THE INVERTER

X

X. Selecting Inverter Capacity

10.1 Inverter and Motor Selection

10.2 Braking Unit and Braking Resistor Selection

10. Selecting Inverter Capacity

10.1 Inverter and Motor Selection

10.1.1 Characteristics of Output Torque

Figure 9.1 shows the output torque characteristics. The output torque is classified into the following quadrants by speed and torque-applied direction.

	(Speed)	(Torque)	
• Quadrant I :	+	+	… Driving in forward rotation
• Quadrant II :	−	+	… Braking in reverse rotation
• Quadrant III :	−	−	… Driving in reverse rotation
• Quadrant IV :	+	−	… Braking in forward rotation

In the figure below, **the speed rate (%) is expressed by regarding the base speed as 100%**, and **the torque rate (%) is expressed by regarding the continuous rated torque as 100%**.

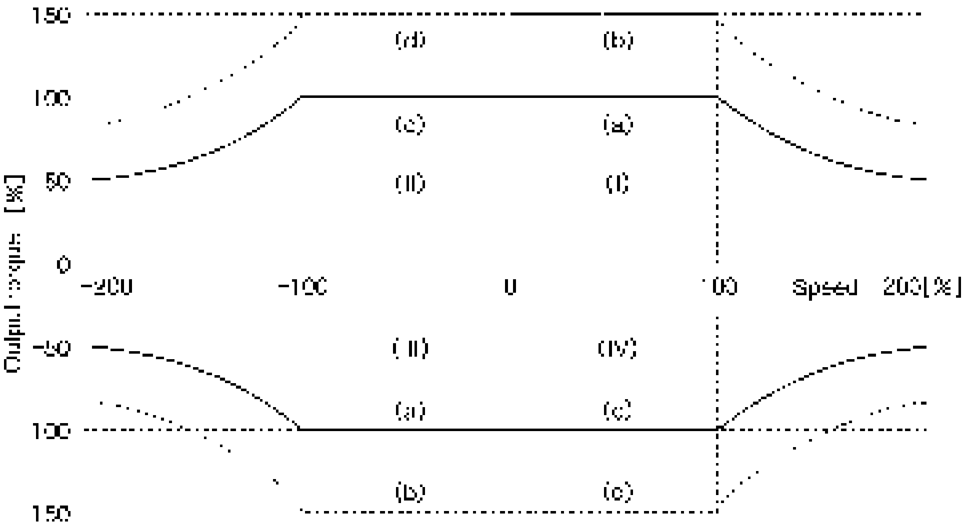

Figure 10-1 Characteristics of the Output Torque (CT Specification)

(1) Allowable continuous driving torque (curve (a) in the 1st and 3rd quadrants)

Curve (a) shows the torque that is available continuously in driving mode.
In the area below the base speed (100%) in the speed control range (0 to 200%), the rated torque is obtained. In the area above the base speed, the constant output is obtained, and the output torque is in inverse to proportion to the speed.
At very low speeds below the speed control range, the allowable torque drops to 80% for less than 0.5Hz converted into inverter output frequency. The motor can be operated continuously considering motor slip in practice.

(2) Max. driving torque in a short-time (curve (b) in the 1st and 3rd quadrants)

Curve (b) shows the torque that is allowed for a short-time (60 seconds) in driving mode.
In general, this torque is 150% of rated torque, and used for acceleration or deceleration.
At very low speeds below the speed control range, due to the restriction of inverter internal temperature, the allowable torque drops to 100% for less than 0.5Hz converted into inverter output frequency.

(3) Starting torque (around speed zero (0) in the 1st and 3rd quadrants)

The starting torque is the torque at speeds around 0 in the 1st and 3rd quadrants.
Although the continuous torque is 80%, the starting torque becomes as high as 150% because the curve passes the very low speed range in quite a short period (30 seconds or less).

(4) Braking torque (the 2nd and 4th quadrants)

The 2nd and 4th quadrants are the braking mode range. Curve (c) shows the braking torque that is available in the continuous rated current range of the inverter; curve (d) is the braking torque that is available for 60-second rated current. In the very low speed range, the torque drops to 80% similar to that in the driving mode.

The time rating of the braking torque is limited by the braking resistor and braking unit capacity, because the energy of the machine system is regenerated.

10.1.2 Selection Procedure

Figure 9-5 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.

(1) Calculation of load torque during constant speed running
(For detailed calculation, see Section 10.1.3.1)
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 10.1.3.2)
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 Section 10.1.3.2. The moment of inertia of motor is shown in Section 2.2.3.
2) Calculate minimum acceleration torque. (See Figure 10-2)
The acceleration torque is the difference between motor short time output torque (60s rating) explained in Section 10.1.1(2) and load torque (τ_L/η_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 (3.15) in Section 10.1.3.2 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.

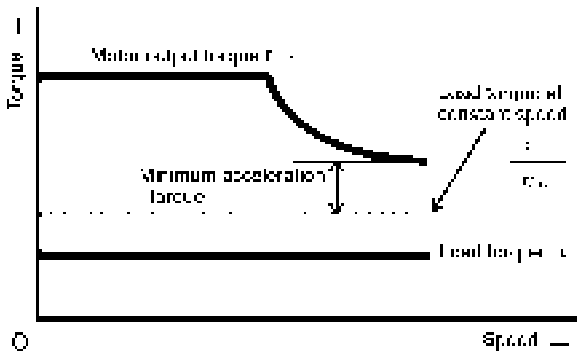

Figure 10-2 Example Study of Minimum Acceleration Time

(3) Deceleration time
(For detailed calculation, see Section 10.1.3.2)
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 Figure 10-3)
   * Same as for acceleration time.
3) Calculate the deceleration time.
   Assign the value calculated above to the expression (3.16) in Section 10.1.3.2 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.

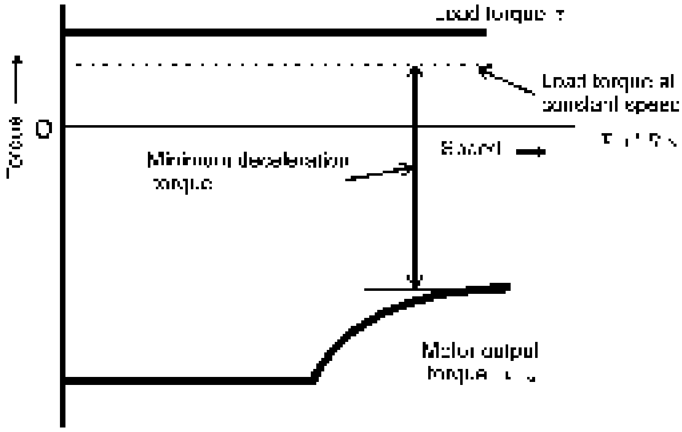

Figure 10-3 Example Study of Minimum Deceleration Torque (1)

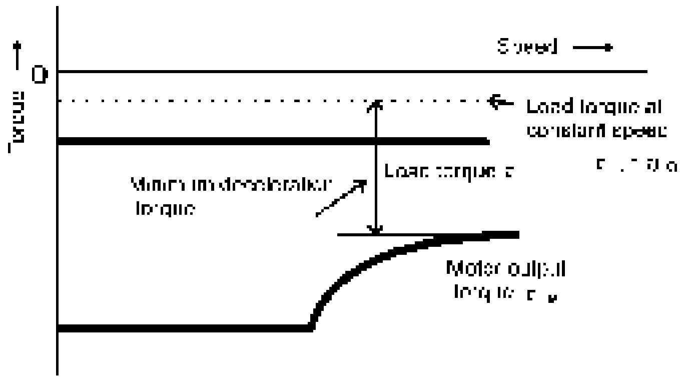

Figure 10-4 Example Study of Minimum Deceleration Torque (2)

However, note that minimum deceleration torque becomes smaller due to regenerative operation when lifting or lowering a load. (See Figure 10-4)

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(4) Braking resistor rating
(For detailed calculation, see Section 10.1.3.3)
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.
  The actual value for the maximum braking energy is indicated by the characteristics curve.

(5) Motor RMS current
(For detailed calculation, see Section 10.1.3.4)
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.

(6) Notes for examining inverter capacity
- When selecting an inverter for driving a Fiji's inverter-dedicated motor, ensure that the root mean square of the motor torque is lower than the inverter rated torque (80% of the rated torque for HT use).
- When selecting a general-purpose motor, ensure that the root mean square of the motor current is lower than the motor rated current for effective motor cooling. In this case, select an inverter so that the root mean square of the current is lower than the inverter rated current (80% of the rated current for HT use).

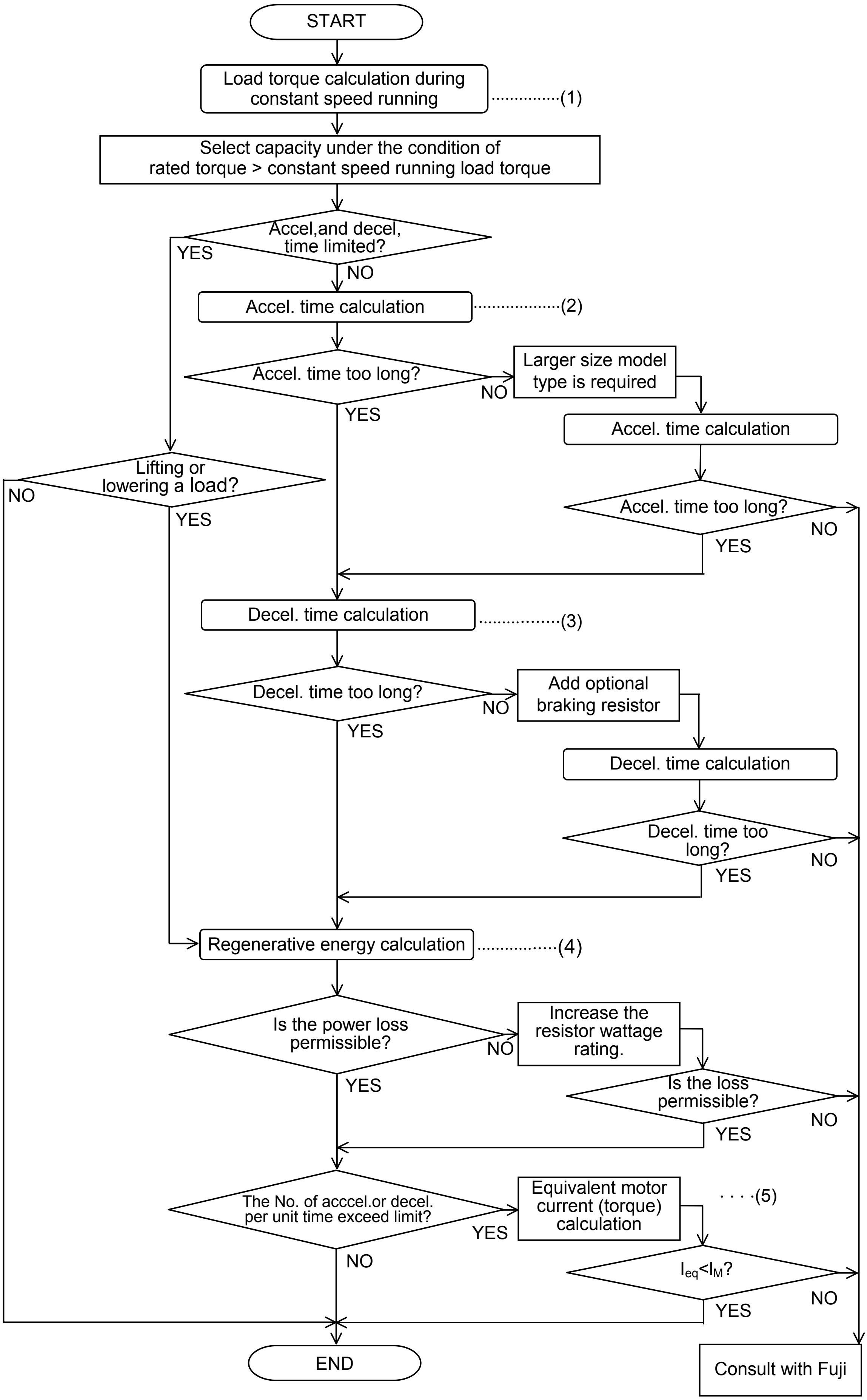


Figure 10-5 Selection Procedure

10.1.3 Calculations for Selecting Capacity

10.1.3.1 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 ν [m/s] is F[N] and the motor speed for driving this is N_M [r/min], the required motor output torque τ_M [N·m] is as follows:

$$\tau_M = \frac{60 \cdot \nu}{2\pi \cdot N_M} \cdot \frac{F}{\eta_G} \text{ [N·m]} \quad \cdots\cdots (3.1)$$

Where, η_G: Reduction-gear efficiency

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

$$\tau_M = \frac{60 \cdot \nu}{2\pi \cdot N_M} \cdot F \cdot \eta_G \text{ [N·m]} \quad \cdots\cdots (3.2)$$

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

(2) Moving a load horizontally

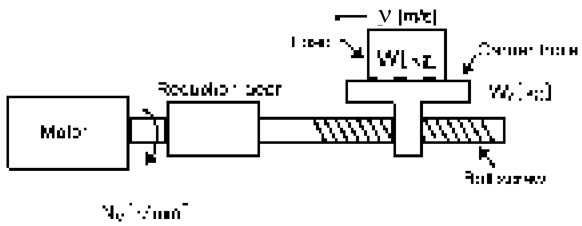


Figure 10-6 Moving a Load Horizontally

As shown in Figure 10-6, where the carrier table weight is W_0 [kg], load is W [kg], and friction coefficient of the ball screw is μ, friction force F [N] is expressed as follows:

$$F = (W_o + W) \cdot g \cdot \mu \text{ [N]} \quad \cdots\cdots (3.3)$$

Where, g : Gravity acceleration (≈ 9.8 m/s^2)

Then, required driving torque around the motor shaft is expressed as follows:

$$\tau_M = \frac{60 \cdot \nu}{2\pi \cdot N_M} \cdot \frac{(W_o + W) \cdot g \cdot \mu}{\eta_G} \text{ [N·m]} \quad \cdots\cdots (3.4)$$

(3) Moving a load vertically

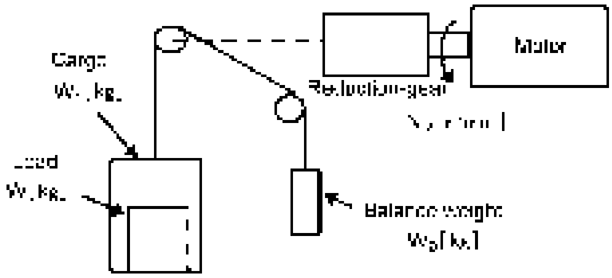


Figure 10-7 Moving a Load Vertically

As shown in Figure 10-7, 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)

$$F = (W_O + W - W_B) \cdot g \text{ [N]} \qquad (3.5)$$

(Lowering)

$$F = (W_B + W - W_O) \cdot g \text{ [N]} \qquad (3.6)$$

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 τ around the motor shaft in the driving mode by expression (3.1) and that in the braking mode by expression (3.2). That is, if F is positive, use expression (3.1); if it is negative, use expression (3.2).

(4) Moving a load along a slope

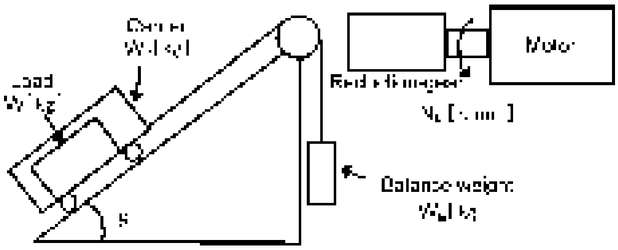


Figure 10-8 Moving a Load Along a Slope

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. Therefore, the expression for lifting a load is a little different from that for lowering a load. Where slope angle is θ and friction coefficient is μ, as shown in Figure 10-8, driving force F [N] is as follows:

(Lifting)

$$F = (W_O + W)(\sin\theta + \mu \cdot \cos\theta) - W_B \cdot g \text{ [N]} \qquad (3.7)$$

(Lowering)

$$F = (W_B - (W_O + W)(\sin\theta + \mu \cdot \cos\theta) \cdot g \text{ [N]} \qquad (3.8)$$

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 (3.1); when it is negative, use expression (3.2).

10.1.3.2 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:

$$E = \frac{J}{2} \cdot \left(\frac{2\pi \cdot N}{60}\right)^2 \quad [J] \quad \cdots\cdots (3.9)$$

To accelerate the above rotation, kinetic energy will be increased; to decelerate, kinetic energy must be dis-charged.
The torque required for acceleration and deceleration can be expressed as follows:

$$\tau = J \cdot \frac{2\pi}{60} \left(\frac{dN}{dt}\right) \quad [N \cdot m] \quad \cdots\cdots (3.10)$$

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.

Moment of inertia $J = \sum (W_i \cdot r_i^2) \quad [kg \cdot m^2] \quad \cdots\cdots (3.11)$

1) Hollow cylinder and solid cylinder

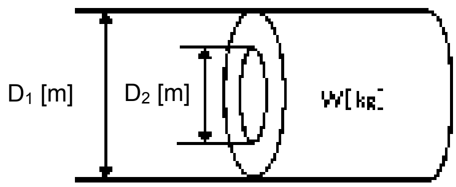


Figure 10-9 Hollow

The common shape of a rotating body is hollow cylinder. The moment of inertia J [kg·m^2] 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 Figure 10-9.

$$J = \frac{W \cdot (D_1^2 + D_2^2)}{60} \quad [kg \cdot m^2] \quad \cdots\cdots (3.12)$$

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

2) For a general rotating body

Table 10-1 lists the calculation expressions of moment of inertia of various rotating bodies including the above cylindrical rotating body.

3) For a load running horizontally

As shown in Figure 10-6, a carrier table can be driven by a motor. If the table speed is υ [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:

$$J = \left(\frac{60\upsilon}{2\pi \cdot N_M}\right)^2 \cdot (W_O + W) \quad [kg \cdot m^2] \quad \cdots\cdots (3.13)$$

4) For lifting and lowering load

As shown in Figures 10-7 and 10-8, two loads tied with the rope move in different directions. The moment of inertia can be calculated by obtaining the sum of the moving objects weight as follows:

$$J = \left(\frac{60\upsilon}{2\pi \cdot N_M}\right)^2 \cdot (W_O + W + W_B) \quad [kg \cdot m^2] \quad \cdots\cdots (3.14)$$

(2) Calculation of the acceleration time

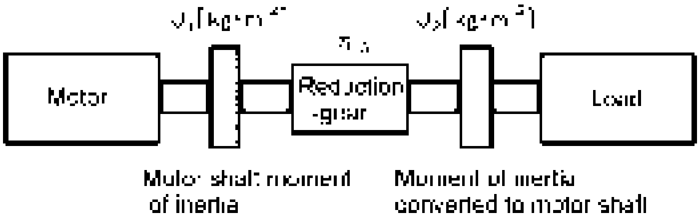


Figure 10-10 Load Model Including Reduction-gear

Figure 10-10 shows a general load model. Here, the load is tied via a reduction-gear with efficiency η_G. The time required to accelerate this load to a speed of N_M [r/min] is calculated with the following expression:

$$t_{ACC} = \frac{J_1 + J_2 / \eta_G}{\tau_M - \tau_L / \eta_G} \cdot \frac{2\pi \cdot (N_M - 0)}{60} \quad [s] \quad \cdots\cdots\cdots (3.15)$$

Where,
- J_1 : Motor shaft moment of inertia [kg·m^2]
- J_2 : Load shaft moment of inertia converted to motor shaft [kg·m^2]
- τ_M : Minimum motor output torque in driving mode [N·m]
- τ_L : Maximum load torque converted to motor shaft [N·m]
- η_G : Reduction-gear efficiency

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

(3) Calculation of the deceleration time

In Figure 10-10, the time required to stop the motor rotating at a speed of N_M [r/min] is calculated with the following expression:

$$t_{DEC} = \frac{J_1 + J_2 \cdot \eta_G}{\tau_M - \tau_L \cdot \eta_G} \cdot \frac{2\pi \cdot (0 - N_M)}{60} \quad [s] \quad \cdots\cdots\cdots (3.16)$$

Where,
- J_1 : Motor shaft moment of inertia [kg·m^2]
- J_2 : Load shaft moment of inertia converted to motor shaft [kg·m^2]
- τ_M : Minimum motor output torque in braking (deceleration) mode [N·m]
- τ_L : Maximum load torque converted to motor shaft [N·m]
- η_G : Reduction-gear efficiency

In the above expression, generally output torque τ_M is negative and load torque τ_L is positive. So, deceleration time becomes shorter. However, in a lifted and lowered load, τ_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.

(4) Non-linear (S-curve) accel./decel. time

For loads that are frequently accelerated and decelerated, it is often necessary to minimize the accel. and decel. time by using accel. and decel. torques. Vector control inverters are ideal for such operations.

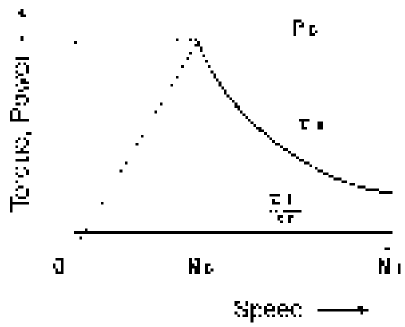


Figure 10-11 Sample of Driving Device which Includes the Constant Power Characteristic

In this operation, the accel. and decel. characteristic becomes non-linear, so the time required to accel. or decel. cannot be expressed by a simple formula.

Therefore, in general, the method employed divides speed N into small sections (ΔN) to calculate the partial accel./decel. time and sums these until accel. or decel. ends.
The smaller the divisions, the higher the calculation accuracy.
The above figure shows a sample torque-speed characteristic of a driving system: the curve shows a constant-torque in the range below N_0 and constant-output in the range from N_0 to N_1.
The accel. time is expressed as follows:

$$\Delta t_{ACC} = \frac{J_1 + J_2 / \eta_G}{\tau_M + \tau_L / \eta_G} \cdot \frac{2\pi \cdot \Delta N}{60} \quad [s] \quad \cdots\cdots (3.17)$$

Obtaining in advance the moment of inertia of the motor shaft (J_1) and of the load shaft (after conversion into motor shaft) (J_2) and load torque τ_L (after conversion into motor shaft) as well as the efficiency of the reduction speed device (η_G), the maximum motor torque (τ_M) is calculated using one of the following formulas depending on the speed range:

- τ_M when $N \le N_0$: constant-torque range

$$\tau_M = \frac{60 \cdot P_O}{2\pi \cdot N_O} \quad [N \cdot m] \quad \cdots\cdots (3.18)$$

- τ_M when $N_0 \le N \le N_1$: constant-output range (torque is inversely proportional to speed)

$$\tau_M = \frac{60 \cdot P_O}{2\pi \cdot N} \quad [N \cdot m] \quad \cdots\cdots (3.19)$$

If the result of the above calculation differs from the expected result, select a drive system by one frame larger.

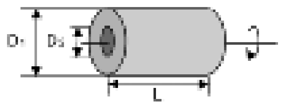
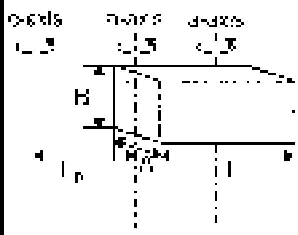
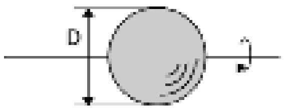
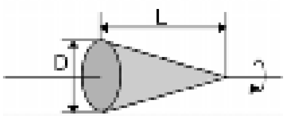
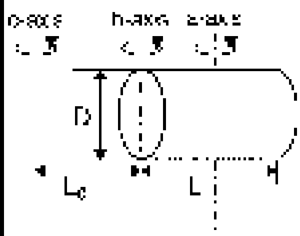
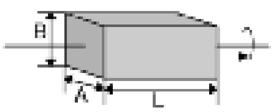
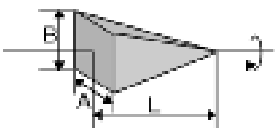
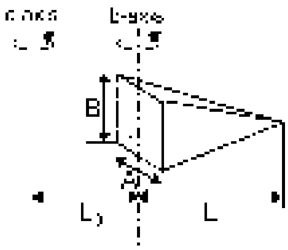
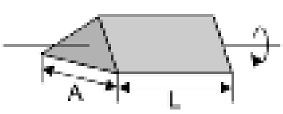
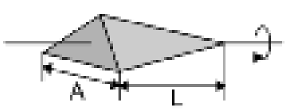
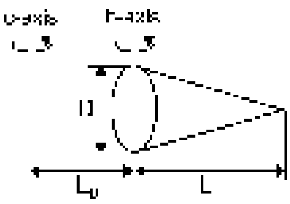
(5) Calculation for nonlinear decelerating time

Decelerating time can be calculated by the same formula as used for calculating accelerating time.

$$\Delta t_{DEC} = \frac{J_1 + J_2 \cdot \eta_G}{\tau_M - \tau_L \cdot \eta_G} \cdot \frac{2\pi \cdot \Delta N}{60} \quad [s] \quad \cdots\cdots (3.20)$$

In this formula, because both τ_M and Δ_N are negative value, load torque τ_L generally promotes deceleration. However, lift load has a mode in which τ_L becomes negative. In this mode, the polarity differs between τ_M and τ_L, which blocks deceleration.

Table 10.1 Moment of Inertia of Various Rotating Bodies

Shape	Mass: W [kg] Moment of inertia: J [kg·m^2]	Shape	Mass: W [kg] Moment of inertia: J [kg·m^2]
Hollow cylinder 	$W = \frac{\pi}{4} \cdot (D_1^2 - D_2^2) \cdot L \cdot \rho$ $J = \frac{1}{8} \cdot W \cdot (D_1^2 + D_2^2)$		$W = A \cdot B \cdot L \cdot \rho$ $J_a = \frac{1}{12} \cdot W \cdot (L^2 + A^2)$ $J_b = \frac{1}{12} \cdot W \cdot (L^2 + \frac{1}{4} \cdot A^2)$ $J_c \approx W \cdot (L_0^2 + L_0 \cdot L + \frac{1}{3} \cdot L^2)$
Sphere 	$W = \frac{\pi}{6} \cdot D^3 \cdot \rho$ $J = \frac{1}{10} \cdot W \cdot D^2$		
Cone 	$W = \frac{\pi}{12} \cdot D^2 \cdot L \cdot \rho$ $J = \frac{3}{40} \cdot W \cdot D^2$		$W = \frac{\pi}{4} \cdot D^2 \cdot L \cdot \rho$ $J_a = \frac{1}{12} \cdot W \cdot (L^2 + \frac{3}{4} \cdot D^2)$ $J_b = \frac{1}{3} \cdot W \cdot (L^2 + \frac{3}{16} \cdot D^2)$ $J_c \approx W \cdot (L_0^2 + L_0 \cdot L + \frac{1}{3} \cdot L^2)$
Rectangular prism 	$W = A \cdot B \cdot L \cdot \rho$ $J = \frac{1}{12} \cdot W \cdot (A^2 + B^2)$		
Square cone (pyramid, rectangular base) 	$W = \frac{1}{3} \cdot A \cdot B \cdot L \cdot \rho$ $J = \frac{1}{20} \cdot W \cdot (A^2 + B^2)$		$W = \frac{1}{3} \cdot A \cdot B \cdot L \cdot \rho$ $J_b = \frac{1}{10} \cdot W \cdot (L^2 + \frac{1}{4} \cdot A^2)$ $J_c \approx W \cdot (L_0^2 + \frac{3}{2} \cdot L_0 \cdot L + \frac{3}{5} \cdot L^2)$
Triangular prism 	$W = \frac{\sqrt{3}}{4} \cdot A^2 \cdot L \cdot \rho$ $J = \frac{1}{3} \cdot W \cdot A^2$		
Triangle cone (tetrahedron with equilateral triangular base) 	$W = \frac{\sqrt{3}}{12} \cdot A^2 \cdot L \cdot \rho$ $J = \frac{1}{5} \cdot W \cdot A^2$		$W = \frac{\pi}{12} \cdot D^2 \cdot L \cdot \rho$ $J_b = \frac{1}{10} \cdot W \cdot (L^2 + \frac{3}{8} \cdot D^2)$ $J_c \approx W \cdot (L_0^2 + \frac{3}{2} \cdot L_0 \cdot L + \frac{3}{5} \cdot L^2)$

Main metal density (at 20°C) ρ[kg/m^3]
Carbon steel: 7860, Copper: 8940, Aluminum: 2700

10.1.3.3 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.

(1) 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· m^2] rotates at a speed N_2 [r/min], its kinetic energy is as follows:

$$E = \frac{J}{2} \cdot \left(\frac{2\pi \cdot N_2}{60}\right)^2 \text{ [J]} \quad \cdots\cdots (3.21)$$

$$\approx \frac{1}{182.4} \cdot J \cdot N_2^2 \text{ [J]} \quad \cdots\cdots (3.21)'$$

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

$$E = \frac{J}{2} \cdot \left[\left(\frac{2\pi \cdot N_2}{60}\right)^2 - \left(\frac{2\pi \cdot N_1}{60}\right)^2\right] \text{ [J]} \quad \cdots\cdots (3.22)$$

$$\approx \frac{1}{182.4} \cdot J \cdot (N_2^2 - N_2^2) \text{ [J]} \quad \cdots\cdots (3.22)'$$

The energy regenerated to the inverter as shown in Figure 9-10 is calculated by considering the reduction-gear efficiency η_G and motor efficiency η_M as follows:

$$E \approx \frac{1}{182.4} \cdot (J_1 + J_2 \cdot \eta_G) \cdot \eta_M \cdot (N_2^2 - N_1^2) \text{ [J]} \quad \cdots\cdots (3.23)$$

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:

$$E = W \cdot g \cdot (h_2 - h_1) \text{ [J]} \quad \cdots\cdots (3.24)$$

Where, $g \approx 9.8065$ [m/s^2]

Regenerative energy to the inverter circuit is calculated by considering the reduction-gear efficiency η_G and motor efficiency η_M as follows:

$$E = W \cdot g \cdot (h_2 - h_1) \cdot \eta_G \cdot \eta_M \text{ [J]} \quad \cdots\cdots (3.25)$$

10.1.3.4 Calculating RMS Rating of Motor

In case of the load which repeats the operation very frequently, the load current fluctuates largely and enters into the short-time rating range of the motor repeatedly. It is, therefore, required to review the thermal allowable value. The exothermicity is approximately considered to be in proportion to the square of the load current. In case of the dedicated motor of VG7S which utilizes the forced cooling fan method, the temperature will increase in proportion to the exothermicity itself.
When the operation is repeated in such an interval as to be short enough compared with the thermal time constant of the motor, calculate the "equivalent RMS current" as mentioned below, and select the unit such that this RMS current does not over the rated current of the motor.

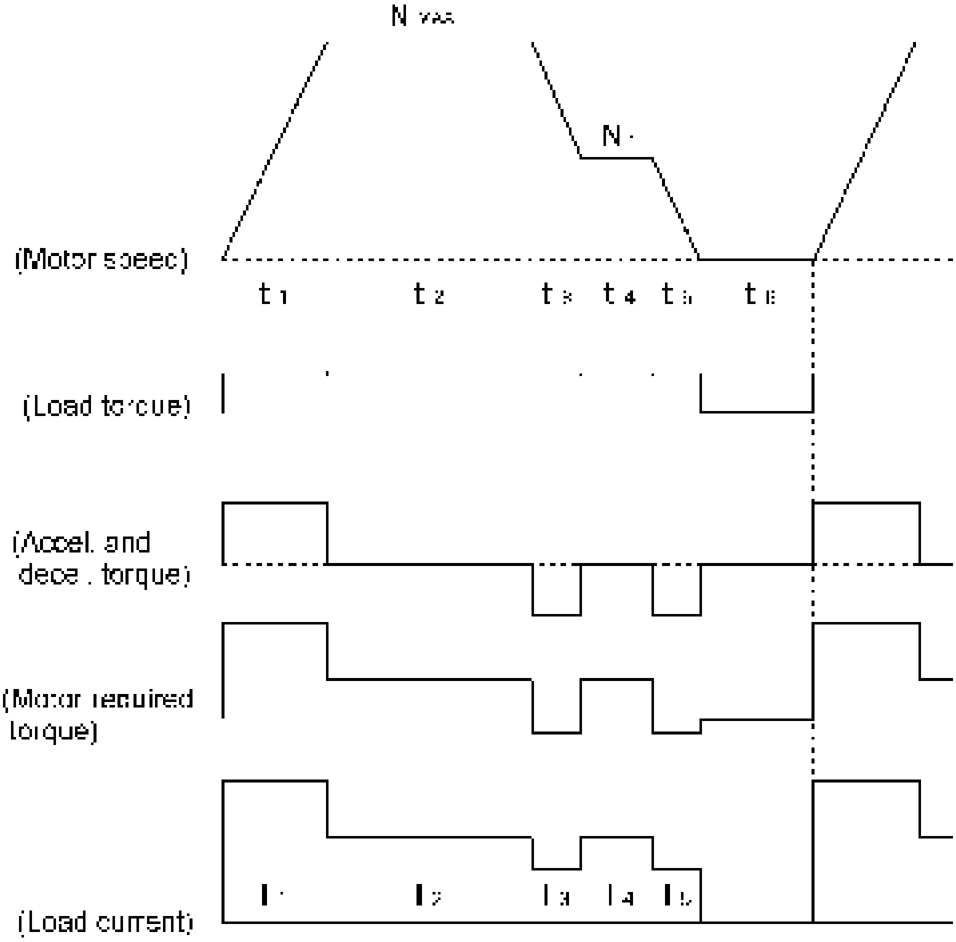


Figure 10-12 Sample of the Repetitive Operation

Firstly, calculate the required torque of each part based on the speed pattern. Then using the torque-current curve of motor, convert this torque to the pattern of the load current. The "equivalent RMS current, I eq" can be finally calculated by the following formula.

$$I_{eq} = \sqrt{\frac{I_1^2 \cdot t_1 + I_2^2 \cdot t_2 + I_3^2 \cdot t_3 + I_4^2 \cdot t_4 + I_5^2 \cdot t_5}{t_1 + t_2 + t_3 + t_4 + t_5 + t_6}} \text{ [A]} \quad \cdots\cdots (3.26)$$

The torque-current curve for the dedicated motor is not available for actual calculation. So, calculate the load current I from the load torque τ_1 using the following formula (3.27). Then, calculates the equivalent current Ieq.

$$I = \sqrt{\left(\frac{\tau_1}{100} \times It_{100}\right)^2 + Im_{100}^2} \text{ [A]} \quad \cdots\cdots (3.27)$$

Here, τ_1: load torque [%], It_{100} = torque current (P09; M1 torque current), Im_{100} = (exciting current) (P08; M1 exciting current)

- For the function code data of P08 and P09, refer to Chapter 14 Replacement data.
- When using the second motor, refer to the torque current and exciting current of A code instead of those of P code.

10.1.3.5 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

$1\ [\mathrm{kgf}] \approx 9.8\ [\mathrm{N}]$

$1\ [\mathrm{N}] \approx 0.102\ [\mathrm{kgf}]$

2) Torque

$1\ [\mathrm{kgf \cdot m}] \approx 9.8\ [\mathrm{N \cdot m}]$

$1\ [\mathrm{N \cdot m}] \approx 0.102\ [\mathrm{kgf \cdot m}]$

3) Work and energy

$1\ [\mathrm{kgf \cdot m}] \approx 9.8\ [\mathrm{N \cdot m}] = 9.8\ [\mathrm{J}] = 9.8\ [\mathrm{W \cdot s}]$

4) Power

$1\ [\mathrm{kgf \cdot m/s}] \approx 9.8\ [\mathrm{N \cdot m/s}] = 9.8\ [\mathrm{J/s}] = 9.8\ [\mathrm{W}]$

$1\ [\mathrm{N \cdot m/s}] \approx 1\ [\mathrm{J/s}] = 1\ [\mathrm{W}] \approx 0.102\ [\mathrm{kgf \cdot m/s}]$

5) Rotation speed

$$1\ [\mathrm{r/min}] = \frac{2\pi}{60}\ [\mathrm{rad/s}] \approx 0.1047\ [\mathrm{rad/s}]$$

$$1\ [\mathrm{rad/s}] = \frac{60}{2\pi}\ [\mathrm{r/min}] \approx 9.549\ [\mathrm{r/min}]$$

6) Inertia constant

$J\ [\mathrm{kg \cdot m^2}]$: Moment of inertia

$GD^2\ [\mathrm{kg \cdot m^2}]$: Flywheel effect

$GD^2 = 4J$

$$J = \frac{GD^2}{4}$$

7) Pressure and stress

$1\ [\mathrm{mmAq}] \approx 9.8\ [\mathrm{Pa}] \approx 9.8\ [\mathrm{N/m^2}]$

$1\ [\mathrm{Pa}] \approx 1\ [\mathrm{N/m^2}] \approx 0.102\ [\mathrm{mmAq}]$

$1\ [\mathrm{bar}] \approx 100000\ [\mathrm{Pa}] \approx 1.02\ [\mathrm{kg \cdot cm^2}]$

$1\ [\mathrm{kg \cdot cm^2}] \approx 98000\ [\mathrm{Pa}] \approx 980 [\mathrm{mbar}]$

1 atmospheric pressure

$= 1013\ [\mathrm{mbar}] = 760\ [\mathrm{mmHg}]$

$= 101300\ [\mathrm{Pa}] \approx 1.033\ [\mathrm{kg \cdot cm^2}]$

(2) Calculation formula

1) Torque, power and rotation speed

$$P\ [\mathrm{W}] \approx \frac{2\pi}{60} \cdot N\ [\mathrm{r/min}] \cdot \tau\ [\mathrm{N \cdot m}]$$

$$P\ [\mathrm{W}] \approx 1.026 \cdot N\ [\mathrm{r/min}] \approx T\ [\mathrm{kgf \cdot m}]$$

$$\tau\ [\mathrm{N \cdot m}] \approx 9.55 \cdot \frac{P\ [\mathrm{W}]}{N\ [\mathrm{r/min}]}$$

$$T\ [\mathrm{kgf \cdot m}] \approx 0.974 \cdot \frac{P\ [\mathrm{W}]}{N\ [\mathrm{r/min}]}$$

2) Kinetic energy

$$E\ [\mathrm{J}] \approx \frac{1}{182.4} \cdot J\ [\mathrm{kg \cdot m^2}] \cdot N^2\ [(\mathrm{r/min})^2]$$

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

3) Torque of linear moving load

[Driving mode]

$$\tau\ [\mathrm{N \cdot m}] \approx 0.159 \frac{V\ [\mathrm{m/min}]}{N_M\ [\mathrm{r/min}] \cdot \eta_G} \cdot F\ [\mathrm{N}]$$

$$T\ [\mathrm{kgf \cdot m}] \approx 0.159 \frac{V\ [\mathrm{m/min}]}{N_M\ [\mathrm{r/min}] \cdot \eta_G} \cdot F\ [\mathrm{kgf}]$$

[Braking mode]

$$\tau\ [\mathrm{N \cdot m}] \approx 0.159 \frac{V\ [\mathrm{m/min}]}{N_M\ [\mathrm{r/min}] \cdot \eta_G} \cdot F\ [\mathrm{N}]$$

$$T\ [\mathrm{kgf \cdot m}] \approx 0.159 \frac{V\ [\mathrm{m/min}]}{N_M\ [\mathrm{r/min}] \cdot \eta_G} \cdot F\ [\mathrm{kgf}]$$

4) Acceleration torque

[Driving mode]

$$\tau\ [\mathrm{N \cdot m}] \approx \frac{J\ [\mathrm{kg \cdot m^2}]}{9.55} \cdot \frac{\Delta N\ [\mathrm{r/min}]}{\Delta t\ [\mathrm{s}] \cdot \eta_G}$$

$$T\ [\mathrm{kgf \cdot m}] \approx \frac{GD^2\ [\mathrm{kg \cdot m^2}]}{375} \cdot \frac{\Delta N\ [\mathrm{r/min}]}{\Delta t\ [\mathrm{s}]\ ] \cdot \eta_G}$$

[Braking mode]

$$\tau\ [\mathrm{N \cdot m}] \approx \frac{J\ [\mathrm{kg \cdot m^2}]}{9.55} \cdot \frac{\Delta N\ [\mathrm{r/min}] \cdot \eta_G}{\Delta t\ [\mathrm{s}]}$$

$$T\ [\mathrm{kgf \cdot m}] \approx \frac{GD^2\ [\mathrm{kg \cdot m^2}]}{375} \cdot \frac{\Delta N\ [\mathrm{r/min}] \cdot \eta_G}{\Delta t\ [\mathrm{s}]}$$

5) Acceleration time

$$t_{ACC}\ [\mathrm{s}]\ \frac{J_1 + J_2/\eta_G\ [\mathrm{kg \cdot m^2}]}{\tau_M - \tau_L/\eta_G\ [\mathrm{N \cdot m^2}]} \cdot \frac{\Delta N\ [\mathrm{r/min}]}{9.55}$$

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

6) Deceleration time

$$t_{DEC}\ [\mathrm{s}]\ \frac{J_1 + J_2 \cdot \eta_G\ [\mathrm{kg \cdot m^2}]}{\tau_M - \tau_L \cdot \eta_G\ [\mathrm{N \cdot m^2}]} \cdot \frac{\Delta N\ [\mathrm{r/min}]}{9.55}$$

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

10.2 Braking Unit and Braking Resistor Selection

10.2.1 Selection Procedure

- The following three requirements must be satisfied simultaneously:

(1) Maximum braking torque must not exceed values listed in Tables 9.4.1(1) to 9.4.5(2)in Chapter 9. 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 Tables 9.4.1 (1) to 9.4.5 (2) in Chapter 9.

(3) Average loss obtained by dividing discharge energy by cyclic period must not exceed the average loss [kW] listed in the Table.

The selecting conditions depend on the periodic duty cycle as described follows:

1) If the periodic duty cycle is 100s or shorter, the above conditions 1) and 3) must be satisfied.

2) If the periodic duty cycle is longer than 100s, the above conditions 1) and 2) must be satisfied.

10.2.2 Notes on Selection

- Braking time and duty cycle (%ED) 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.

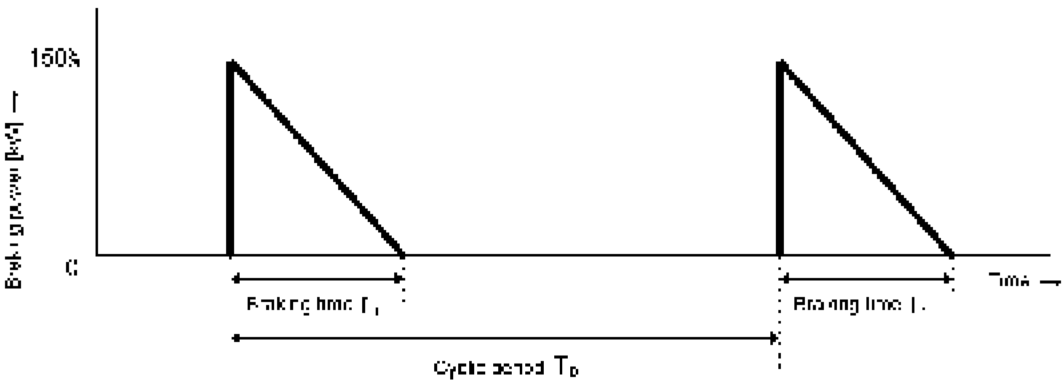


Figure 10-13 Duty Cycle

$$\text{Duty cycle (\%ED)} = \frac{T_1}{T_0} \times 100$$

- MEMO -