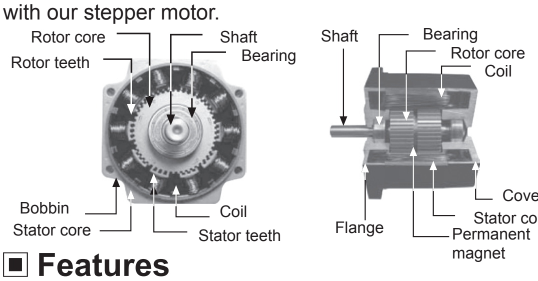
Technical Description

▣ Overview

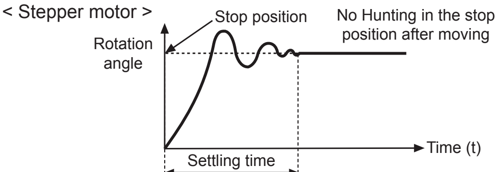
Stepper motor is a high accuracy position control motor which digital control rotating by a set mechanical angle decided by input pulses is available. It is available to control a rotation angle and speed accurately and it has lots of proper applications to be used. We have hybrid stepper motor with high characteristic such as a high accuracy and torque, which is used in a wide range of FA to OA field. Also, we have the driver (MD5/MD2U Series) and controllers (PMC Series) in order to get a high efficiency with our stepper motor.



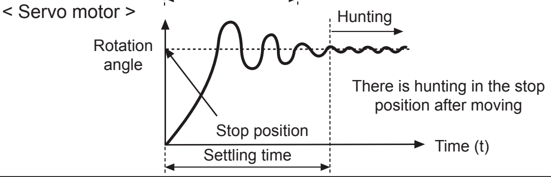
▣ Features

- **It is available to control a rotation angle and speed easily.**
  5-phase stepper motor is available to control the rotation angle and speed easily by electrical pulse (digital) signal as it is the motor rotating by a set mechanical angle decided by input pulse (digital) signal.
- **It is a high torque and response motor.**
  Stepper motor is small & light and can get a high torque. Also, rapid starting/stopping and reversing are available due to rapid acceleration as it has a stopping and starting torque.
- **It is available to control a position in a high resolution and accuracy.**
  Our 5-phase hybrid stepper motor rotates by 0.72°/ pulse and it is a high-resolution motor, which is available to rotate by 0.00288°/pulse when using micro step driver with 250 division. And, it stops in a high accuracy of ±3min (0.05° at non-load) when driving by 0.72°/pulse.
- **It has a self-holding torque.**
  5-phase stepper motor has a high holding torque when stopped in power on.
  Therefore, it is available to hold a stop position without mechanical break or control signal.
- **Settling time is short and there is no hunting status when stopped.**
  Settling time which motor axis is stopped after normal and reverse rotation by load inertia is short when motor is stopped at a stop position. There is no hunting which motor axis is stopped with delicate normal and reverse rotation when holding a stop position after settling time.

< Stepper motor >



< Servo motor >

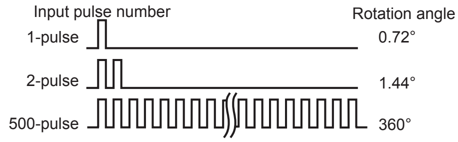


▣ Usage of Stepper Motor

Stepper motor can control a rotation angle and speed easily by number and speed of input pulse as follows.

- Rotation angle control

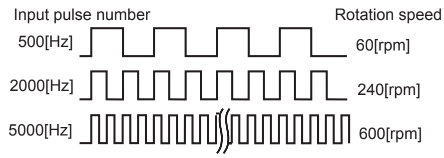
Rotation angle[°]=Step angle[°]×Pulse number



< Full step operation of 5-phase stepper motor (0.72°) >

- Rotation speed control

$$\text{Rotation speed[rpm]} = \frac{\text{Pulse speed[Hz]}}{360°/\text{Stop angle[°]}} \times 60[\text{Sec}]$$



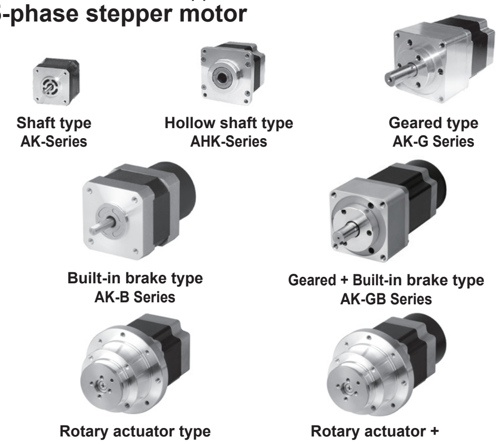
< Full step operation of 5-phase stepper motor (0.72°) >

A driver only for the stepper motor and the controller only for controlling the driver are necessary in order to drive the stepper motor.

- **Stepper motor**

Autonics has various stepper motor to meet customer's needs.

- **5-phase stepper motor**

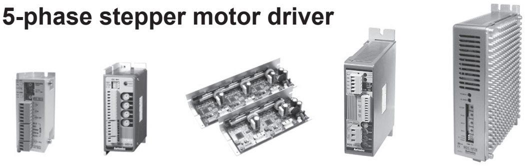


Shaft type AK-Series | **Hollow shaft type AHK-Series** | **Geared type AK-G Series** | **Built-in brake type AK-B Series** | **Geared + Built-in brake type AK-GB Series** | **Rotary actuator type AK-R Series** | **Rotary actuator + Built-in brake type AK-RB Series**

- **Driver**

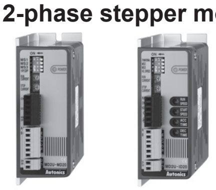
It is an exclusive driving circuit to drive the stepper motor and provides power to the motor in the order of the motor phase. We have the dedicated drivers for stepper motor.

- **5-phase stepper motor driver**



MD5-ND14 | **MD5-HD14** | **MD5-HD14 -2X/3X** | **MD5-HF14** | **MD5-HF28**

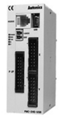
- **2-phase stepper motor driver**



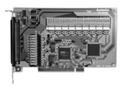
MD2U-MD20 | **MD2U-ID20**

- **Controller**

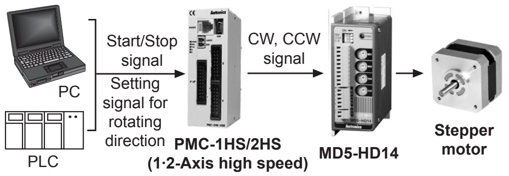
It controls a rotation angle and speed etc. of the stepper motor. We have the dedicated controllers.


PMC-1HS/2HS (1/2-Axis high speed)


PMC-2HSP/2HSN (2-Axis high speed Interpolation Normal)


PMC-4B-PCI (4-Axis board type)

- **Stepper motor driving system**



▣ Micro Step?

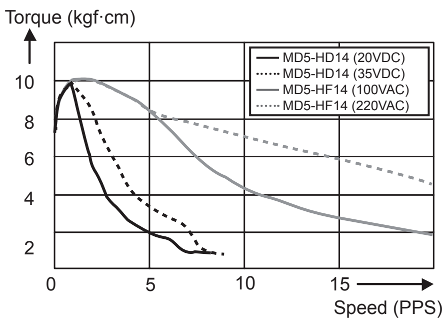
Micro step is a way to divide the basic step angle of the motor into smaller steps by decreasing the current to one phase. Micro step has the better resonance and vibration characteristics. It realizes high-accuracy controlling with smaller step angles divided by controlling coil current.

- Realizing low-speed / low-vibration and low noise driving
- Dividing motor's basic step angle into 250 divisions (0.72° to 0.00288°)

▣ DC Power Driver Vs AC Power Driver

◎ Characteristics

- In case of AC power supply, the higher speed, the better torque characteristics than DC power.
- Under the same driver conditions, the higher the power supply, the better torque characteristics motors can have. Proper safety countermeasures must be ensured when supplying high power supply. It may cause high heat generation.



DC Power Driver		AC Power Driver
• 20 to 35VDC • Relatively low torque characteristics • Simple circuit structure • Cost effective	**VS**	• 100 to 220VAC • High torque characteristics • Relatively complex circuit structure due to AC to DC conversion circuit • Expensive

▣ Failure Diagnosis and Countermeasures

◎ Resonance

The motor may cause resonance within the specific frequency area. Take the measurement before driving the motor.

- 5-phase stepper motor driver resonance area: Approx. 300 to 500pps
- 2-phase stepper motor driver resonance area: Approx. 200pps

● How to improve vibration characteristics

- Adjusting RUN current
- Changing input pulse frequency
- Applying micro step function
- Selecting geared type motors
- Using DAMPER
- Using anti-vibration rubber
- Using elastic couplings

◎ Heat generation

Possible causes for heat generation include applying higher power supply, driving with higher RUN current than rated current and long time & continuous driving without stops.

● How to improve heat generation characteristics

- Adjusting RUN current
- Adjusting RUN DUTY ratio (Setting STOP time longer than RUN time.)
- Mounting heat prevention panels
- Applying Auto current down, HOLD OFF functions
- Using a fan

◎ Missing step

A phenomenon that a stepper motor is incapable of rotating as the frequency of input pulse .

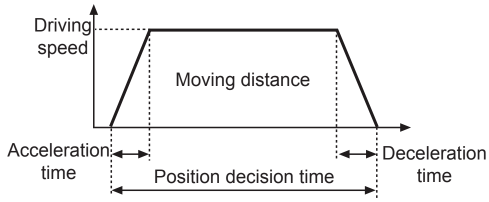
Major Causes	Troubleshooting
Motor failure	Change a motor
Rapid De/Acceleration of Motor	Reduce driving speed / Make motor's acceleration time longer
Improper motor torque selecting for load	Change a motor having high torque. Select a geared type motor
Wrong driving speed setting (lower than max. starting frequency)	Drive a motor within starting frequency band. (Refer to motor's characteristics.)
Low input current	Increase input current

▣ Calculation Method for Selecting Stepper Motor

It shows calculation method required in the selecting order. In real calculation it is impossible to get mechanical constant in many cases. Therefore, simple calculations are shown herewith.

◎ Decision of driving pattern

It is shown as the drawing converting the operation of the driving equipment to the rotating operation of the motor in the equipment using stepper motor. The below chart by starting speed acceleration /deceleration time, driving speed and position decision time of motor. The stepper motor is selected based on driving pattern chart.



< Driving Pattern >

● Calculation of Necessary pulse number

It is the number of the pulse that should be input to stepper motor in order to transfer an object from starting position to target position by the carrying equipment. It is calculated as follows.

Necessary pulse number

$$= \frac{\text{Moving distance of object}}{\text{Moving distance for 1 revolution}} \times \frac{360°}{\text{Step angle}}$$

● Calculation of the Driving pulse speed

It is the necessary pulse speed in order to rotate as much as the necessary pulse number in the set position decision time.

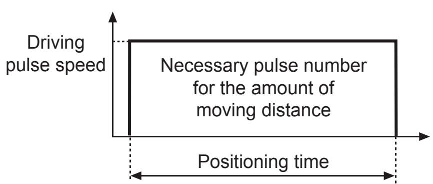
The necessary pulse number, the position decision time and the acceleration/deceleration time calculate the driving pulse speed.

1)For start-stop driving

Start-stop driving is what the stepper motor stops after revolving as much as the necessary pulse number for the position decision time operating in the driving pulse speed without acceleration/ deceleration on the motor driving. Start-stop driving is used when driving a motor in low speed. Also, it needs high acceleration/deceleration torque as it needs a rapid speed change. The driving pulse speed of start-stop driving is calculated as follows:

Driving pulse speed[Hz]

$$= \frac{\text{Necessary pulse number[Pulse]}}{\text{Positioning time[sec]}}$$



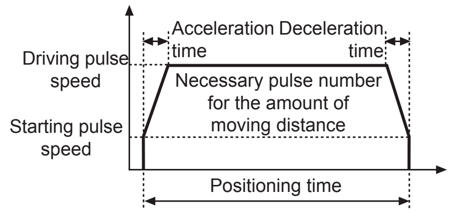
< Start-stop driving pattern >

2)For acceleration/deceleration driving

Acceleration/deceleration driving is what stepper motor stops decelerating the speed into the starting region after driving at the pulse speed for certain time when driving in accelerating the rotation speed of the motor by changing slowly the driving pulse speed in the starting region for the positioning time. Acceleration/deceleration time should be set properly depending on the carrying distance/speed and positioning time. In case of acceleration/deceleration driving it needs lower acceleration/deceleration torque than self-start driving as its speed changes gently. The driving pulse speed of acceleration /deceleration is calculated as below.

Driving pulse speed[Hz]

$$= \frac{\text{Necessary pulse number-Starting pulse speed [Hz]} \times \text{Acceleration·Deceleration time[sec]}}{\text{Positioning time[sec]} - \text{Acceleration·Deceleration time[sec]}}$$



< Acceleration·Deceleration driving pattern >

◎ Simple calculation of the necessary motor torque

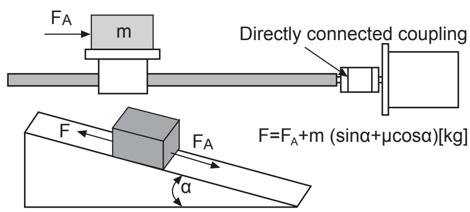
The necessary motor torque=
(Load torque + Acceleration·Deceleration torque)
× Safety rate

● Calculation of load torque (T_L)

Load torque indicates the friction power of a contacting part of the carrying equipment and this torque is always needed when the motor is driving.

Load torque is changed by the kinds of carrying equipment and the weight of an object. The calculation of load torque according to the kinds of carrying equipment is as below. Simple calculations without considering the constant are shown as below because it is impossible to get mechanical constant in many cases. Load torque can be calculated referring to below figures and numerical formulas.

1) Ball-Screw driving



※Calculation of load torque

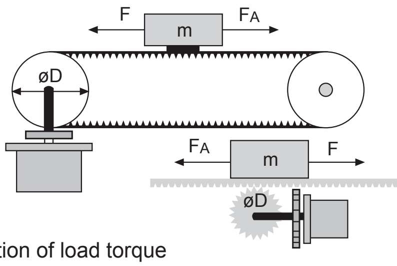
$$T_L = \left(\frac{F\cdot P_B}{2\pi\eta} + \frac{\mu_0 F_0 P_B}{2\pi}\right) \times \frac{1}{i} \text{ [kgf·cm]}$$

※Simple calculation of load torque

$$T_L = \frac{m\cdot P_B}{2\pi\eta} \times \frac{1}{i} \text{ [kgf·cm] (horizontal load)}$$

$$T_L = \frac{m\cdot P_B}{2\pi\eta} \times \frac{1}{i} \times 2 \text{ [kgf·cm] (vertical load)}$$

2) Wire-Belt/Rack-Pinion driving



※Calculation of load torque

$$T_L = \frac{F}{2\pi\eta} \times \frac{\pi D}{i} = \frac{FD}{2\eta i} \text{ [kgf·cm]}$$

$$F = F_A + m(\sin + \mu\cos\alpha) \text{ [kg]}$$

※Simple calculation of load torque

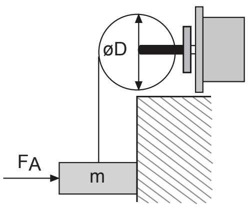
$$T_L = \frac{D}{2} \times m \times \frac{1}{\eta} \times \frac{1}{i} \text{ [kgf·cm] (horizontal load)}$$

$$T_L = \frac{D}{2} \times m \times \frac{1}{\eta} \times \frac{1}{i} \times 2 \text{ [kgf·cm] (vertical load)}$$

3) Pulley driving

※Calculation of load torque

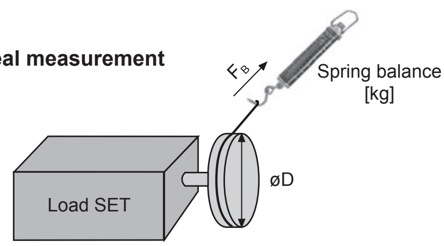
$$T_L = \frac{\mu F_A + m}{2\pi} \times \frac{\pi D}{i} = \frac{(\mu F_A + m)D}{2i} \text{ [kgf·cm]}$$



※Simple calculation of load torque

$$T_L = \frac{D}{2} \times m \times \frac{1}{i} \text{ [kgf·cm]}$$

4) By real measurement



It is the calculation method by reading the scale mark of the spring balance at the time when the pulley is rotated when drawing the spring balance slowly. It is available to get more accuracy load torque than by the calculation.
It is available to calculate the load torque as follows with the value (F_B) calculated by the spring balance.

$$T_L = \frac{F_B D}{2\pi} \text{ [kgf·cm]}$$

[Index]

- F : Load of axis direction[kg]
- η : Efficiency ratio (0.85 to 0.95)
- F_A : External force[kg]
- μ : Friction coefficient
- μ_0 : Internal friction coefficient of pre-pressure NUT (0.1 to 0.3)
- P_B : Ball-screw pitch[cm/rev]
- F_B : The force when starting the revolution of main shaft[kg]
- D : Outside diameter of pulley
- F_0 : Pre-pressure load [kg] (≅ 1/3 F)
- i : Deceleration rate
- m : The total weight of work and table[kg]
- α : Slop angle[°]

● Calculation of Acceleration/Deceleration torque (Ta)

Acceleration·Deceleration torque is for accelerating or decelerating the carrying equipment connected to the motor. It changes largely depending on the time of acceleration·deceleration and the value of load inertia moment of the carrying equipment. Therefore, the torque between self-start driving and acceleration·deceleration driving will show a big difference. Acceleration·Deceleration Torque is calculated as follows:

※For start-stop driving (high acceleration·deceleration torque is required)

Acceleration·Deceleration Torque[kg·cm] =

$$\frac{\text{Rotator inertia moment[kgf·m}^2\text{] + Load inertia moment[kg·m}^2\text{]}}{\text{Gravitational acceleration[cm/sec}^2\text{]}} \times \frac{\pi \times \text{Step angle[°]} \times \text{Driving frequency}^2\text{[Hz]}}{180 \times 3.6° / \text{Step angle[°]}}$$

※Acceleration/Deceleration driving

Acceleration·Deceleration Torque[kgf·cm] =

$$\frac{\text{Rotator inertia moment[kg·m}^2\text{] + Load inertia moment[kg·m}^2\text{]}}{\text{Gravitational acceleration[cm/sec}^2\text{]}} \times \frac{\pi \times \text{Step angle[°]}}{180°} \times \frac{\text{Driving frequency[Hz]-Starting frequency[Hz]}}{\text{Acceleration·Deceleration time[sec]}}$$

▣ Calculation Example for Motor Selection

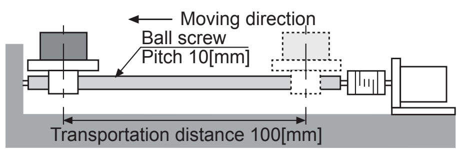
◎ Calculation of the number of the necessary pulse and the speed of the driving pulse.

These are practical examples for the number of the necessary pulse and the speed of the driving pulse with 5-phase stepper motor as below.

● When driving ball-screw

When carrying an object as follow figure for 1sec. by using 5-phase stepper motor (0.72°/step), the number of the necessary pulse and the speed of the driving pulse are calculated as follows:

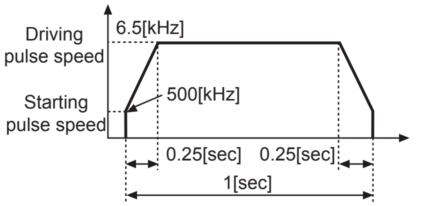
$$\text{Necessary pulse number} = \frac{100}{10} \times \frac{360°}{0.72°} = 5{,}000\text{[Pulse]}$$



If it executes start-stop driving for a second the speed of the driving pulse is calculated as 5,000[Pulse]/1[sec]=5[kHz] but, the start-stop driving is impossible at 5[kHz] and it should be driven with acceleration·deceleration driving. If calculating with setting the acceleration ·deceleration time as 25% of the position decision time and 500[Hz] of the starting pulse speed, it will be calculated as follows:

$$\text{Driving pulse speed[Hz]} = \frac{500\text{[Pulse]} - 500\text{[Hz]} \times 0.25\text{[sec]}}{1\text{[sec]} - 0.25\text{[sec]}} = 6.5\text{[kHz]}$$

It will be figured as follows:

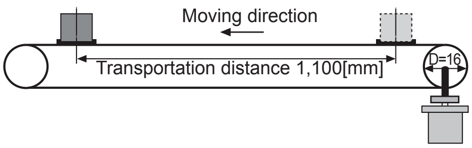


<Acceleration·Deceleration driving pattern >

● When driving the timing belt

When carrying an object as following figure for 1sec. by using 5-phase stepper motor (0.72°/step), the moving distance/revolution is approx. 50[mm] by 2πr as the circumference of the pulley. As the moving distance/revolution is 50[mm] the number of the necessary pulse is calculated as follows:

$$\text{Necessary pulse number} = \frac{1,100}{50} \times \frac{360°}{0.72°} = 11,000[\text{Pulse}]$$

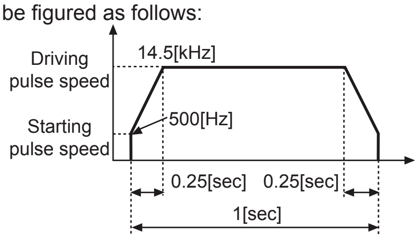


If driving with acceleration·deceleration like the example of a ball-screw the driving pulse speed is calculated as follows:

$$\text{Driving pulse speed[Hz]} = \frac{11,000[\text{Pulse}] - 500[\text{Hz}] \times 0.25[\text{sec}]}{1[\text{sec}] - 0.25[\text{sec}]}$$

$$= 14.5[\text{kHz}]$$

It will be figured as follows:



<Acceleration·Deceleration driving pattern >

◎ Calculation example of load torque (T_L)

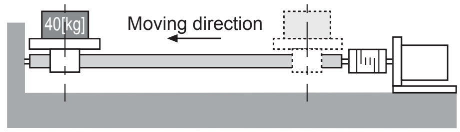
It is a real calculation example of load torque by using 5-phase stepper motor by simple numerical formulas.

● When using ball-screw for driving horizontal load

When carrying an object by using a ball-screw with 90[%] of efficiency and 40[kg] of the load weight as following figure, the load torque is calculated as follows;

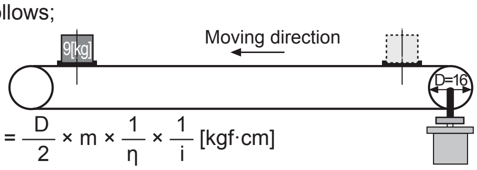
$$T_L = \frac{m \cdot P_B}{2\pi\eta} \times \frac{1}{i} \; [\text{kgf·cm}]$$

$$T_L = \frac{40[\text{kg}] \times 1[\text{cm}]}{2\pi \times 0.9} \times \frac{1}{1} ≒ 7.07[\text{kgf·cm}]$$



● When using timing belt for driving horizontal load

When carrying an object by using a timing belt with 90[%] of efficiency, 16[mm] diameter of pulley and 9[kg] of the load weight as following figure, the load torque is calculated as follows;

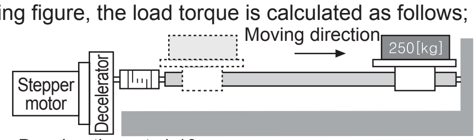


$$T_L = \frac{D}{2} \times m \times \frac{1}{\eta} \times \frac{1}{i} \; [\text{kgf·cm}]$$

$$T_L = \frac{1.6[\text{cm}]}{2} \times 9[\text{kg}] \; \frac{1}{0.9} \times \frac{1}{1} = 8[\text{kgf·cm}]$$

● When using ball-screw and decelerator for driving horizontal load

When carrying an object by using a ball screw with 5[mm] pitch, 90[%] of efficiency and 250[kg] of the load weight as following figure, the load torque is calculated as follows;



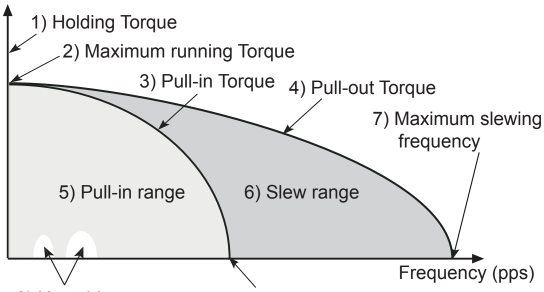
Deceleration rate1:10

$$T_L = \frac{m \cdot P_B}{2\pi\eta} \times \frac{1}{i} \; [\text{kgf·cm}]$$

$$T_L = \frac{250[\text{kg}] \times 0.5[\text{cm}]}{2\pi \times 0.9} \times \frac{1}{10} = 2.21[\text{kgf·cm}]$$

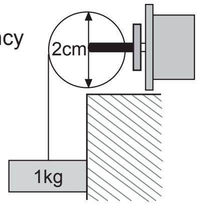
The calculation result is for a horizontal load. Vertical load torque is 2 times of the horizontal load torque. Its result is only for load torque.
Acceleration·Deceleration torque should be added for real necessary torque of the motor. But, it is very difficult to get the moment of load inertia in the calculation.
In order to solve the difficulty it will be easy to calculate applying the start-stop driving or a large safety rate when acceleration·deceleration is rapid at the calculated load torque.

■ Glossary



- Torque

Torque, moment of force, is the tendency of a force to rotate an object.
※Torque unit: N·m or kgf·cm
(1 N·m = 10.1972 kgf·cm)
※Required torque to rotate a rotator of which radius is 1cm in case of 1kg weight is applied.



- Refer to torque-frequency reference below. 1) to 6) have direct effect on driver's performance.

1) Holding torque
The amount of torque the motors produce at standstill while rated current is applied to the motors. In general, it is referred to as stepper motor's driving capacity.
2) Maximum running Torque
Max. torque when running stepper motor with low speed (10pps)
3) Pull-in torque
Max. torque to drive a load within starting frequency range.
4) Pull-out torque
Max. torque required for a stepper motor to drive without pull-out within maximum starting frequency.
5) Pull-in range (Max. starting range)
Max. torque range that a stepper motor can drive a load with a certain frequency lower than max. starting frequency. It is allowed for the load to start & stop and forward & reverse rotation without de/acceleration within pull-in range. In case of driving a motor out of pull-in range, start a motor within pull-in range and do de/acceleration driving.
6) Slew range (Pull-out range)
Max. torque range required for a stepper motor to drive without pull-out within maximum starting frequency
7) Maximum slewing frequency
Max. frequency at which a stepper motor can rotate without fail to synchronize when driving a motor within max. starting frequency range in order to increase input frequency.
8) Maximum starting frequency
Maximum frequency is required for stepper motors to start & stop and forward & reverse rotation without de/acceleration in the state of no load. If it is required to drive a motor with higher frequency than max. starting frequency, drive a motor from max. starting frequency and do de/acceleration driving.
9) Unstable range
Within low speed area, resonance may occur.
Drive the motor after taking the measurement for resonance area.