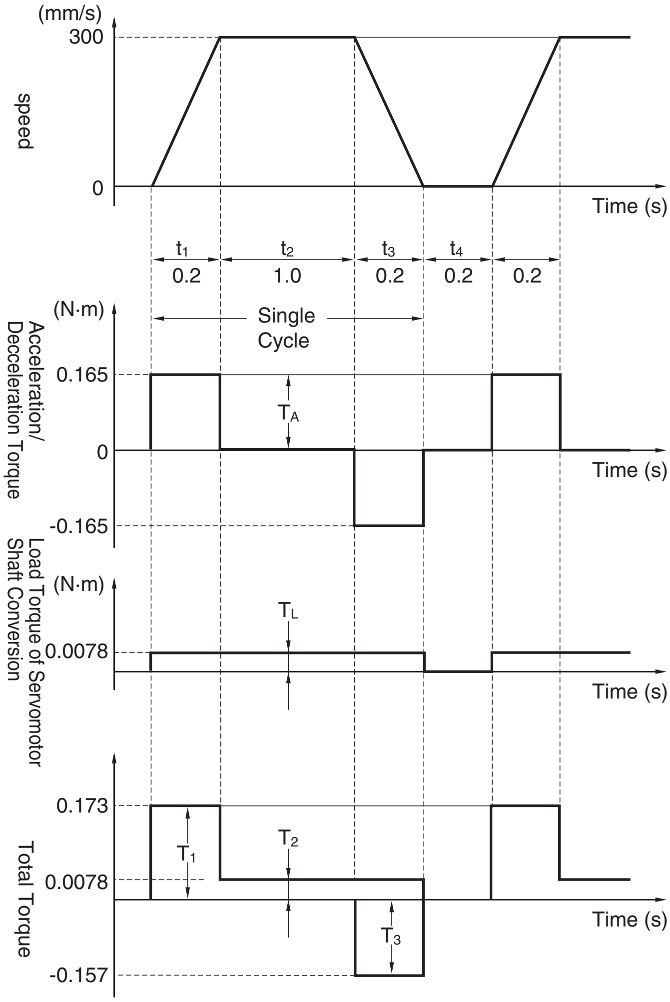
⑧Calculation of Maximum Momentary Torque, Effective Torque

Required Max. Momentary Torque is

$$T_1 = T_A + T_L = 0.165 + 0.0078$$
$$= 0.173 \text{ (N·m)}$$
$$T_2 = T_L = 0.0078 \text{ (N·m)}$$
$$T_3 = T_L - T_A = 0.0078 - 0.165$$
$$= -0.157 \text{ (N·m)}$$

Effective Torque Trms is

$$Trms = \sqrt{\frac{T_1^2 \cdot t_1 + T_2^2 \cdot t_2 + T_3^2 \cdot t_3}{t_1 + t_2 + t_3 + t_4}}$$
$$= \sqrt{\frac{0.173^2 \times 0.2 + 0.0078^2 \times 1.0 + 0.157^2 \times 0.2}{0.2 + 1.0 + 0.2 + 0.2}}$$
$$= 0.0828 \text{ (N·m)}$$



⑨Result of Examination

Load Inertia	**[Load Inertia $J_L = 1.63 \times 10^{-4}$ (kg·m²)] ≤ [Motor Rotor Inertia $J_M = 1.23 \times 10^{-5}$] × [Applied Inertia = 30]**	**Conditions Satisfied**
Effective Torque	**[Effective Torque Trms = 0.0828 (N·m)] < [Servomotor Rated Torque 0.637 (N·m) × 0.8]**	**Conditions Satisfied**
Maximum Momentary Torque	**[Maximum Momentary Torque T_1 = 0.173 N·m < [Servomotor Maximum Momentary Torque 1.91 (N·m) × 0.8]**	**Conditions Satisfied**
Maximum Rotation Speed	**[Maximum Rotations Required N = 1800 (r/min)] ≤ [Servomotor Rated Rotation Speed 3000 (r/min)]**	**Conditions Satisfied**
Encoder Resolution	**The encoder resolution when the positioner multiplication factor is set to 1 is** $R = \frac{P \cdot G}{Ap \cdot S} = \frac{10 \times 1}{0.01 \times 1} = 1000$ (Pulses/Rotations) **The encoder specification of U Series 2048 (pulses/rotation) should be set 1000 with the Encoder Dividing Rate Setting.**	**Conditions Satisfied**

Note. This example omits calculations for the regenerative energy, operating conditions, or positioner characteristics.