Servo Motor Selection Flow Chart

START Selection

Has the machine Been Selected? — NO

YES

Has the Operating Pattern Been Selected? — NO

YES

Calculating the Load Inertia For Motor Shaft Conversion Value

Calculating the Added Load Torque For Motor Shaft Conversion Value

Select a motor temporarily

Calculate Acceleration/ Deceleration Torque

Confirm Maximum Momentary Torque and Calculate Effective Torque

2   1

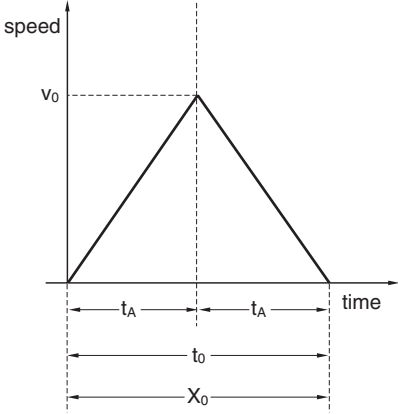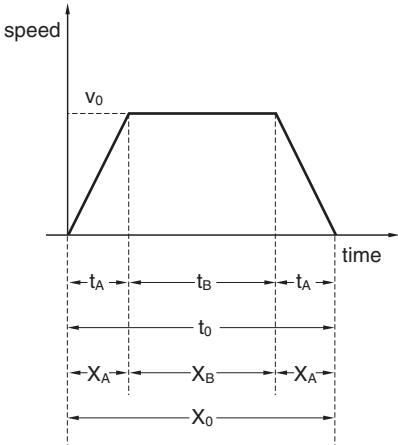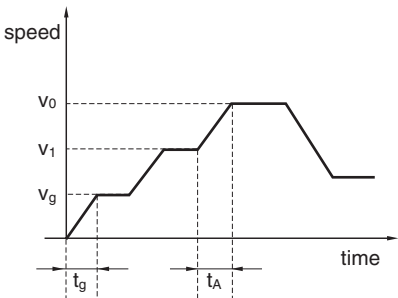| Explanation	References
• Determine the size, mass, coefficient of friction, and external forces of all the moving part of the Servo Motor the rotation of which affects.	---
• Determine the operating pattern (relationship between time and speed) of each part that must be controlled. • Convert the operating 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

② ①

Calculate Regenerative Energy

Is the Resolution OK?	NO →	

YES

Are the Check Items on Characteristics All OK?	NO →	

YES

END Selection

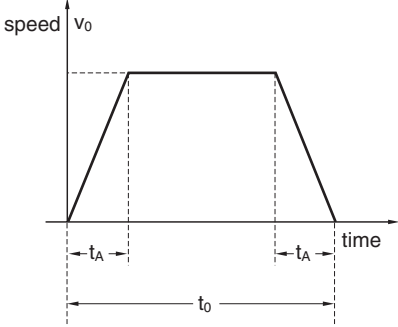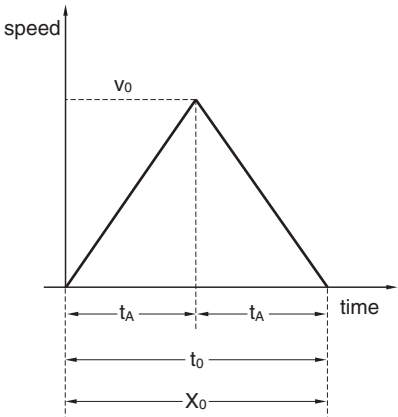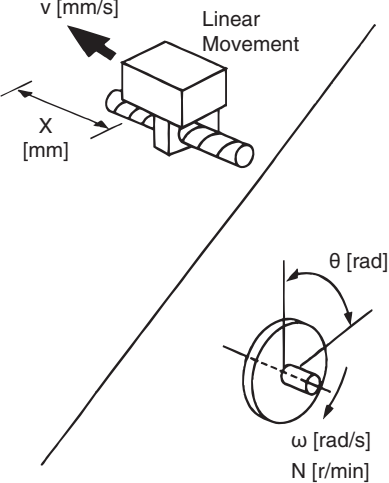| Explanation	References
• Calculate Regenerative Energy from the Torque of all the moving parts.	• Please see the user manual of each product for the details on calculation of the regenerative energy.
• Check if the the number of encoder pulses meets the system specified resolution.	• Accuracy of Positioning
• 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.
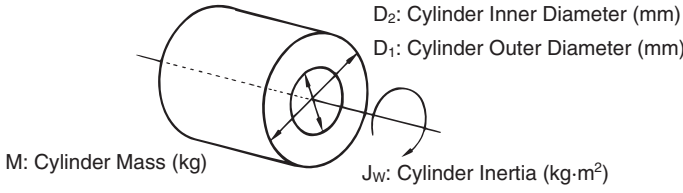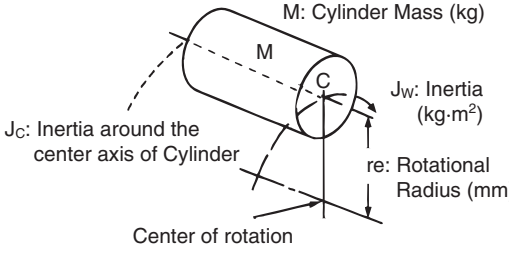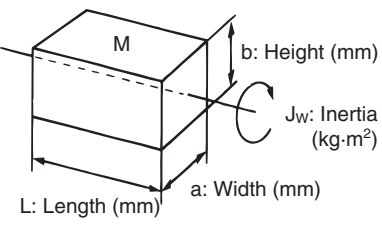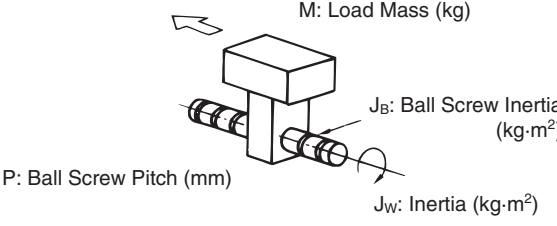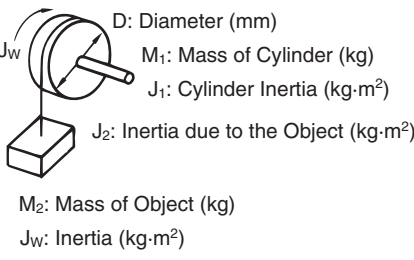
Formulas
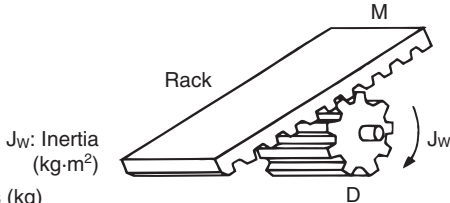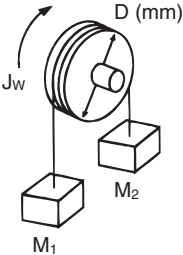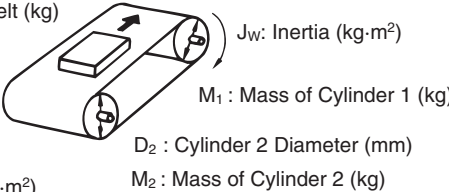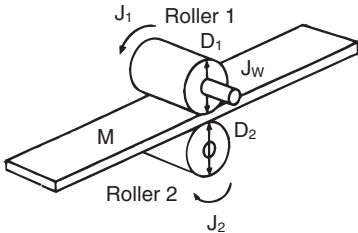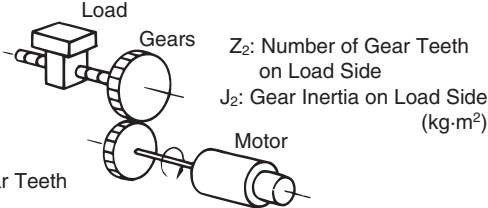
■Formulas for Operating Patterns

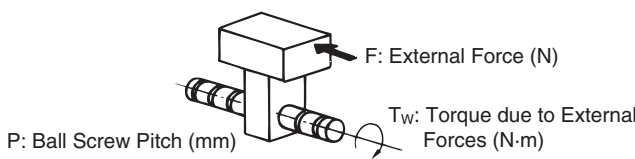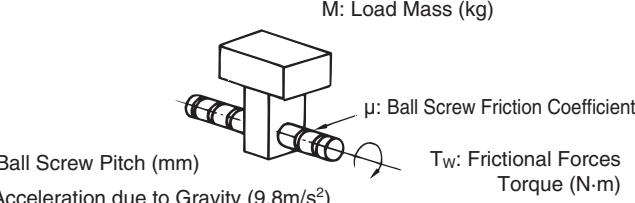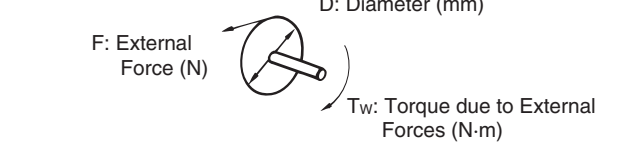|		
Triangular		**Maximum Speed** $v_0 = \dfrac{X_0}{t_A}$ X_0: Distance Moved in t_0 Time (mm) v_0: Maximum Speed (mm/s) **Acceleration/Deceleration Time** $t_A = \dfrac{X_0}{v_0}$ t_0: Positioning Time (s) t_A: Acceleration/ Deceleration Time (s) **Travel Distance** $X_0 = v_0 \cdot t_A$
Trapezoid		**Maximum Speed** $v_0 = \dfrac{X_0}{t_0 - t_A}$ **Acceleration/Deceleration Time** $t_A = t_0 - \dfrac{X_0}{v_0}$ **Total Travel Time** $t_0 = t_A + \dfrac{X_0}{v_0}$ **Constant-velocity travel time** $t_B = t_0 - 2 \cdot t_A = 2\,\dfrac{2 \cdot X_0}{v_0} - t_0 = \dfrac{X_0}{v_0} - t_A$ **Total Travel Distance** $X_0 = v_0\,(t_0 - t_A)$ **Acceleration/Deceleration Travel Distance** $X_A = \dfrac{v_0 \cdot t_A}{2} = \dfrac{v_0 \cdot t_0 - X_0}{2}$ **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 $\alpha = \dfrac{v_g}{t_g}$	**Ascending Time** $t_A = \dfrac{v_0 - v_1}{\alpha}$ **Ascending Time (t_A) including distance moved** $X_A = \dfrac{1}{2}\,\alpha \cdot t_A{}^2 + v_1 \cdot t_A$ $\quad\; = \dfrac{1}{2}\,\dfrac{(v_0 - v_1)^2}{\alpha} + v_1 \cdot t_A$ **Speed after Ascending** $v_0 = v_1 + \alpha \cdot t_A$
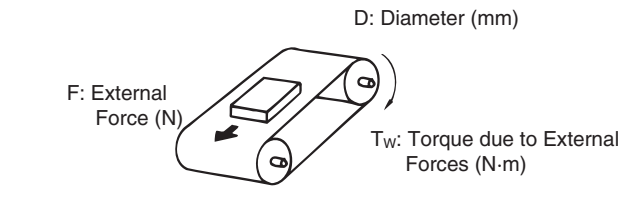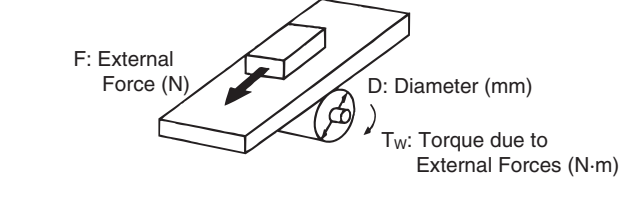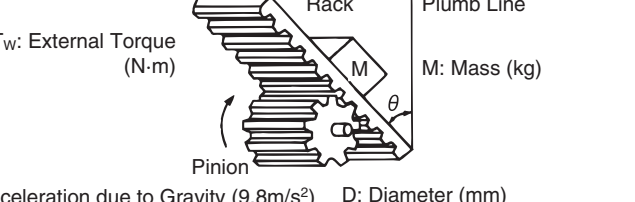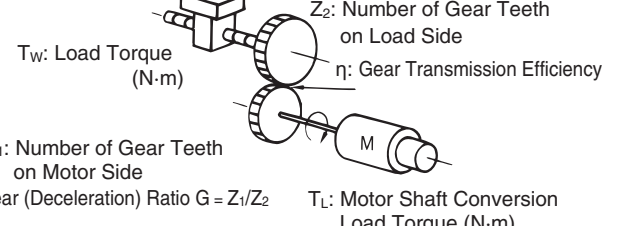
Speed and Slope Trapezoid pattern		**Conditions for Trapezoidal Operating Pattern** $$X_0 < \frac{t_0{}^2 \cdot \alpha}{4}$$ **Maximum Speed** $$v_0 = \frac{t_0 \cdot \alpha}{2}\left(1 - \sqrt{1 - \frac{4X_0}{t_0 \cdot \alpha}}\right)$$ **Ascending Time** $$t_A = \frac{v_0}{\alpha} = \frac{t_0}{2}\left(1 - \sqrt{1 - \frac{4X_0}{t_0 \cdot \alpha}}\right)$$ 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
Speed and Slope Triangular Pattern		**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** $$t_A = \sqrt{\frac{X_0}{\alpha}}$$
Rotating Part		**Perform the following unitary conversions** | Linear Movement	Rotating Movement
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X: Distance (mm)	θ: Angle (rad)
v: Speed (mm/s)	ω: Angular Velocity (rad/s)	 $$\left(\begin{array}{c} \omega = \dfrac{2\pi \cdot N}{60} \\ N\text{: Rotating Speed (r/min)} \end{array}\right)$$

■Inertia Formulas

Cylindrical Inertia	D_2: Cylinder Inner Diameter (mm) D_1: Cylinder Outer Diameter (mm) M: Cylinder Mass (kg) J_W: Cylinder Inertia (kg·m²)	$J_W = \dfrac{M(D_1^2 + D_2^2)}{8} \times 10^{-6}$ (kg·m²)
Eccentric Disc Inertia (Cylinder which rotates off the center axis)	M: Cylinder Mass (kg) J_W: Inertia (kg·m²) J_C: Inertia around the center axis of Cylinder re: Rotational Radius (mm) Center of rotation	$J_W = J_C + M \cdot re^2 \times 10^{-6}$ (kg·m²)
Inertia of Rotating Square Cylinder	M: Square Cylinder Mass (kg) b: Height (mm) J_W: Inertia (kg·m²) L: Length (mm) a: Width (mm)	$J_W = \dfrac{M(a^2 + b^2)}{12} \times 10^{-6}$ (kg·m²)
Inertia of Linear Movement	M: Load Mass (kg) J_B: Ball Screw Inertia (kg·m²) P: Ball Screw Pitch (mm) J_W: Inertia (kg·m²)	$J_W = M \left(\dfrac{P}{2\pi}\right)^2 \times 10^{-6} + J_B$ (kg·m²)
Inertia of Lifting Object by Pulley	J_W D: Diameter (mm) M_1: Mass of Cylinder (kg) J_1: Cylinder Inertia (kg·m²) J_2: Inertia due to the Object (kg·m²) M_2: Mass of Object (kg) J_W: Inertia (kg·m²)	$J_W = J_1 + J_2$ $= \left(\dfrac{M_1 \cdot D^2}{8} + \dfrac{M_2 \cdot D^2}{4}\right) \times 10^{-6}$ (kg·m²)

Inertia of Rack and Pinion Movement	J_W: Inertia (kg·m²) M: Mass (kg) D: Pinion Diameter (mm)	$J_W = \dfrac{M \cdot D^2}{4} \times 10^{-6}$ (kg·m²)
Inertia of Suspended Counterbalance	J_W: Inertia (kg·m²) M_1: Mass (kg) M_2: Mass (kg)	$J_W = \dfrac{D^2 (M_1 + M_2)}{4} \times 10^{-6}$ (kg·m²)
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·m²) M_1 : Mass of Cylinder 1 (kg) D_2 : Cylinder 2 Diameter (mm) M_2 : Mass of Cylinder 2 (kg) J_W : Inertia (kg·m²) J_1 : Cylinder 1 Inertia (kg·m²) J_2 : Inertia due to Cylinder 2 (kg·m²) J_3 : Inertia due to the Object (kg·m²) J_4 : Inertia due to the Belt (kg·m²)	$J_W = J_1 + J_2 + J_3 + J_4$ $= \left(\dfrac{M_1 \cdot D_1^2}{8} + \dfrac{M_2 \cdot D_2^2}{8} \cdot \dfrac{D_1^2}{D_2^2} + \dfrac{M_3 \cdot D_1^2}{4} + \dfrac{M_4 \cdot D_1^2}{4} \right) \times 10^{-6}$ (kg·m²)
Inertia where Work is Placed between Rollers	J_W : System Inertia (kg·m²) J_1 : Roller 1 Inertia (kg·m²) J_2 : Roller 2 Inertia (kg·m²) D_1 : Roller 1 Diameter (mm) D_2 : Roller 2 Diameter (mm) M : Equivalent Mass of Work (kg)	$J_W = J_1 + \left(\dfrac{D_1}{D_2} \right)^2 J_2 + \dfrac{M \cdot D_1^2}{4} \times 10^{-6}$ (kg·m²)
Inertia of a Load Value Converted to Motor Shaft	J_W: Load Inertia (kg·m²) Z_2: Number of Gear Teeth on Load Side J_2: Gear Inertia on Load Side (kg·m²) Z_1: Number of Gear Teeth on Motor Side J_1: Gear Inertia on Motor Side (kg·m²) Gear Ratio G = Z_1/Z_2 J_L: Motor Shaft Conversion Load Inertia (kg·m²)	$J_L = J_1 + G^2 (J_2 + J_W)$ (kg·m²)

■Load Torque Formulas

Torque against external force	F: External Force (N) P: Ball Screw Pitch (mm) T_W: Torque due to External Forces (N·m)	$T_W = \dfrac{F \cdot P}{2\pi} \times 10^{-3}$ (N·m)
Torque against frictional force	M: Load Mass (kg) μ: Ball Screw Friction Coefficient P: Ball Screw Pitch (mm) T_W: Frictional Forces Torque (N·m) g: Acceleration due to Gravity (9.8m/s²)	$T_W = \mu Mg \cdot \dfrac{P}{2\pi} \times 10^{-3}$ (N·m)
Torque when external force is applied to a rotating object	D: Diameter (mm) F: External Force (N) T_W: Torque due to External Forces (N·m)	$T_W = F \cdot \dfrac{D}{2} \times 10^{-3}$ (N·m)
Torque of an object on the conveyer belt to which the external force is applied	D: Diameter (mm) F: External Force (N) T_W: Torque due to External Forces (N·m)	$T_W = F \cdot \dfrac{D}{2} \times 10^{-3}$ (N·m)
Torque of an object to which the external force is applied by Rack and Pinion	F: External Force (N) D: Diameter (mm) T_W: Torque due to External Forces (N·m)	$T_W = F \cdot \dfrac{D}{2} \times 10^{-3}$ (N·m)
Torque when work is lifted at an angle.	Rack Plumb Line T_W: External Torque (N·m) M: Mass (kg) Pinion g: Acceleration due to Gravity (9.8m/s²) D: Diameter (mm)	$T_W = Mg \cdot \cos\theta \cdot \dfrac{D}{2} \times 10^{-3}$ (N·m)
Torque of a Load Value Converted to Motor Shaft	Z_2: Number of Gear Teeth on Load Side T_W: Load Torque (N·m) η: Gear Transmission Efficiency Z_1: Number of Gear Teeth on Motor Side Gear (Deceleration) Ratio $G = Z_1/Z_2$ T_L: Motor Shaft Conversion Load Torque (N·m)	$T_L = T_W \cdot \dfrac{G}{\eta}$ (N·m)

■Acceleration/Deceleration Torque Formula

η: Gear Transmission Efficiency

N: Motor Rotation Speed (r/min)

J_M: Motor Inertia (kg·m²)

J_L: Motor Shaft Conversion Load Inertia (kg·m²)

Speed (Rotation Speed)
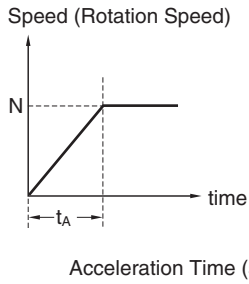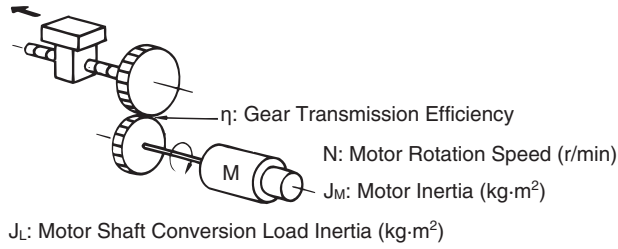
N: Rotation Speed (r/min)

T_A: Acceleration/Deceleration Torque (N·m)

Acceleration Time (s)

Acceleration/Deceleration Torque (T_A)

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

■Calculation of Maximum Momentary Torque, Effective Torque

Rotation Speed (rpm)

N (r/min)

Acceleration Time (s)

Torque

Single Cycle
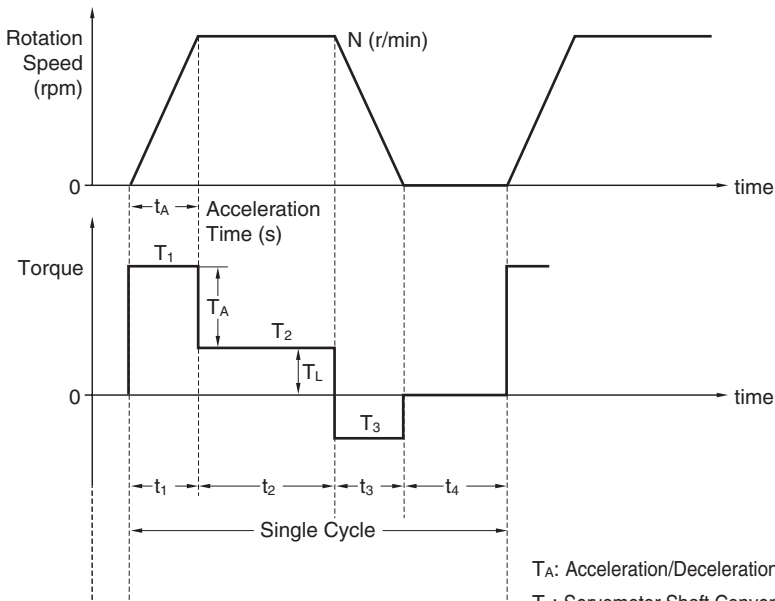
T_A: Acceleration/Deceleration Torque (N·m)

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)

$$T_1 = T_A + T_L \ (N{\cdot}m)$$
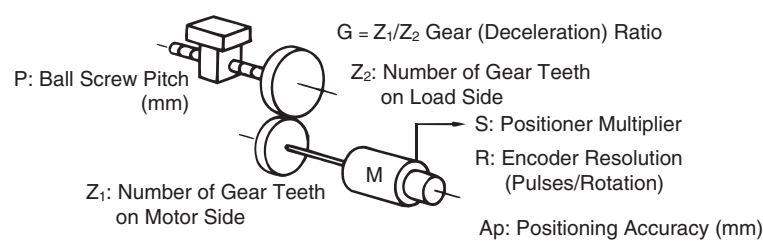
Effective Torque (Trms)

$$Trms = \sqrt{\frac{T_1^2{\cdot}t_1 + T_2^2{\cdot}t_2 + T_3^2{\cdot}t_3}{t_1 + t_2 + t_3 + t_4}}$$

$$(N{\cdot}m)$$
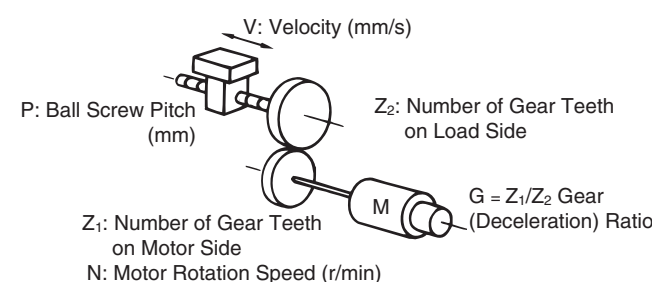
$$T_2 = T_L \ (N{\cdot}m)$$

$$T_3 = T_L - T_A \ (N{\cdot}m)$$

$$t_1 = t_A \ (N{\cdot}m)$$

■Positioning Accuracy

G = Z_1/Z_2 Gear (Deceleration) Ratio

Z_2: Number of Gear Teeth on Load Side

P: Ball Screw Pitch (mm)

S: Positioner Multiplier

R: Encoder Resolution (Pulses/Rotation)

Z_1: Number of Gear Teeth on Motor Side

Ap: Positioning Accuracy (mm)

Positioning Accuracy (A_P)

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

■Straight Line Speed and Motor Rotation Speed

V: Velocity (mm/s)

P: Ball Screw Pitch (mm)

Z_2: Number of Gear Teeth on Load Side

Z_1: Number of Gear Teeth on Motor Side

G = Z_1/Z_2 Gear (Deceleration) Ratio

N: Motor Rotation Speed (r/min)

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 μ = 0.1
- Since there is no decelerator, G = 1, η = 1
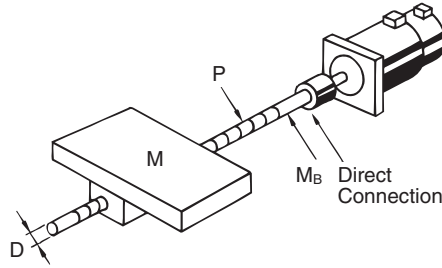
②Determining Operating Pattern

- 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)
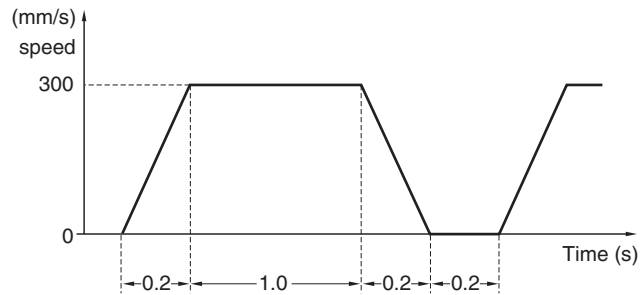
③Calculation of Motor Shaft Conversion Load Inertia

Ball screw Inertia J_B	$J_B = \dfrac{M_B D^2}{8} \times 10^{-6}$	$J_B = \dfrac{3 \times 20^2}{8} \times 10^{-6} = 1.5 \times 10^{-4}$ (kg·m²)
Load Inertia J_W	$J_W = M\left(\dfrac{P}{2\pi}\right)^2 \times 10^{-6} + J_B$	$J_W = 5 \times \left(\dfrac{10}{2 \times 3.14}\right)^2 \times 10^{-6} + 1.5 \times 10^{-4} = 1.63 \times 10^{-4}$ (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	$T_W = \mu M g \dfrac{P}{2\pi} \times 10^{-3}$	$T_W = 0.1 \times 5 \times 9.8 \times \dfrac{10}{2 \times 3.14} \times 10^{-3} = 7.8 \times 10^{-3}$ (N·m)
Motor Shaft Conversion Load Torque T_L	$T_L = \dfrac{G}{\eta} \cdot T_W$	$T_L = T_W = 7.8 \times 10^{-3}$ (N·m)

⑤Calculation of Rotation Speed

Rotations N	$N = \dfrac{60V}{P \cdot G}$	$N = \dfrac{60 \times 300}{10 \times 1} = 1800$ (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	$JM \geq \dfrac{J_L}{30}$	$\dfrac{J_L}{30} = \dfrac{1.63 \times 10^{-4}}{30} = 5.43 \times 10^{-6}$ (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	$T_A = \dfrac{2\pi \cdot N}{60 t_A}\left(J_M + \dfrac{J_L}{\eta}\right)$	$T_A = \dfrac{2\pi \times 1800}{60 \times 0.2} \times \left(1.23 \times 10^{-5} + \dfrac{1.63 \times 10^{-4}}{1.0}\right) = 0.165 \ (\text{N·m})$

⑧Calculation of Maximum Momentary Torque, Effective Torque

Required Max. Momentary Torque is

$T_1 = T_A + T_L = 0.165 + 0.0078$

$\qquad = 0.173 \ (\text{N·m})$

$T_2 = T_L = 0.0078 \ (\text{N·m})$

$T_3 = T_L - T_A = 0.0078 - 0.165$

$\qquad = -0.157 \ (\text{N·m})$

Effective Torque Trms is

$T_{rms} = \sqrt{\dfrac{T_1{}^2 \cdot t_1 + T_2{}^2 \cdot t_2 + T_3{}^2 \cdot t_3}{t_1 + t_2 + t_3 + t_4}}$

$\quad = \sqrt{\dfrac{0.173^2 \times 0.2 + 0.0078^2 \times 1.0 + 0.157^2 \times 0.2}{0.2 + 1.0 + 0.2 + 0.2}}$

$\quad = 0.0828 \ (\text{N·m})$

⑨Result of Examination

Load Inertia	[Load Inertia $J_L = 1.63 \times 10^{-4}$ (kg·m^2)] $\leq$ [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)] $\leq$ [Servomotor Rated Rotation Speed 3000 (r/min)]	Conditions Satisfied
Encoder Resolution	The encoder resolution when the positioner multiplication factor is set to 1 is $R = \dfrac{P \cdot G}{A_P \cdot S} = \dfrac{10 \times 1}{0.01 \times 1} = 1000$ (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.

OMRON

13