# Optimal Type Selection

## Contents


**1. Inverter and Motor Selection ........ 4-2**

1.1 Motor output torque characteristics ........ 4-2

1.2 Selection procedure ........ 4-4

1.3 Selection calculation expressions ........ 4-6

1.3.1 Load torque during constant speed running ........ 4-6

1.3.2 Acceleration and deceleration time calculation ........ 4-7

1.3.3 Heat energy calculation of braking resistor ........ 4-9

1.3.4 Appendix (calculation for other than in SI Unit) ........ 4-10

**2. Braking Unit and Braking Resistor Selection ........ 4-11**

2.1 Selection procedure ........ 4-11

2.2 Notes on selection ........ 4-11

2.3 Optional fan unit ........ 4-11

# 1. Inverter and Motor Selection

When selecting a general-purpose inverter, select a motor first and next inverter.

(1) To select a motor, determine what kind of load machine is used, calculate the moment of inertia, and then select an appropriate motor capacity.
(2) To select an inverter, consider in what operating conditions (acceleration time, deceleration time, or frequency in operation) the mechanical system is used for the motor capacity selected in (1), and calculate acceleration torque, deceleration torque, and braking torque.

Here, the selection procedure for the above (1) and (2) is described. First, explained is the output torque obtained by using the inverter FRENIC5000G11S/P11S.

◆ **Motor output torque characteristics (See Section 1.1)**
Torque characteristics (continuous output torque, output torque in a short time, braking torque) obtained when frequency control is made by inverter, are described for the whole range of speed control using figures.

◆ **Selection procedure (See Section 1.2 and 1.3)**
1 Selection procedure: Explained using a flowchart.
2 Selection calculation expressions: Calculation method shown in the selection flowchart is explained with calculation expressions.

## 1.1 Motor output torque characteristics

Fig. 4.1 and 4.2 show the output torque characteristics individually according to 50Hz and 60Hz base for the rated output frequency.

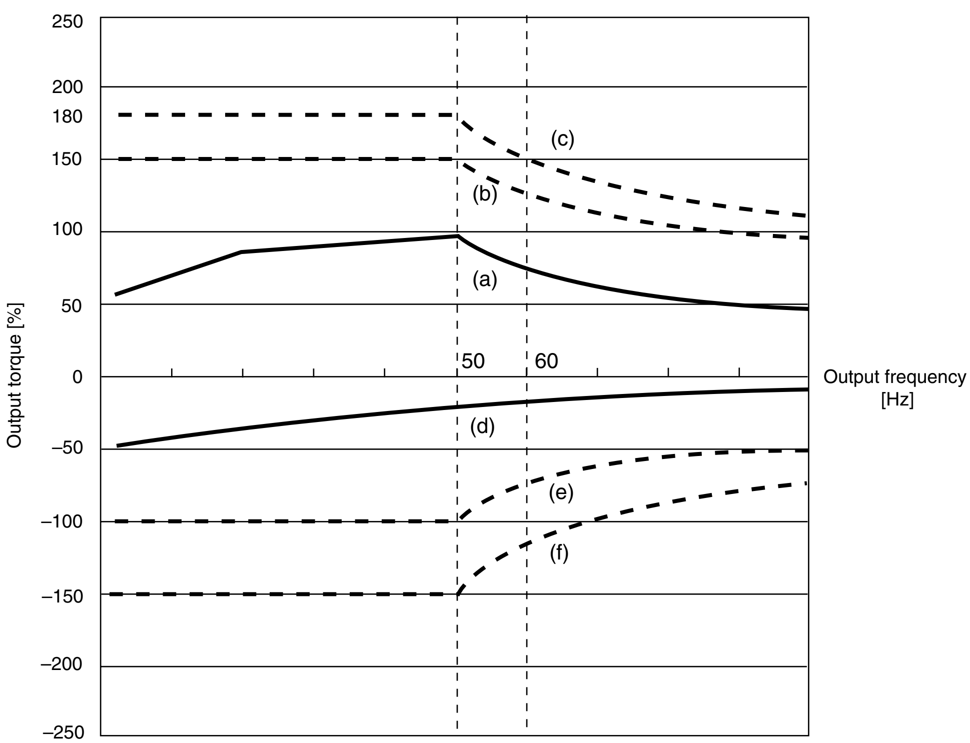



**Fig. 4.1 Output torque characteristics (50Hz base)**

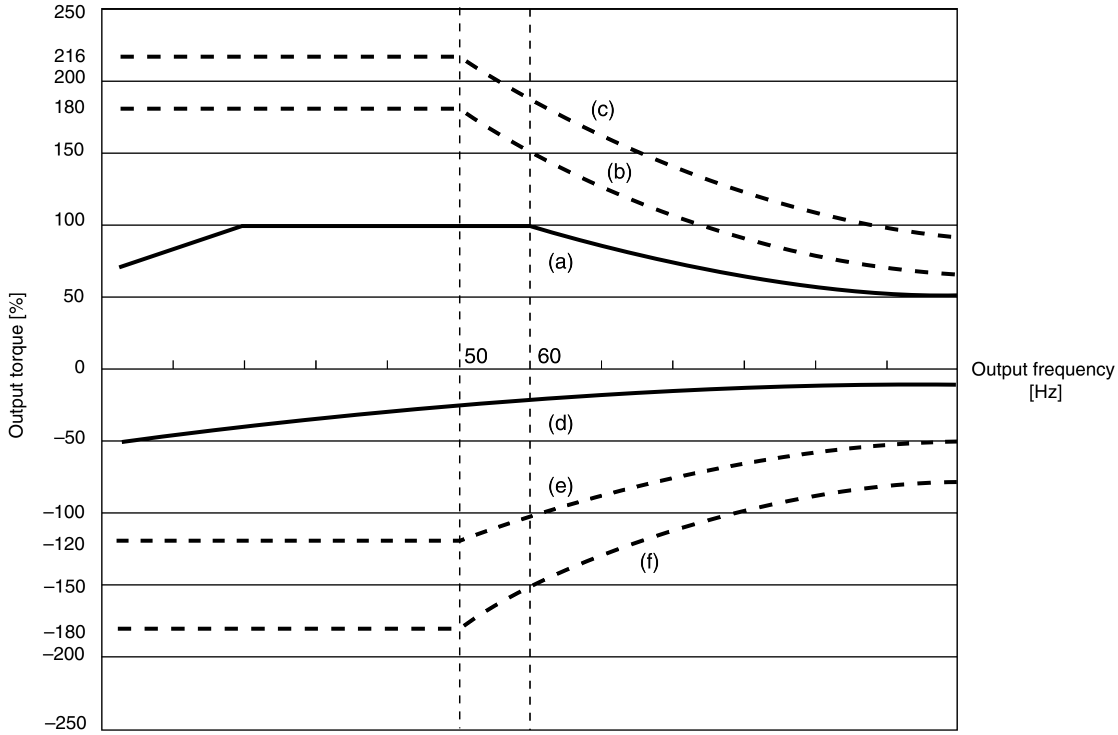



**Fig. 4.2 Output torque characteristics (60Hz base)**

**(1) Continuous allowable driving torque (Fig. 4.1 and 4.2, curve (a))**

Curve (a) is the torque that can be obtained in a range of the inverter continuous rated current. This value can be obtained continuously by observing the motor cooling characteristic. In 60Hz running, 100% output torque is obtained, but in 50Hz running, output torque is a somewhat reduced compared with that during commercial running, and it is further reduced during low speed running. Reduction of output in 50Hz running is due to increased loss by inverter driving, and that in low speed running is mainly due to air flow reduction of motor cooling fan.

**(2) Maximum driving torque in a short time (Fig. 4.1 and 4.2, curves (b) and (C))**

Curve (b) is the torque that can be obtained in a range of the inverter rated current in short time (150% for one minute) when torque vector control is selected. At that time, the motor cooling characteristics have little effect to the output torque.
Curve (c) is an example of output torque when one size larger capacity inverter is used to increase the short time maximum torque. At that time, short time torque is 20 to 30% greater than that when standard capacity inverter is applied.

**(3) Starting torque (around speed 0 in Fig. 4.1 and 4.2)**

Maximum torque in a short time is starting torque as it is.

**(4) Braking torque (Fig. 4.1 and 4.2, curves (d), (e), and (f))**

n braking mode, mechanical energy is converted to electrical energy and regenerated to the smoothing capacitor in the inverter. A large braking torque, as shown in curve (e), can be obtained by discharging this electrical energy to the braking resistor. If a braking resistor is not provided, only the motor and inverter losses consume the regenerated braking energy, so the torque becomes smaller, as shown in curve (d). A 10HP or smaller capacity inverter unit incorporates a small braking resistor, so a large braking torque can be obtained even if optional resistor is not used. For further information, see Chapter 1, Specifications.
Braking torque when a braking resistor is used is allowable only for a short time. Its time ratings are mainly determined by the braking resistor ratings. In this manual and associated catalogues, the allowable value [HP] obtained from average discharging loss and allowable value [kWs] obtained from discharging capability that can be discharged at one time are shown.
The torque % value varies according to the inverter capacity.
For a 15HP or larger capacity inverter unit, a discharging transistor unit (braking unit) is necessary, in addition to the braking resistor. So, selecting an optimum braking unit enables a braking torque value to be selected comparatively freely in a range below short time maximum torque in driving mode, as shown in curve (f).
For torque values and other allowable values of standard selection of braking unit and resistor, see Chapter 3, Section 4.

### 1.2 Selection procedure

Fig. 4.3 shows the general selection procedure for optimal inverter selection. Inverter capacity can be easily selected if there are no limitation regarding acceleration and deceleration time. The cases such as “Lifting or lowering a load”, “Acceleration and deceleration time is restricted”, or “Highly frequent acceleration and deceleration” make the selection procedure a little bit complex.

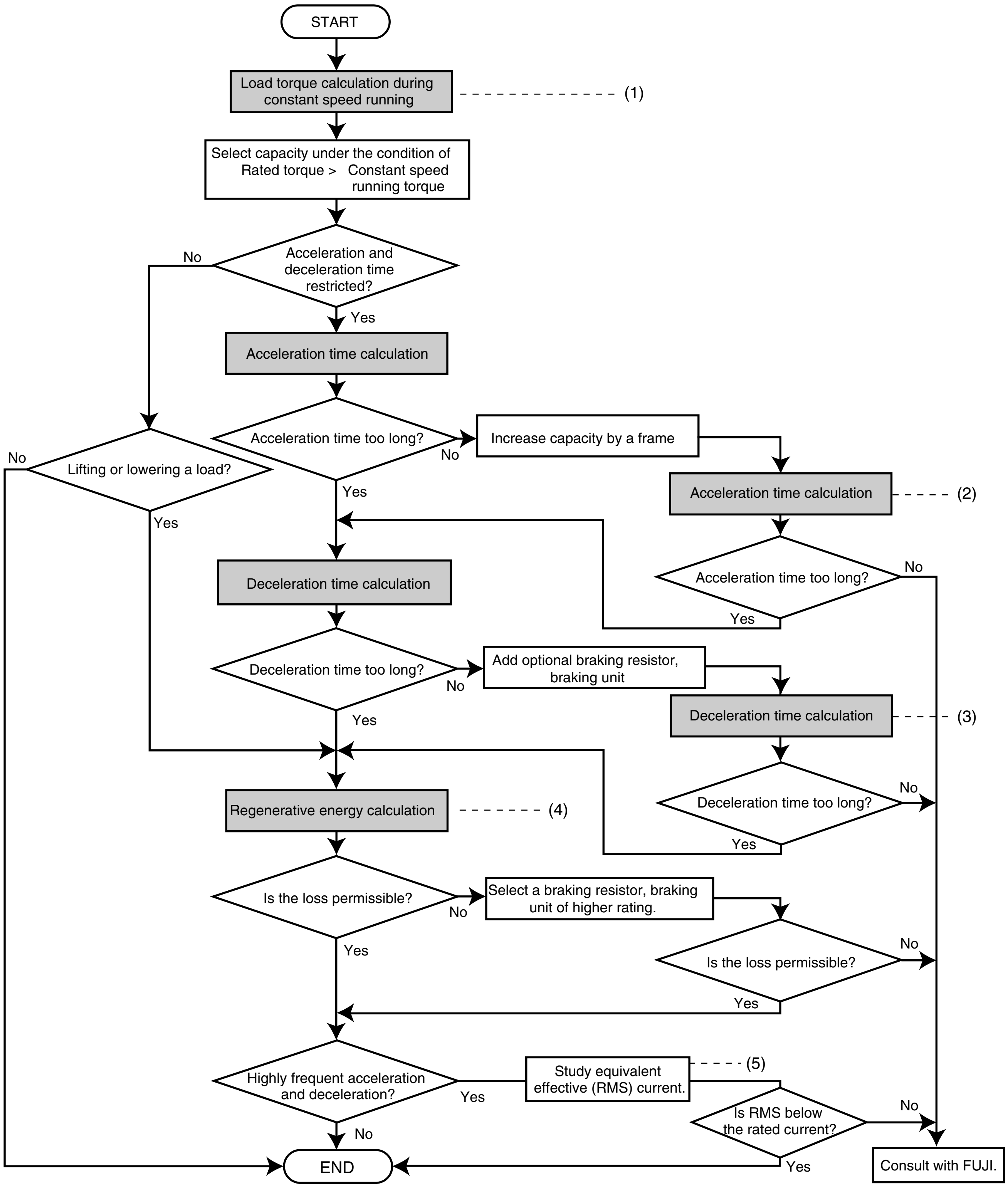



**Fig. 4.3 Selection procedure**

**(1) Calculation of load torque during constant speed running (For detailed calculation, see Section 1.3.1)**

This step is necessary for capacity selection for all loads. Determine the rated torque of the motor during constant speed running higher than that of the load torque, and select a tentative capacity. To perform capacity selection efficiently, it is necessary to match the rated speeds (base speeds) of the motor and load.

To do this, select an appropriate reduction-gear (mechanical transmission) ratio and number of motor poles. If acceleration/deceleration time is not limited and the system is not a lifting machine, capacity selection is completed as it is.

**(2) Acceleration time**
**(For detailed calculation, see Section 1.3.2)**

When there are specified requirements for the acceleration time, calculate it using the following procedure:

① **Calculate moment of inertia for the load and motor.**
Calculate moment of inertia for the load by referring to Section1.3.2.

② **Calculate minimum acceleration torque. (See Fig. 4.4)**
The acceleration torque is the difference between motor short time output torque (60s rating) explained in Section 1.1 and load torque ($\tau_L/\eta_G$) during constant speed running calculated in the above ① . Calculate minimum acceleration torque for the whole range of speed.

③ **Calculate the acceleration time.**
Assign the value calculated above to the expression (4.15) in Section 1.3.2 to calculate the acceleration time. If the calculated acceleration time is longer than the requested time, select one size larger capacity inverter and motor and calculate it again.

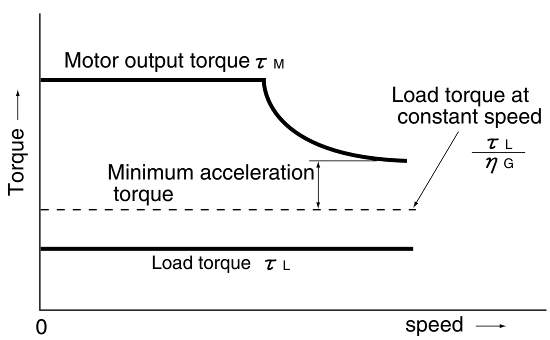



**Fig. 4.4 Example study of minimum acceleration torque**

**(3) Deceleration time**
**(For detailed calculation, see Section 1.3.2)**

To calculate the deceleration time, check the motor deceleration torque characteristics for the whole range of speed in the same way as for the acceleration time.

① **Calculate moment of inertia for the load and motor.**
Same as for acceleration time.

② **Calculate minimum deceleration torque.**
**(See Fig. 4.5)**
Same as for deceleration time.

③ **Calculate the deceleration time.**
Assign the value calculated above to the expression (4.16) in Section 1.3.2 to calculate the deceleration time. If the calculated deceleration time is longer than the requested time, select one size larger capacity and calculate it again.

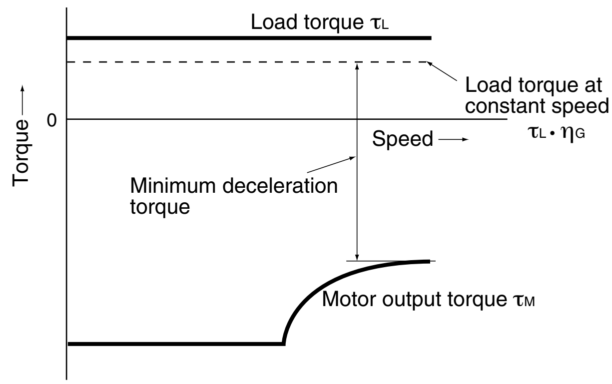



**Fig. 4.5 Example study of minimum deceleration torque (1)**

However, note that minimum deceleration torque becomes smaller due to regenerative operation when lifting or lowering a load. (See Fig. 4.6)

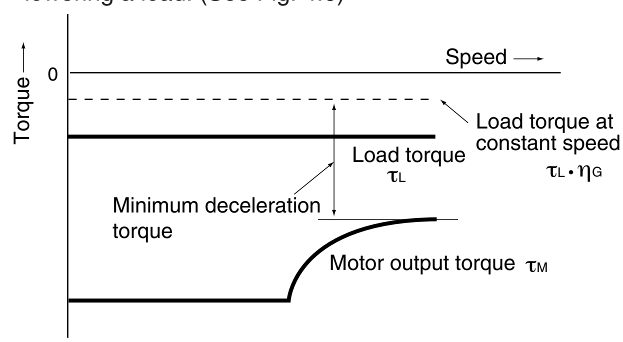



**Fig. 4.6 Example study of minimum deceleration torque (2)**

**(4) Braking resistor rating**
**(For detailed calculation, see Section 1.3.3)**

Braking resistor rating is divided into two types according to the braking periodic duty cycle:

① **When periodic duty cycle is 100s or less:**
Calculate average loss to determine rated values.

② **When periodic duty cycle is 100s or more:**
Allowable braking energy depends on maximum braking power. Allowable values are listed in Chapter 3, Section 4.

**(5) Motor RMS current**

In metal processing machine and carriage machinery requiring positioning control, highly frequent running with short time rating is performed. In this case, calculate an equivalent RMS current value not to exceed the allowable value for the motor.

## 1.3 Selection calculation expressions

### 1.3.1 Load torque during constant speed running

**1. General expression**

The frictional force acting on a horizontally moved load must be calculated. For loads lifted or lowered vertically or along a slope, the gravity acting on the load must be calculated. Calculation for driving a load along a straight line with the motor is shown below.
Where the force to move a load linearly at constant speed $\upsilon$ [m/s] is F[N] and the motor speed for driving this is $N_M$ [r/min], the required motor output torque $\tau_M$ [N·m] is as follows:

$$\tau_M = \frac{60\upsilon}{2\pi \cdot N_M} \cdot \frac{F}{\eta_G} \quad [\text{N·m}] \quad \text{..........} (4.1)$$

Where, $\eta_G$: Reduction-gear efficiency

When the motor is in braking mode, efficiency works inversely, so the required motor torque should be calculated as follows:

$$\tau_M = \frac{60\upsilon}{2\pi \cdot N_M} \cdot F \cdot \eta_G \quad [\text{N·m}] \quad \text{..........} (4.2)$$

$(60\upsilon)/(2\pi \cdot N_M)$ in the above expression is an equivalent rotation radius corresponding to speed $\upsilon$ around the motor shaft.
The value F in the above expressions changes according to the load type.

**2. Obtaining the required force F**

**(1) Moving a load horizontally**

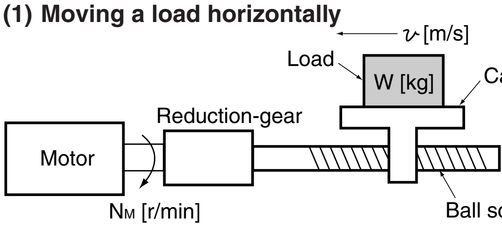



**Fig. 4.7 Moving a load horizontally**

As shown in Fig. 4.7, where the carrier table weight is $W_0$ [kg], load is W [kg], and friction coefficient of the ball screw is $\mu$, friction force F [N] is expressed as follows:

$$F = (W_0 + W) \cdot g \cdot \mu \quad [\text{N}] \quad \text{..........} (4.3)$$

Where, g : Gravity acceleration (≒ 9.8 m/s²)
Then, required driving torque around the motor shaft is expressed as follows:

$$\tau_M = \frac{60\upsilon}{2\pi \cdot N_M} \cdot \frac{(W_0 + W) \cdot g \cdot \mu}{\eta_G} \quad [\text{N·m}] \quad \text{..........} (4.4)$$

**(2) Moving a load vertically**

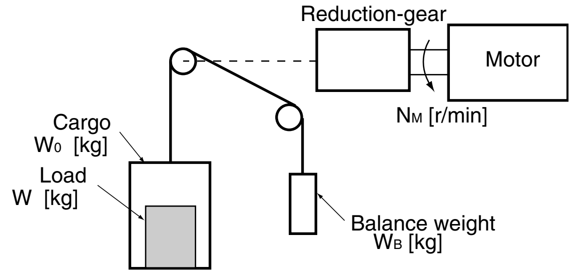



**Fig. 4.8 Moving a load vertically**

As shown in Fig. 4.8, where a cage weight, load weight, and balance-mass weight are $W_0$, W, and $W_B$ [kg], the force of gravity F [N] is as follows:

(Lifting)

$$F = (W_0 + W - W_B) \cdot g \quad [\text{N}] \quad \text{..........} (4.5)$$

(Lowering)

$$F = (W_B + W - W_0) \cdot g \quad [\text{N}] \quad \text{..........} (4.6)$$

Where maximum load is $W_{max}$, generally $W_B$ equals to $(W_o + W_{max}) / 2$. So, F may become a negative force to brake both lifting and lowering movements depending on the load weight.
Calculate the required torque $\tau$ around the motor shaft in the driving mode by expression (4.1) and that in the braking mode by expression (4.2). That is, if F is positive, use expression (4.1); if it is negative, use expression (4.2).

**(3) Moving a load along a slope**

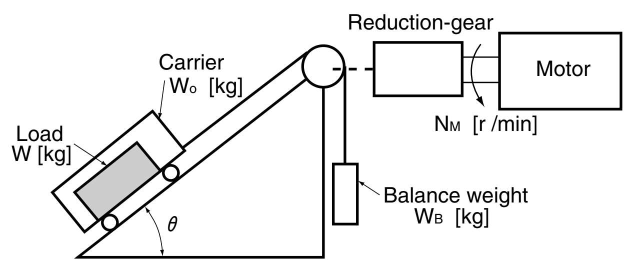



**Fig. 4.9 Moving a load along a slope**

Lifting and lowering a load along a slope may seem to be like lifting and lowering a load vertically, but friction force between the load and the slope cannot be ignored in lifting and lowering along a slope. Therefore, the expression for lifting a load is a little different from that for lowering a load. Where slope angle is $\theta$ and friction coefficient is $\mu$, as shown in Fig. 4.9, driving force F [N] is as follows:

(Lifting)

$$F = ((W_0 + W)(\sin\theta + \mu \cdot \cos\theta) - W_B) \cdot g \quad [\text{N}] \quad \text{..........} (4.7)$$

(Lowering)

$$F = (W_B - (W_0 + W)(\sin\theta - \mu \cdot \cos\theta)) \cdot g \quad [\text{N}] \quad \text{..........} (4.8)$$

The force of gravity F may become a negative force to brake both lifting and lowering movements, depending on the load weight. This is the same as for vertical lifting and lowering. Required torque around the motor shaft can be also calculated similarly. That is, when F is positive, use expression (4.1); when it is negative, use expression (4.2).

### 1.3.2 Acceleration and deceleration time calculation

When an object whose moment of inertia is J [kg·m$^2$] rotates at the speed N [r/min], it has the following kinetic energy:

$$E = \frac{J}{2}\left(\frac{2\pi \cdot N}{60}\right)^2 \quad [J] \quad \cdots\cdots (4.9)$$

To accelerate the above rotation, kinetic energy will be increased; to decelerate, kinetic energy must be discharged.

The torque required for acceleration and deceleration can be expressed as follows:

$$\tau = J \cdot \frac{2\pi}{60}\left(\frac{dN}{dt}\right) \quad [N\cdot m] \quad \cdots\cdots (4.10)$$

In this way, the mechanical moment of inertia is an important element in acceleration and deceleration. First, calculation method of moment of inertia is described, then that for acceleration and deceleration time are explained.

**1. Calculation of moment of inertia**

For an object that rotates around the rotation axis, vertually divide the object into small segments and square the distance from the rotation axis to each segment. Then, sum the squares of the distances and the masses of the segments to calculate the moment of inertia.

$$\text{Moment of inertia } J = \sum (Wi \cdot ri^2) \quad [kg\cdot m^2] \quad \cdots\cdots (4.11)$$

**① Hollow cylinder and solid cylinder**

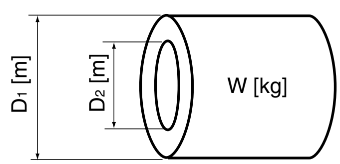



**Fig. 4.10 Hollow cylinder**

The common shape of a rotating body is hollow cylinder. The moment of inertia around the hollow cylinder center axis can be calculated as follows, where the outer and inner diameters are $D_1$ and $D_2$ [m] and total weight is W [kg] in Fig. 4.10.

$$J = \frac{W \cdot (D_1^2 + D_2^2)}{8} \quad [kg\cdot m^2] \quad \cdots\cdots (4.12)$$

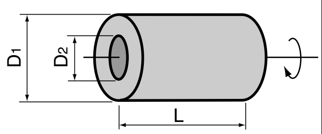
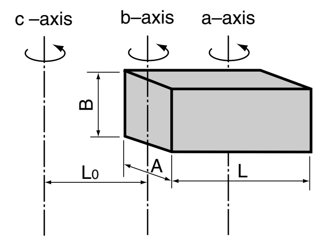
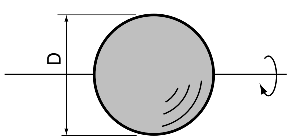
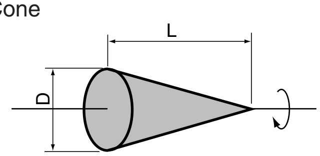
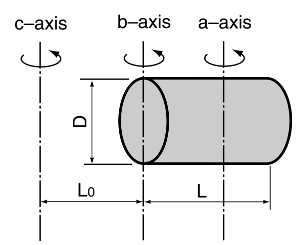
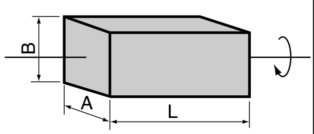
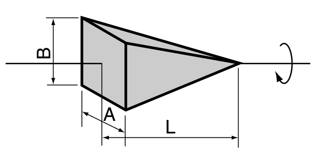
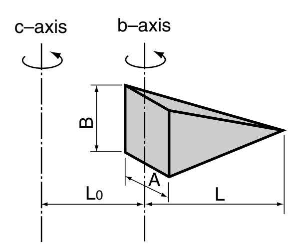
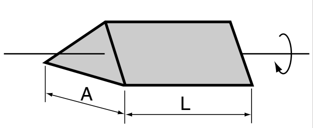
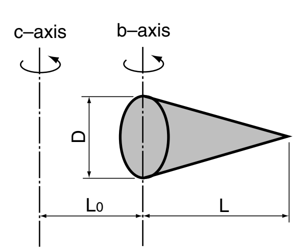
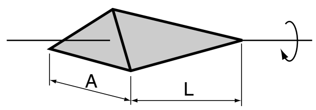
For a similar shape, a solid cylinder, calculate the moment of inertia as $D_2$ is 0.

4

② **For a general rotating body**

Table 4.1 lists the calculation expressions of moment of inertia of various rotating bodies including the above cylindrical rotating body.

**Table 4.1 Moment of inertia of various rotating bodies**

| Shape | Mass :W [kg] / Moment of inertia :J [kg·m²] | Shape | Mass :W [kg] / Moment of inertia :J [kg·m²] |
|---|---|---|---|
| Hollow cylinder  | $W = \frac{\pi}{4}(D_1^2 - D_2^2)\cdot L\cdot\rho$ <br> $J = \frac{1}{8}\cdot W\cdot(D_1^2 + D_2^2)$ |  | $W = A\cdot B\cdot L\cdot\rho$ <br> $J_a = \frac{1}{12}\cdot W\cdot(L^2 + A^2)$ <br> $J_b = \frac{1}{12}\cdot W\cdot(L^2 + \frac{1}{4}\cdot A^2)$ <br> $J_c \fallingdotseq W\cdot(L_0^2 + L_0\cdot L + \frac{1}{3}\cdot L^2)$ |
| Sphere  | $W = \frac{\pi}{6}D^3\cdot\rho$ <br> $J = \frac{1}{10}\cdot W\cdot D^2$ | | |
| Cone  | $W = \frac{\pi}{12}D^2\cdot L\cdot\rho$ <br> $J = \frac{3}{40}\cdot W\cdot D^2$ |  | $W = \frac{\pi}{4}D^2\cdot L\cdot\rho$ <br> $J_a = \frac{1}{12}\cdot W\cdot(L^2 + \frac{3}{4}\cdot D^2)$ <br> $J_b = \frac{1}{3}\cdot W\cdot(L^2 + \frac{3}{16}\cdot D^2)$ <br> $J_c \fallingdotseq W\cdot(L_0^2 + L_0\cdot L + \frac{1}{3}\cdot L^2)$ |
| Rectangular prism  | $W = A\cdot B\cdot L\cdot\rho$ <br> $J = \frac{1}{12}\cdot W\cdot(A^2 + B^2)$ | | |
| Pyramid, rectangular base  | $W = \frac{1}{3}A\cdot B\cdot L\cdot\rho$ <br> $J = \frac{1}{20}\cdot W\cdot(A^2 + B^2)$ |  | $W = \frac{1}{3}A\cdot B\cdot L\cdot\rho$ <br> $J_b = \frac{1}{10}\cdot W\cdot(L^2 + \frac{1}{4}\cdot A^2)$ <br> $J_c \fallingdotseq W\cdot(L_0^2 + \frac{3}{2}L_0\cdot L + \frac{3}{5}\cdot L^2)$ |
| Triangular prism  | $W = \frac{\sqrt{3}}{4}\cdot A^2\cdot L\cdot\rho$ <br> $J = \frac{1}{3}\cdot W\cdot A^2$ |  | $W = \frac{\pi}{12}\cdot D^2\cdot L\cdot\rho$ <br> $J_b = \frac{1}{10}\cdot W\cdot(L^2 + \frac{3}{8}\cdot D^2)$ <br> $J_c \fallingdotseq W\cdot(L_0^2 + \frac{3}{2}L_0\cdot L + \frac{3}{5}\cdot L^2)$ |
| Tetrahedron with an equilateral triangular base  | $W = \frac{\sqrt{3}}{12}\cdot A^2\cdot L\cdot\rho$ <br> $J = \frac{1}{5}\cdot W\cdot A^2$ | | |

Main metal density (at 20˚C) $\rho$ [kg/m³]  Iron : 7860, Copper : 8940, Aluminum : 2700

③ **For a load running horizontally**

As shown in Fig. 4.7, a carrier table can be driven by a motor. If the table speed is $\upsilon$ [m/s] when the motor rotation speed is $N_M$ [r/min], an equivalent distance from the rotation axis is $60\upsilon/(2\pi \cdot N_M)$ [m]. Then, the moment of inertia of table and load to the rotation axis is calculated as follows:

$$J = \left(\frac{60\upsilon}{2\pi \cdot N_M}\right)^2 \cdot (W_0 + W) \quad [kg \cdot m^2] \quad \text{.................. (4.13)}$$

④ **For lifting and lowering load**

As shown in Figures 4.8 and 4.9, two loads tied with the rope move in different directions. The moment of inertia can be calculated by obtaining the sum of the moving object's weight as follows:

$$J = \left(\frac{60\upsilon}{2\pi \cdot N_M}\right)^2 \cdot (W_0 + W + W_B) \quad [kg \cdot m^2] \quad \text{........... (4.14)}$$

## 2. Calculation of the acceleration time

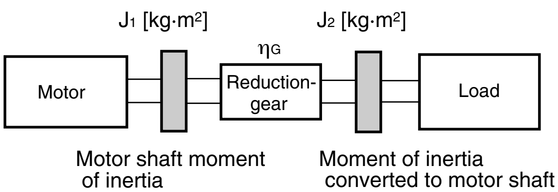



**Fig. 4.10 Load model including reduction-gear**

Fig.4.10 shows a general load model. Here, the load is tied via a reduction-gear with efficiency $\eta_G$.

The time required to accelerate this load to a speed of $N_M$ [r/min] is calculated with the following expression:

$$t_{ACC} = \frac{J_1 + J_2/\eta_G}{\tau_M - \tau_L/\eta_G} \cdot \frac{2\pi \cdot (N_M - 0)}{60} \quad [s] \quad \text{............................. (4.15)}$$

Where,

$J_1$: Motor shaft moment of inertia [kg·m²]

$J_2$: Load shaft moment of inertia converted to motor shaft [kg·m²]

$\tau_M$: Minimum motor output torque in driving mode [N·m]

$\tau_L$: Maximum load torque converted to motor shaft [N·m]

$\eta_G$: Reduction-gear efficiency

As clarified in the above expression, equivalent moment of inertia becomes $(J_1+J_2/\eta_G)$ considering the reduction gear efficiency.

## 3. Calculation of the deceleration time

In Fig. 4.10, the time required to stop the motor rotating at a speed of $N_M$ [r/min] is calculated with the following expression:

$$t_{DEC} = \frac{J_1 + J_2 \cdot \eta_G}{\tau_M - \tau_L \cdot \eta_G} \cdot \frac{2\pi \cdot (0 - N_M)}{60} \quad [s] \quad \text{...................... (4.16)}$$

Where,

$J_1$: Motor shaft moment of inertia [kg·m²]

$J_2$: Load shaft moment of inertia converted to motor shaft [kg·m²]

$\tau_M$: Minimum motor output torque in braking (deceleration) mode [N·m]

$\tau_L$: Maximum load torque converted to motor shaft [N·m]

$\eta_G$: Reduction-gear efficiency

In the above expression, generally output torque $\tau_M$ is negative and load torque $\tau_L$ is positive. So, deceleration time becomes shorter. However, in a lifted and lowered load, $\tau_L$ may become a negative value in braking mode. In this case, the deceleration time becomes longer.

* For lifting or lowering load
In inverter and motor capacity selection for lifted and lowered load, the deceleration time must be calculated by using the maximum value that makes the load torque negative.

### 1.3.3 Heat energy calculation of braking resistor

Braking by an inverter causes mechanical energy to be regenerated in the inverter circuit.
This regenerative energy is often discharged to the resistor. In this section, braking resistor rating is explained.

**Calculation of regenerative energy**

Regenerative energy generated in the inverter operation consists of kinetic energy of a moving object and its potential energy.

① **Kinetic energy of a moving object**

When an object with moment of inertia J [kg·m²] rotates at a speed $N_2$ [r/min], its kinetic energy is as follows:

$$E = \frac{J}{2} \cdot \left(\frac{2\pi \cdot N_2}{60}\right)^2 \quad [J] \quad \text{.................................... (4.17)}$$

$$\fallingdotseq \frac{1}{182.4} \cdot J \cdot N_2^2 \quad [J = kWs] \quad \text{........................ (4.17)'}$$

The output energy when this object is decelerated to a speed $N_1$ [r/min] is as follows:

$$E = \frac{J}{2} \cdot \left[\left(\frac{2\pi \cdot N_2}{60}\right)^2 - \left(\frac{2\pi \cdot N_1}{60}\right)^2\right] \quad [J] \quad \text{............. (4.18)}$$

$$\fallingdotseq \frac{1}{182.4} \cdot J \cdot (N_2^2 - N_1^2) \quad [J] \quad \text{............................. (4.18)'}$$

The energy regenerated to the inverter as shown in Fig. 4.10 is calculated by considering the reduction-gear efficiency $\eta_G$ and motor efficiency $\eta_M$ as follows:

$$E \fallingdotseq \frac{1}{182.4} \cdot (J_1+J_2 \cdot \eta_G) \cdot \eta_M \cdot (N_2^2-N_1^2) \; [J] \quad \text{........... (4.19)}$$

② **Potential energy of an object**

When an object of W [kg] is lowered from height $h_2$ [m] to $h_1$ [m], the output potential energy is expressed as follows:

$$E = W \cdot g \cdot (h_2 - h_1) \quad [J] \quad \text{.................................. (4.20)}$$

Where, $g \fallingdotseq 9.8065$ [m/s²]

Regenerative energy to the inverter circuit is calculated by considering the reduction-gear efficiency $\eta_G$ and motor efficiency $\eta_M$ as follows:

$$E = W \cdot g \cdot (h_2 - h_1) \cdot \eta_G \cdot \eta_M \quad [J] \quad \text{........................... (4.21)}$$

### 1.3.4 Appendix (calculation for other than in SI Unit)

All the expressions in this document are based on SI units (International System of Units). In this section, how to convert expressions to other units is explained.

**1. Conversion of unit**

**(1)Force**

- 1[kgf] ≒ 9.8[N]
- 1[N] ≒ 0.102[kgf]

**(2)Torque**

- 1[kgf · m] ≒ 9.8[N · m]
- 1[N · m] ≒ 0.102[kgf · m]

**(3)Work and energy**

- 1[kgf · m] ≒ 9.8[N · m] = 9.8[J] = 9.8[W · s]

**(4)Power**

- 1[kgf · m/s] ≒ 9.8[N · m/s] = 9.8[J/s] = 9.8[W]
- 1[N · m/s] ≒ 1[J/s] = 1[W] = 0.102[kgf · m/s]

**(5)Rotation speed**

- $1[r/min] = \frac{2\pi}{60}[rad/s] \fallingdotseq 0.1047[rad/s]$
- $1[rad/s] = \frac{60}{2\pi}[r/min] \fallingdotseq 9.549[r/min]$

**(6)Inertia constant**

- $J[kg \cdot m^2]$ : moment of inertia
- $GD^2[kg \cdot m^2]$ : flywheel effect
- $GD^2 = 4J$
- $J = \frac{GD^2}{4}$

**(7)Pressure and stress**

- 1[mmAq] ≒ 9.8[Pa] ≒ 9.8[N/m²]
- 1[Pa] ≒ 1[N/m²] ≒ 0.102[mmAq]
- 1[bar] ≒ 100000[Pa] ≒ 1.02[kg · cm²]
- 1[kg · cm²] ≒ 98000[Pa] ≒ 980[mbar]
- 1 atmospheric pressure =1013[mbar] = 760[mmHg]
  = 101300[Pa] ≒ 1.033[kg/cm²]

**2. Calculation formula**

**(1)Torque, power and rotation speed**

- $P[W] \fallingdotseq \frac{2\pi}{60} \cdot N[r/min] \cdot \tau[N \cdot m]$
- $P[W] \fallingdotseq 1.026 \cdot N[r/min] \cdot T[kgf \cdot m]$
- $\tau[N \cdot m] \fallingdotseq 9.55 \cdot \frac{P[W]}{N[r/min]}$
- $T[kgf \cdot m] \fallingdotseq 0.974 \cdot \frac{P[W]}{N[r/min]}$

**(2)Kinetic energy**

- $E[J] \fallingdotseq \frac{1}{182.4} \cdot J[kg \cdot m^2] \cdot N^2[(r/min)^2]$
- $E[J] \fallingdotseq \frac{1}{730} \cdot GD^2[kg \cdot m^2] \cdot N^2[(r/min)^2]$

**(3) Torque of linear moving load**

**[Driving mode]**

- $\tau[N \cdot m] \fallingdotseq 0.159 \frac{V[m/min]}{N_M[r/min] \cdot \eta_G} \cdot F[N]$
- $T[kgf \cdot m] \fallingdotseq 0.159 \frac{V[m/min]}{N_M[r/min] \cdot \eta_G} \cdot F[kgf]$

**[Braking mode]**

- $\tau[N \cdot m] \fallingdotseq 0.159 \frac{V[m/min]}{N_M[r/min] \cdot \eta_G} \cdot F[N]$
- $T[kgf \cdot m] \fallingdotseq 0.159 \frac{V[m/min]}{N_M[r/min] \cdot \eta_G} \cdot F[kgf]$

**(4) Acceleration torque**

**[Driving mode]**

- $\tau[N \cdot m] \fallingdotseq \frac{J[kg \cdot m^2]}{9.55} \cdot \frac{\Delta N[r/min]}{\Delta t[s] \cdot \eta_G}$
- $T[kgf \cdot m] \fallingdotseq \frac{GD^2[kg \cdot m^2]}{375} \cdot \frac{\Delta N[r/min]}{\Delta t[s] \cdot \eta_G}$

**[Braking mode]**

- $\tau[N \cdot m] \fallingdotseq \frac{J[kg \cdot m^2]}{9.55} \cdot \frac{\Delta N[r/min] \cdot \eta_G}{\Delta t[s]}$
- $T[kgf \cdot m] \fallingdotseq \frac{GD^2[kg \cdot m^2]}{375} \cdot \frac{\Delta N[r/min] \cdot \eta_G}{\Delta t[s]}$

**(5)Acceleration time**

- $t_{ACC}[s] \fallingdotseq \frac{J_1+J_2/\eta_G[kg \cdot m^2]}{\tau_M-\tau_L/\eta_G[N \cdot m]} \cdot \frac{\Delta N[r/min]}{9.55}$
- $t_{ACC}[s] \fallingdotseq \frac{GD_1^2+GD_2^2/\eta_G[kg \cdot m^2]}{T_M-T_L/\eta_G[kgf \cdot m]} \cdot \frac{\Delta N[r/min]}{375}$

**(6)Deceleration time**

- $t_{DEC}[s] \fallingdotseq \frac{J_1+J_2 \cdot \eta_G[kg \cdot m^2]}{\tau_M-\tau_L \cdot \eta_G[N \cdot m]} \cdot \frac{\Delta N[r/min]}{9.55}$
- $t_{DEC}[s] \fallingdotseq \frac{GD_1^2+GD_2^2 \cdot \eta_G[kg \cdot m^2]}{T_M-T_L \cdot \eta_G[kgf \cdot m]} \cdot \frac{\Delta N[r/min]}{375}$

# 2. Braking Unit and Braking Resistor Selection

## 2.1 Selection Procedure

The following three requirements must be satisfied simultaneously:

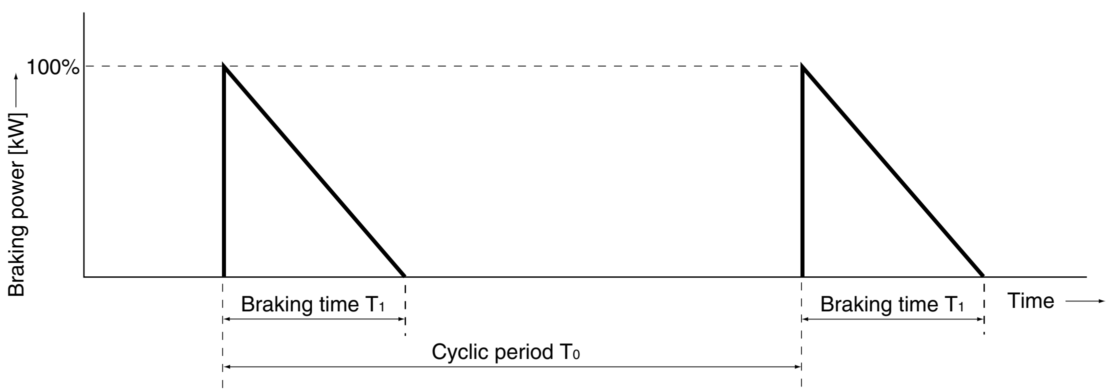
1) Maximum braking torque must not exceed values listed in Tables 3.1 and 3.2 in Chapter 3.
   To use maximum braking torque exceeding values in the above tables, select one size larger capacity braking unit and resistor.

2) Discharge energy for a single braking action must not exceed discharging capability [kWs] listed in the Table.
   For detailed calculation, see Section 1.3.3 Heat Energy Calculation of Braking Resistor.

3) Average loss obtained by dividing discharge energy by cyclic period must not exceed average loss [kW] listed in the Tables 3.1 and 3.2 in Chapter 3.

## 2.2 Notes on Selection

- The P11S series uses one size smaller capacity braking unit and resistor than those of the G11S series.
- Braking time and duty cycle are converted under deceleration braking conditions based on the rated torque as shown below. However, these value need not be considered when selecting braking unit and resistor capacity.




**Duty cycle (%) =** $\frac{T_1}{T_0}$ **x 100**

**Fig. 4.11 Duty cycle**

## 2.3 Optional fan unit

The standard duty cycle of the optional braking unit of 30kW or larger is 10%. The braking capacity can be increased up to 30% duty cycle by adding an optional fan unit (BU-F).